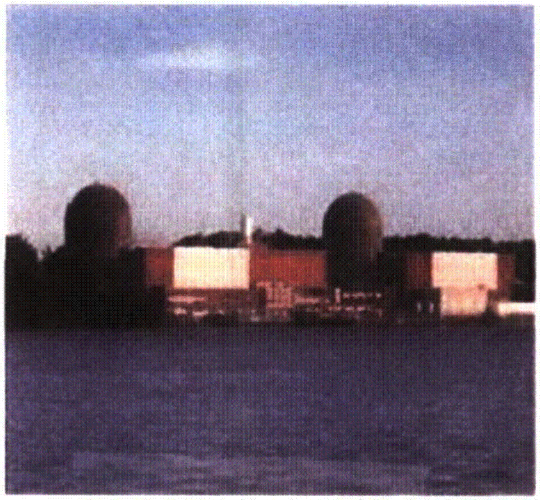
INDIAN POINT UNIT 2 AND UNIT 3



Coastal Zone Management Act Consistency Certification

In support of
Renewal of Indian Point Unit 2 and Unit 3 USNRC Operating Licenses

Submitted by:

Entergy Nuclear Indian Point 2, LLC
Entergy Nuclear Indian Point 3, LLC
Entergy Nuclear Operations, Inc.

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SUPPLEMENTAL INFORMATION ON NATIONAL AND STATE INTERESTS

VOL. II OF IV

SEPTEMBER 26, 2014

LIST OF SUPPLEMENTAL ATTACHMENTS:

S-1	Alice L. Buck, A History of the Atomic Energy Commission, U.S. Department of Energy, July, 1983
S-2	Report of the Subcommittee on Research and Development on the Five-Year Power Reactor Development Program Proposed by the Atomic Energy Commission, March, 1954
S-3-1, 3-2; 3-3 and 3-4	Deed dated October 30, 1954, recorded at Liber 5392, Page 29; Deed dated December 1, 1954, recorded at Liber 5398, Page 340; Deed dated January 1, 1955, recorded at Liber 5419, Page 283; Deed dated January 31, 1955, recorded at Liber 5538, Page 404
S-4	Excerpt from Major Activities in the Atomic Energy Programs, January—December 1961, United States Atomic Energy Commission, January, 1962, at Appendix 8, *License Applications Filed and Actions Taken: Summary of License Actions.*
S-5	Excerpt from Final Environmental Statement Relating to the Operation of Indian Point Nuclear Generating Plant No. 3, United States Nuclear Regulatory Commission, February, 1975. Attachment 21 to Consistency Certification, December, 2012; excerpts included as Attachment S-5 to this Supplemental Filing.
S-6	Message of the Governor in relation to the Use of Atomic Energy for Peaceful Purposes, State of New York Legislative Document No. 46 (1959)
S-7	Act inserting Article 19-D, Atomic Energy Law, and establishing the New York Office of Atomic Development, 1959 N.Y. Sess. Law 72 (McKinney)
S-8	Deed from New York State to Consolidated Edison Company dated October 17, 1959, recorded at Liber 5973, Page 283
S-9	An Atomic Development Plan for the State of New York, A Report to Governor Nelson A. Rockefeller, New York Office of Atomic Development, December 1, 1959.
S-10	Pub. Auth. Law § 1850-a, 1962 N.Y. Sess. Law. 428 (McKinney) (c. 210).
S-11	Civilian Nuclear Power . . . a Report to the President—1962, Atomic Energy Commission, November, 1962
S-12	Energy Resources: A Report to the Committee on Natural Resources, National Academy of Sciences, National Research Council, December, 1962.

S-13	National Power Survey, Federal Power Commission, October 31, 1964.
S-14	A Report by the Federal Communications Commission on the Northeast Power Failure of November 9-10, 1965, and its Effect on Communications, Federal Communications Commission, February 23, 1966.
S-15	Certificate dated January 1, 1966, recorded at Liber 6589, Page 308.
S-16	Deed from New York State to Consolidated Edison Company dated April 21, 1966, recorded at Liber 6614, Page 70.
S-17	Dr. Glenn T. Seaborg, *A New Look at Nuclear Power* Volume 8, Number 3: 8 Atomic Energy L.J. No. 3, 191 (1966).
S-18	Oliver Townsend, *Atomic Power Development in New York State*, 8 Atomic Energy L.J. No. 3, 207, 215 (1966).
S-19	Civilian Nuclear Power—The 1967 Supplement to the 1962 Report to the President, Atomic Energy Commission, February, 1967.
S-20	Neal L. Moylan, *The Role of Power in Economic Development,* 10 Atomic Energy L.J., No. 1, (1968)
S-21	United States v. Consolidated Edison of New York, Inc., 580 F.2d 1122 (2nd Cir. 1978).
S-22	Committee on Energy and National Resources, Executive Energy Documents, Publication No. 95-114 (Comm. Print July 1978).
S-23	Deed from Consolidated Edison Company to New York State dated August 31, 1971, recorded at Liber 7006, Page 298.
S-24	Letter from Federal Power Commission (T.A. Phillips, Chief, Bureau of Power) to Atomic Energy Commission, dated May 10, 1972.
S-25	A Review of Consolidated Edison Company 1972 Summer Power Supply Problems and Twenty-Year Expansion Plans, Bureau of Power Federal Power Commission, September, 1972.
S-26	Excerpt from Final Environmental Statement Relating to the Operation of Indian Point Nuclear Generating Plant No. 2, United States Atomic Energy Commission, September, 1972. Attachment 20 to Consistency Certification; excerpts included as Attachment S-26 to this Supplemental Filing.
S-27	Legislative History of the Coastal Zone Management Act of 1972, as Amended in 1974 and 1976 With a Section-By-Section Index, U.S. Government Printing

	Office, December 1976, at 211, reprinting Senate Report No. 92-753 (1972).
S-28	Joint Committee on Atomic Energy, Understanding the "National Energy Dilemma", 99-730 (Joint Comm. Print 1973).
S-29	The Nation's Energy Future, Atomic Energy Commission, December 1, 1973.
S-30	Letter from Federal Power Commission (T.A. Phillips, Chief, Bureau of Power) to Atomic Energy Commission dated December 13, 1973.
S-31	Pub. Auth. Law § 1001-a (1974), "Emergency Provisions for the Metropolitan Area of the City of New York," N.Y. Sess. Law 1974 c. 369, 1974 N.Y. Sess. Laws 505 (McKinney).
S-32	Deed from Consolidated Edison Company to Power Authority of the State of New York, dated December 30, 1974, recorded at Liber 7306, Page 736.
S-33	Annual Report, The Power Authority of the State of New York, March 25, 1976.
S-34	Atomic Energy Commission, 1974 Annual Report to Congress, January 17, 1975.
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S-38	Factors Affecting The Electric Power Supply: 1980-85, Federal Power Commission December 1, 1976.
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S-40	Letter of Basil A. Patterson, August 13, 1982; NYCMP II-1, at 2
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S-43	New York State Assembly, The Electric Industry in New York, Sheldon

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S-45	Deed from Power Authority of State of New York to Entergy dated November 21, 2000, recorded at Westchester County Registry, Control Number 403340618.
S-46	National Energy Policy Report by the National Energy Policy Development Group (May, 2001)
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S-48	A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010, United States Department of Energy Office of Nuclear Energy, Science and Technology and its Nuclear Energy Research Advisory Committee Subcommittee of Generation IV Technology Planning (October 31, 2001)
S-49	The Future of Nuclear Power, An Interdisciplinary MIT Study, Massachusetts Institute of Technology, 2003.
S-50	White House National Economic Council, Advanced Energy Initiative, February, 2006.
S-51	Press Release, Governor Spitzer Unveils Cutting-Edge Global Warming Regulations, October 24, 2007.
S-52	Effects of Climate Change on Energy Production and Use in the United States, National Science and Technology Council, U.S. Climate Change Science Program, February 2008.
S-53	Press Release, "Governor Paterson Rings in New Era to Combat Climate Change," September 26, 2008.
S-54	Update of the MIT 2003 Future of Nuclear Power, An Interdisciplinary MIT Study, Massachusetts Institute of Technology, 2009.
S-55	U.S. Department of Energy, National Electric Transmission Congestion Study, December, 2009.
S-56	U.S. Department of Energy, Nuclear Energy Research and Development Roadmap, Report to Congress, April 2010.
S-57	President Obama, State of the Union Address, January 25, 2011.

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S-59	Governor Cuomo 2012 State of the State Address.
S-60	Energy Security in the United States, Congressional Budget Office, May, 2012.
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S-66	Restoring U.S. Leadership in Nuclear Energy—A National Security Imperative, Center for Strategic & International Studies, June, 2013
S-67	Redrawing the Energy-Climate Map, International Energy Agency, June 10, 2013.
S-68	PlaNYC: A Stronger, More Resilient New York, The City of New York and Mayor Michael R. Bloomberg, June 11, 2013.
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S-70	U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather, U.S. Department of Energy, July 2013.
S-71	Hurricane Sandy Rebuilding Strategy, Hurricane Sandy Rebuilding Task Force, August, 2013.
S-72	Indian Point Contingency Plan, Final Generic Environmental Impact Statement (New York Public Service Commission, September, 2013)

S-73	Executive Order #13653, Preparing the United States for the Impacts of Climate Change
S-74	Excerpt from Climate Change Impacts in the United States, U.S. National Climate Assessment, U.S. Global Change Research Program, May, 2014
S-75	PlaNYC—New York City's Pathways to Deep Carbon Reductions, The City of New York, NYC Mayor's Office, December, 2013.
S-76	Annual Energy Outlook 2014, Energy Information Administration, May 7, 2014.
S-77	U.S. Environmental Protection Agency, Fact Sheet: Clean Power Plan State Roles (June 2, 2014)
S-78	2014 Reliability Needs Assessment, New York System Independent Operator, Final Report
S-79	U.S. Senators Lisa Murkowski and Tim Scott, Plenty at Stake: Indicators of American Energy Insecurity, An Energy 20/20 White Paper

DOE/ES-0003/1

A HISTORY OF THE ATOMIC ENERGY COMMISSION

by:
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July 1983

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Introduction

Almost a year after World War II ended, Congress established the United States Atomic Energy Commission to foster and control the peacetime development of atomic science and technology. Reflecting America's postwar optimism, Congress declared that atomic energy should be employed not only in the Nation's defense, but also to promote world peace, improve the public welfare, and strengthen free competition in private enterprise. After long months of intensive debate among politicians, military planners and atomic scientists, President Harry S. Truman confirmed the civilian control of atomic energy by signing the Atomic Energy Act on August 1, 1946.(1)

The provisions of the new Act bore the imprint of the American plan for international control presented to the United Nations Atomic Energy Commission two months earlier by U.S. Representative Bernard Baruch. Although the Baruch proposal for a multinational corporation to develop the peaceful uses of atomic energy failed to win the necessary Soviet support, the concept of combining development, production, and control in one agency found acceptance in the domestic legislation creating the United States Atomic Energy Commission.(2)

Congress gave the new civilian Commission extraordinary power and independence to carry out its awesome responsibilities. Five Commissioners appointed by the President would exercise authority for the operation of the Commission, while a general manager, also appointed by the President, would serve as chief executive officer. To provide the Commission exceptional freedom in hiring scientists and professionals, Commission employees would be exempt from the Civil Service system. Because of the need for great security, all production facilities and nuclear reactors would be government-owned, while all technical information and research results would be under Commission control, and thereby excluded from the normal application of the patent system.

In addition, the Act provided for three major advisory committees: a Congressional Joint Committee on Atomic Energy, a Military Liaison Committee, and a General Advisory Committee of outstanding scientists.(3)

The First Commission

On January 1, 1947, the fledgling Atomic Energy Commission took over from the Manhattan Engineer District the massive research and production facilities built during World War II to develop the atomic bomb. The facilities were the product of an extraordinary mission accomplished in three years in almost complete secrecy. Under the direction of General Leslie R. Groves of the Army Corps of Engineers, the laboratory experiments of Enrico Fermi and other American and European scientists had been transformed into operating plants capable of producing a military weapon of devastating power. When the atomic bomb was dropped on Hiroshima on August 6, 1945, and three days later on Nagasaki, not only was a long and costly war brought to an end, but the world also became aware of a completely new and largely unexpected technology.(4)

As the first chairman of the agency created to control the peacetime development of the new technology, President Harry Truman appointed David E. Lilienthal, a lawyer and former head of the Tennessee Valley Authority. During the preceding year, Lilienthal and Under Secretary of State Dean Acheson had co-authored the well-known Acheson-Lilienthal report which had formed the basis for the American plan for international control of atomic energy. Serving with Lilienthal on the Commission were Sumner T. Pike, a businessman from New England, William T. Waymack, a farmer and newspaper editor from Iowa, Lewis L. Strauss, a conservative banker and reserve admiral, and Robert F. Bacher, a physicist from Los Alamos and the only scientist on the Commission. Carroll L. Wilson, a young engineer who had helped Vannevar Bush organize the National Defense Research Committee during the war, was appointed general manager. Two floors of the New War Department Building in Washington provided a temporary home for the Commission. A few months later more permanent headquarters were found at 19th and Constitution Avenue, N.W., in the former wartime offices of the Joint Chiefs of Staff.

The new Commission faced a challenging future. World War II was quickly followed by an uneasy international situation commonly referred to as the Cold War, and Lilienthal and his colleagues soon found that most of the Commission's resources had to be devoted to weapon development and production. The requirements of national defense thus quickly obscured their original goal of developing the full potential of the peaceful atom. For two decades military-related programs would command the lion's share of the Commission's time and the major portion of the budget.(5)

The Nuclear Arsenal

To meet the Nation's expanding requirements for fissionable material the Commission set about refurbishing the production and research facilities built during the war. A major overhaul of the original reactors and two new plutonium reactors were authorized for the Hanford, Washington plant. Oak Ridge was scheduled for an addition to the existing K-25 plant and a third gaseous diffusion plant for the production of uranium 235. The Commission decided to adopt the Army's practice of hiring private corporations to operate plants and laboratories, thereby extending into peacetime the contractor system previously used by the Government only in times of national emergency.

The first test of new weapons was conducted at Enewetak Atoll in April and May 1948. *Operation Sandstone* explored weapon designs and tested a new fission weapon to replace the clumsy tailor-made models used during World War II. By 1948 the Commission had both gun-type and implosion-type non-nuclear and nuclear components in stockpile and was well on the way toward producing an arsenal of nuclear weapons.

In early September 1949 a special Air Force unit detected a large radioactive mass over the Pacific, indicating that the Soviet Union had successfully detonated a nuclear device. The Soviet detonation not only ended the United States' monoploy of nuclear weapons, but also had an immediate effect on the Commission's planned expansion program. During the prolonged debate which followed the announcement of the Soviet event, Commissioner Lewis L. Strauss, supported by fellow Commissioner Gordon Dean, urged the Commission to take a "quantum jump" by developing a thermonuclear weapon. Strong support for the Strauss' position came from the Congressional Joint Committee on Atomic Energy, and from scientists such as Edward Teller, Luis W. Alverez, and Ernest O. Lawrence, who agreed that the development of the superbomb was absolutely essential to the security of the United States. The members of the General Advisory Committee, however, while concurring in the need for giving high priority to the development of atomic weapons for tactical purposes, recommended against an all-out effort to develop a hydrogen bomb. On January 31, 1950, President Truman settled the issue with his momentous decision that the Commission should expedite work on the thermonuclear weapon.(6)

Production Expansion

David Lilienthal resigned on February 15th after three years as chairman of the Atomic Energy Commission. Although his dream of developing the full potential of the peaceful atom had not been fulfilled, the Commission under his leadership had become an effective government institution. Indeed, the future held great promise for the peaceful atom, but for the moment at least the military atom would continue to be in the ascendancy.

By mid July 1950 Gordon Dean had become chairman of the Commission, and the Nation was no longer in a twilight zone between peace and war. Following an attack by North Korean troops across the 38th parallel, President Truman ordered U.S. forces to the aid of South Korea. Suddenly increased military demands, added to the President's decision to develop the hydrogen bomb, threatened to exhaust the Commission's production capacity. Beginning in October 1950 the Commission embarked on a vast expansion program. During the next three years the construction of huge plants increased capacity at each step in the production chain. The new facilities included a feed materials production center at Fernald, Ohio; a plant to produce large quantities of lithium 6 at Oak Ridge; a gaseous-diffusion plant at Paducah, Kentucky; a whole new gaseous diffusion complex at Portsmouth, Ohio; two "Jumbo" reactors and a separation plant for producing plutonium at Hanford; and five heavy-water reactors at the Savannah River site in South Carolina for producing tritium from lithium 6 as well as plutonium. The three year three-billion-dollar expansion program represented one of the greatest federal construction projects in peacetime history.

In addition to having an impact on the Commission's expansion program, the Korean War also focused attention on the need for a continental test site. In December 1950, with the approval of the Department of Defense and the General Advisory Committee, the Commission selected the Las Vegas bombing and gunnery range as the site to conduct the January 1951 *Ranger* test series, the first atomic tests in the United States since the *Trinity* detonation at Alamogordo on July 16, 1945.(7)

The United States detonated the world's first thermonuclear device in the fall of 1952. Code-named *Mike*, the shot was part of the *Ivy* test series conducted at Enewetak. By the end of 1953 more than thirty weapon test devices had been successfully fired at Pacific or Nevada sites, the result of extraordinary efforts by scientists and engineers at the Commission's Los Alamos weapon laboratory. A second weapon laboratory established at Livermore, California in early 1952, soon became the center of a weapon engineering and production network which included the Sandia Laboratory near Albuquerque, New Mexico, as well as new or expanded facilities in Iowa, Texas, Missouri, Ohio, and Colorado.(8)

Organizing the National Laboratories

Fortunately the concentrated effort on weapon production did not mean a total neglect of the Commission's research laboratories. The Commission recognized the need to maintain the vitality of the national labs, and to encourage the university research teams and industry groups whose research on the peaceful uses of atomic energy would provide the technology of the future. The Metallurgical Laboratory at the University of Chicago had been reorganized by the Army in 1946 as the Argonne National Laboratory. The following year the Commission obtained a new site for the lab at Argonne, Illinois and determined that the laboratory should become a large multidisciplinary research center for the midwest. Under the direction of Walter H. Zinn, one of Enrico Fermi's principal assistants in developing the world's first reactor, Argonne very quickly became the Commission's center for reactor development.(9)

The Clinton Laboratories, built during World War II at Oak Ridge, Tennessee, became the regional research center for southeastern United States. Reorganized in 1948 as the Oak Ridge National Laboratory, Oak Ridge became the Nation's largest supplier of radioisotopes for medical, industrial and physical research, as well as a regional center for research in chemistry, physics, metallurgy, and biology. The laboratory also conducted the largest radiation genetics program in the world.

To provide regional research facilities for the northeast, the Commission approved a plan by Associated Universities, Inc. to build and operate a laboratory at Upton, New York. The Brookhaven National Laboratory provided research facilities in reactor physics, high-energy accelerators, and the biomedical sciences. A fourth center in the far west was established by expanding the facilities of the University of California Radiation Laboratory at Berkeley. In addition to the regional centers the Commission continued to support the wartime research laboratories at a number of colleges and universities, and awarded and administered hundreds of contracts with research institutions, universities and nonprofit organizations for basic research in the physical and biological sciences.(10)

Reactor Development

Although by 1953 the vast production complex of the Atomic Energy Commission was almost totally dedicated to military purposes, the idea of a civilian nuclear power system based on American industry was very much alive. As early as 1947, Lilienthal had publicly encouraged a partnership with industry in developing the peaceful uses of atomic energy. The Commission had supported a modest but coherent plan for developing nuclear power and propulsion and had permitted a few industry committees underground tests in accordance with the 1963 treaty. Although the limitations of the treaty imposed severe technical problems, particularly in testing high-yield warheads, the Commission's laboratories nevertheless were highly successful in devising ways to improve and update nuclear weapons by testing underground.

Civilian Power: The Proliferation of the Peaceful Atom in the Sixties

The signing of the Limited Test Ban Treaty in August 1963 also had an impact on the civilian power program. The cessation of weapon testing in the atmosphere gave new hope that the peaceful atom might soon command as large a share of the Commission's time and budget as the military atom had for so many years.

Although the imminence of economic nuclear power had been a main theme at the 1958 Geneva Conference, recurring technical difficulties in many of the prototype and demonstration plants in several European countries continued in the next few years to frustrate hopes for a practical new source of electrical power. In the United States, however, prospects were somewhat more encouraging. In March 1962 President Kennedy had requested the Atomic Energy Commission to take a "new and hard look at the role of nuclear power" in the Nation's economy. In submitting the Commission's report several months later, Seaborg noted optimistically that the Commission's ten-year civilian power program, adopted in 1958, was on the threshold of attaining its primary objective of competitive nuclear power by 1968. Suggested goals for the future included a concentration of resources in the most promising reactor systems, the early establishment of a self-sufficient and growing nuclear power industry, and increased emphasis on the development of improved converter or breeder reactors which would conserve natural uranium resources. The report was broadly circulated and stimulated public confidence in the economic prospects for civilian nuclear power.(24)

On November 22, 1963, Lyndon B. Johnson became President of the United States. One of Johnson's first and probably most significant acts was to order a 25 percent cutback in production of enriched uranium and the shut down of four plutonium piles, with the expectation that other nations might be challenged to do the same. Although verification was difficult, Chairman Khruschev later announced production cutbacks in the Soviet Union.

Another milestone in civilian power development occurred on December 12, 1963, when the Jersey Central Power and Light Company announced that it had contracted for a large nuclear power reactor to be built at Oyster Creek near Toms River, New Jersey. According to the company's own evaluation, the plant would be competitive with a fossil fuel plant. For the first time an American utility company had selected a nuclear power plant on purely economic grounds without government assistance and in direct competition with a fossil-fuel plant. In a commencement address at Holy Cross College on June 10, 1964, President Johnson called it an "economic breakthrough."(25) Two months later private industry received further encouragement from Congress in the form of new legislation.

Private Ownership Legislation

On August 26, 1964, President Johnson brought to an end an eighteen-year mandatory government monopoly of special nuclear materials by signing into law the "Private Ownership of Special Nuclear Materials Act." Enriched uranium for power reactor fuel would no longer have to be leased from the government. Private entities would be permitted to assume title to special nuclear materials. Although the new law provided for a transition period for the changeover from government to private ownership, after June 20, 1973 private ownership of power reactor fuels would become mandatory. The Act also authorized the Commission to offer uranium enriching services to both domestic and foreign customers under long-term contracts, beginning on January 1, 1969. Most of the Atomic Energy Commision's literature on reactor technology had been declassified as early as 1955. With the adoption of the Private Ownership Act in 1964, fissionable materials as well as reactors now entered the public domain, and a full-fledged nuclear industry became a possibility.(26)

But how would a full-fledged nuclear industry be regulated? Could one agency continue to regulate a single energy technology in a time of increasing energy needs? In a few years the energy crisis of 1973 would bring these questions into sharp focus.

Nuclear Power Capacity

The Commission's 1962 report on civilian power had projected 5,000 megawatts of nuclear power capacity by 1970 and 40,000 by 1980. Within five years the outlook had changed so dramatically that in March 1967 the Commission issued a supplementary report doubling its previous predictions. Within a few years, however, even these revised statistics were exceeded. (By the end of 1974 two hundred and thirty-three nuclear central-station generating units, with a capacity of 232,000 megawatts, were either in operation, under construction, or on order in the United States.)(27)

The Breeder Reactor

In addition to predicting dramatic increases in megawatt capacity, the Commission's 1967 report on civilian nuclear power reaffirmed the promise of the breeder reactor for meeting long-term energy needs, and gave the Liquid Metal Fast Breeder Reactor (LMFBR) the highest priority for civilian reactor development. A major boost was given to the program four years later by President Richard Nixon. In his "clean energy" message to Congress on June 4, 1971, the President called for the commercial demonstration of a breeder reactor by 1980, stating that "The breeder reactor could extend the life of our natural uranium fuel supply from decades to centuries, with far less impact on the environment than the power plants which are operating today."(28)

The fast breeder project included a demonstration plant in Oak Ridge, Tennessee—the Clinch River Breeder Reactor (CRBR)—and a test reactor in Richland, Washington—the Fast Flux Test Facility (FFTF). Clinch

River promised to be a major step in the transition from technology to large-scale demonstration of the fast breeder concept. The project was launched in August 1972 with the signing of a memorandum of understanding between the Commission and the principal utility participants, the Commonwealth Edison Company and the Tennessee Valley Authority. The Commission would be responsible for research and development of the demonstration plant while the Commonwealth Edison Company and the Tennessee Valley Authority would engineer, manufacture and proof test equipment and systems.(29)

Licensing and Regulation

Under the terms of the Atomic Energy Act of 1954, Congress had given the Atomic Energy Commission the responsibility for regulating and licensing commercial atomic activities. As the Nation's electric power industry increasingly turned toward nuclear plants, the Commission found it necessary to modify its organizational structure to separate regulatory from non-regulatory functions. In 1961 the regulatory staff was separated from the General Manager's office and placed under a Director of Regulation who reported directly to the Commissioners. Two years later the regulatory and operational functions were separated physically when the regulatory staff was moved from the headquarters building in Germantown, Maryland to offices in Bethesda.(30)

Licensing procedures involved a series of technical reviews and public hearings, including an independent technical safety evaluation by the Advisory Committee on Reactor Safeguards. The Commission itself served as a final review board for all licenses granted, and maintained continuous surveillance of licensed reactors throughout their operating lifetime.

Research

The weapon requirements for national defense in the early years had forced the Commission to postpone goals for an all-out program of research on the peaceful atom. As seen in the development of the power reactor, however, there was a gradual shift in emphasis during the Eisenhower era, and the trend continued to gain momentum during the Kennedy and Johnson Years. In 1966 the AEC budget for the first time was divided about equally between weapons and peaceful uses.

Research and development programs in the 1960's and early 1970's produced a significant fund of knowledge about radiation and its effects, and provided basic data needed to determine radiation protection standards and to assess the environmental impact of nuclear technology. Advances in medical diagnostic techniques based on the use of radioisotopes and radiation machines added to the skills of the medical profession, while immunological research provided the knowledge needed for successful transplants. Other medical breakthroughs included the treatment of Parkinson's Disease, the preservation of cells for transfusion, and the introduction of small accelerators to produce short-lived radioisotopes for immediate use in patients. Although Oak Ridge produced virtually all of the radioisotopes available for physical and biomedical as well as for industrial applications, the Commission gradually transferred production, packaging, and shipping to commercial suppliers, while continuing to support research on new applications.(31)

During the 1960's the Commission produced a series of radioisotope-powered and reactor-powered electrical-generating units for space applications. The first such unit was launched into space from Vandenburg Air Force Base in California on April 3, 1965, under the Systems for Nuclear Auxiliary Power (SNAP) program. Newly discovered heavy isotopes, such as Californium-252, were found useful in both research and industry. In addition, significant progress was made in developing cardiac pacemakers for human use and ultimately artificial hearts using radioisotopic-power sources.(32)

Major research facilities such as high energy accelerators were constructed and operated by the AEC. Building on the accomplishments of the Berkeley Bevatron and the Brookhaven Cosmotron in the 1950's, the Commission supported even larger accelerators in the 1960's and 1970's, including the Alternating Gradient Synchrotron at Brookhaven, the Zero Gradient Synchrotron at Argonne, and the two-mile long Stanford Linear Accelerator. The Fermi National Accelerator Laboratory, completed in 1972, contained the world's most powerful proton synchrotron. The principal centers for research on controlled thermonuclear (fusion) reactors were Oak Ridge, Los Alamos, Livermore, and Princeton, although many universities and industrial facilities were involved on a smaller scale.

Applied Technology

As nuclear technology developed, the Commission perfected special applications of nuclear power, such as nuclear explosives for earth moving and for extracting resources deep underground. *Gnome*, the first experiment in the *Plowshare* series, was conducted in December 1961 in a thick salt bed deposit near Carlsbad, New Mexico, while the first nuclear cratering experiment, Project *Sedan*, was completed the following July at the Nevada Test Site. Project *Gasbuggy* in 1967, *Rulison* in 1969, and *Rio Blanco* in 1973, tested methods for extracting natural gas from impermeable rock. In the early 1970's, the Commission directed applied technology projects toward environmental research, energy storage and transmission systems, synthetic fuels, and nonnuclear energy.

Nonnuclear Research

The scientific and technological expertise gained by the national laboratories in developing nuclear energy made the Commission a logical contender for a strong role in developing new energy options. The doors of the national labs first opened to nonnuclear research in 1960 when the Commission, in a special report to the Joint Committee on Atomic Energy, acknowledged "that the strong capabilities of the laboratories are not the exclusive resources of the atomic energy field; they are held in trust for the Nation as a whole." Accordingly, work from other federal agencies would be accommodated whenever the skills of the national laboratories were needed.(33)

On August 11, 1971, largely in response to President Nixon's energy message of June 4, Congress authorized the Atomic Energy Commission to undertake research and development projects geared to providing a variety of alternatives for meeting the Nation's energy needs. As a result the Commission's industrial contractors and national laboratories became involved in the areas of superconducting power transmission systems, energy storage, solar energy, geothermal resources, and coal gasification.(34)

Reorganization

James R. Schlesinger took over the helm of the Atomic Energy Commission in August 1971, as its twenty-fifth year as an agency was drawing to a close. American troops were still in Vietnam and anti-war protests were widespread. The Nation faced increasing demands for energy, a leveling out of domestic oil production, limitations on coal use due to environmental concerns, inadequate natural gas supplies, and field delays in the licensing and construction of nuclear power plants. The rapid growth in atomic energy activities in the previous decade and changing perspectives in nuclear technology clearly pointed to the need for a substantial reorganization of the Commission's operational and regulatory functions. For nearly a quarter of a century the Commission had focused research and development toward responding to national defense requirements, funding and developing new uses for atomic energy, and fostering the growth of a competitive and viable nuclear industry. The next few years would see increasing attacks on the Commission's role as a regulatory overseer of the nuclear industry, particularly in the areas of quality of product and public safety.(35)

As a first order of business, Schlesinger led the Commission in a comprehensive review of the agency's functions and organization. An economist and former assistant director of the Bureau of the Budget, Schlesinger announced the results of the review in December 1971. The first broad reorganizaton in ten years would bring together various related programs previously scattered throughout the agency. Developmental and operational functions formerly under the jurisdiction of the general manager would now be under six assistant general managers for Energy and Development Programs, Research, Production and Management of Nuclear Materials, Environment and Safety Programs, National Security, and Administration. Reflecting expanding areas of Commission involvement were new divisions of Controlled Thermonuclear Research, International Security Affairs, and Applied Technology.(36) The second half of 1971 also saw a major revamping of the regulatory organization and functions.

Calvert Cliffs Decision

The Nixon Administration believed that nuclear power, as an environmentally "clean" fuel, could help the Nation produce the increasing supply of energy needed for the future. On the other hand ponderous licensing procedures and increasing environmental considerations lengthened the time necessary to bring nuclear power plants on line, and increased costs to the industry, and ultimately to the consumer. As Commissioner Doub informed the Atomic Industrial Forum in October 1971, the Commission harbored no illusions as to the magnitude of the task of trying to match "the capabilities of a dynamic and complex technology to the urgent energy and environmental needs of the country."(37)

The Federal Court of Appeals' August 4, 1971 landmark decision concerning the Calvert Cliffs nuclear power plant became a pivot point for a major revamping of the Commission's licensing procedures. The Court ruled that the Atomic Energy Commission's regulations for implementing the National Environmental Policy Act of 1969 in licensing procedures did not comply in several respects with the Act, and that the Commission should make an independent review and evaluation of all environmental effects at every decision point in the nuclear power plant licensing process.

Moving swiftly to implement the Court's ruling, the Commission made substantive changes in environmental review procedures. Both the Commission and the license applicant would now be required to consider the total impact of the proposed plant on the environment, including water quality. In addition, a cost-benefit analysis would balance the benefits of building the facility against a variety of alternatives.(38) These changes in procedures affected virtually all nuclear power plants whether licensed for operation or under review.

To expedite the additional procedures which the Calvert Cliff's decision required, Schlesinger made significant changes in the Commission's regulatory organization, and added additional personnel to the staff to help with the expanded reactor licensing workload. Additional changes in 1972 further streamlined the regulatory staff. Three directors consolidated the functions previously performed by seven divisions. All licensing activities were centered in the largest of the three, the Directorate of Licensing, headed by John F. O'Leary, former Director of the Bureau of Mines.(39)

The Commission's Last Days

Schlesinger left the Atomic Energy Commission in January 1973 to become head of the Central Intelligence Agency. He was succeeded as chairman by Dr. Dixy Lee Ray, a marine biologist from the state of Washington who had been appointed to the Commission by President Nixon in August 1972. The first woman to be chairman of the Atomic Energy Commission, Ray took over at a time when the Nation was faced with the monumental task of reconciling energy needs, environmental concerns and economic goals. More importantly for the Commission, criticism had begun to mount against an agency that regulated the very same energy source that it helped to produce and operate.

In June 1973, President Nixon directed the chairman of the Atomic Energy Commission to undertake an immediate review of federal and private energy research and development activities and to recommend an integrated program for the Nation.(40) The President's energy proposals to Congress the following January reflected the recommendations submitted by Chairman Ray in the December 1, 1973 report on "The Nation's Energy Future." Because of the energy crisis resulting from the October Arab oil embargo, the President had chosen to break tradition and present his energy request to Congress before delivering his State of the Union address. Both his proposal for a five-year $10 billion energy research and development program, and his determination to double the total federal commitment to energy research and development for fiscal year 1975, were in line with the recommendations made by the Commission chairman. The Ray report also supported the President's recommendation to establish an Energy Research and Development Administration.(41)

Reactor Safety

In December 1973 the Commission announced new requirements for the performance of the emergency core cooling systems (ECCS) installed in light-water-cooled power reactors. Such systems provided the capability for emergency removal of heat from the reactor core in the event of a loss of the normal reactor coolant water. The Commission's action concluded a two-year public rulemaking hearing which had served as a focal point for public discussion of opposing viewpoints on the safety of nuclear power plants. Six months of hearing sessions, between January 27, 1972 and July 25, 1973, had produced a voluminous transcript, a clear witness to the complexity of the technical issues involved in nuclear safety. A constant advocate of the public's right to know and fully understand the possible dangers of radiation, the Joint Committee on Atomic Energy had also held a hearing in early 1973 on the safety of nuclear power plants.

Clearly the handwriting on the wall was spelling out the numbered days of the AEC in 1973. Although nuclear power constituted a significant part of the answer to the Nation's need for additional sources of energy, it was by no means the only answer as had been predicted in the early decades of the Commission's existence.

Summary

When President Ford signed the Energy Reorganization Act of 1974 on October 11, the Atomic Energy Commission's twenty-eight year stewardship of the Nation's nuclear energy program came to an end. On January 19, 1975, the Commission's research and development responsibilities were assumed by the Energy Research and Development Administration, and the regulatory and licensing functions by the Nuclear Regulatory Commission. Six thousand, three hundred and twenty Commission employees went to ERDA while one thousand nine hundred and seventy former regulatory personnel became part of the new Nuclear Regulatory Commission.

In the preceding twenty-eight years the Atomic Energy Commission had accomplished a large portion of the mission established by the Congress in 1946. First, through its weapon laboratories and production contractors, it had developed and stockpiled an array of sophisticated nuclear weapons which for nearly three decades had served as an important element in national defense. Also in the area of defense, the Commission had supported the development of nuclear propulsion reactors which made possible the creation of a fleet of reliable nuclear submarines and surface ships.

Although for many years military related programs commanded the major portion of the budget, the Commission had initiated and supported extensive research in the nuclear sciences. The research contract and the national laboratory had become key instruments in the widespread development and application of nuclear technology for scientific, medical, and industrial purposes. Through participation in the International Atomic Energy Agency, international conferences and bilateral agreements, the United States shared the new technology with other nations.

The congressional mandate of 1946 also called for the use of atomic energy in a way that would strengthen free competition in private enterprise. Although the severe restrictions of the 1946 Act made atomic energy virtually a government monopoly, the Commission in less than a decade advanced nuclear technology to the point where industrial participation was feasible, and then encouraged the passage of new legislation in 1954 which made a nuclear industry possible. By the early 1970's nuclear power offered a promising option for meeting national and world energy needs.

In carrying out the Congressional mandate of 1946, the Atomic Energy Commission essentially worked its way out of existence. After concentrating on defense commitments in the early years, the Commission then focused on the development of a viable nuclear industry, only to come under fire in the late 1960's and 1970's for being in the position of regulating the same industry it helped to create.

This difficulty had been foreseen in 1961 when the functions of the agency were divided between the General Manager and the Director of Regulation. Then in 1963 the two functions were physically separated by being housed in different geographical locations. Finally, the legal separation of the developmental and regulatory functions, requested in 1973 by the Commission itself, was accomplished by the Energy Reorganization Act of 1974. The regulatory and licensing responsibilities became the exclusive focus of a new agency headed by a five-member board, the Nuclear Regulatory Commission, while the developmental functions were placed under a single administrator in a second agency, the Energy Research and Development Administration.

In the preceding decade the Atomic Energy Commission had lost much of its privileged status with Congress and the American public. The exclusive monopoly and the mantle of secrecy had been largely removed, and no longer did atomic energy seemingly provide the perfect formula for both military defense and civilian energy needs. Regulatory restrictions and environmental concerns were a large part of the reason for the demise of the AEC, but more important was the recognition that a single technology should not be the exclusive focus of one agency. The energy crisis would now require the coordination of all major energy programs in a new research and development agency, whose primary purpose would be to assist the Nation in achieving energy independence.

As a legacy to the new agency, the Atomic Energy Commission passed on its unique production facilities, its valuable network of national laboratories, and the proven technological skills, resourcefulness, and experience of its personnel. Three years later the Energy Research and Development Administration, like the Atomic Energy Commission before it, became part of an even larger organization. On October 1, 1977 Congress created a cabinet-level Department of Energy to coordinate Federal energy policies and programs.

FOOTNOTES

1. Sect. 1(a), Atomic Energy Act of 1946 (Public Law 585) 78th Cong. 1st sess.

2. Corbin Allardice and Edward R. Trapnell, *The Atomic Energy Commission* (New York: Praeger Publishers, 1974), pp. 31-32 (hereafter cited as Allardice and Trapnell, *The AEC*).

3. Dr. Richard G. Hewlett, former Chief Historian of the AEC, believes that the most influential group in the early years was not the Commission itself but its General Advisory Committee consisting of such famous scientists as J. Robert Oppenheimer, James B. Conant, Enrico Fermi and Isador I. Rabi. Richard G. Hewlett, "The Advent of Nuclear Power, 1945-1968" (Paper delivered before the American Association for The Advancement of Science, Dallas, TX, Dec. 28, 1968), p. 4 (hereafter cited as Hewlett, "The Advent of Nuclear Power").

4. Richard G. Hewlett, "Nuclear Power in the Public Interest: The Atomic Energy Act of 1954" (Paper delivered before the American Historical Association, Dallas, TX, Dec. 1977), pp. 1-3.

5. Richard G. Hewlett, "The AEC in Retrospect" (unpublished ms., Historian's Office, Feb. 10, 1976), p. 12 (hereafter cited as Hewlett, "The AEC in Retrospect").

6. *Public Papers of the Presidents of the United States: Harry S. Truman 1950* (Washington: Government Printing Office, 1965), p. 138. For a detailed presentation of the decision on the hydrogen bomb, see Richard G. Hewlett and Francis Duncan, *Atomic Shield, 1947-1952, Vol. II of A History of the United States Atomic Energy Commission* (University Park: Pennsylvania State University Press, 1969), pp. 362-409 (hereafter cited as Hewlett and Duncan, *Atomic Shield*).

7. Hewlett and Duncan, *Atomic Shield*, pp. 534-35, 563-64.

8. Hewlett and Duncan *Atomic Shield*, pp. 411, 424-30, 441; "The Eisenhower Imprint," unpublished ms., Department of Energy Historian's Office, pp. 3-4; "A History of the Expansion of AEC Production Facilities," Report by the General Manager, Aug. 16, 1963, pp. 13-20.

9. Hewlett and Duncan, *Atomic Shield*, p. 432; Richard G. Hewlett and Francis Duncan, *Nuclear Navy 1946-1962* (Chicago: University of Chicago Press, 1974), pp. 54-55 (hereafter cited as Hewlett and Duncan, *Nuclear Navy*).

10. *Atomic Shield*, pp. 222-227, 432.

11. Proposal for Industrial Development of Atomic Energy, enc. C.A. Thomas to S. Pike, June 20, 1950; David Lilienthal, Speech before the Economic Club, Detroit, MI, Oct. 6, 1947; AEC Press Release 59, Oct. 6, 1947; Hewlett and Duncan, *Atomic Shield*, pp. 495-98..

12. Hewlett and Duncan, *Nuclear Navy*, pp. 178-79, 235-57; Dean Diary, June 14, 1952.

13. Hewlett, "The Advent of Nuclear Power", p. 12.

14. *Public Papers of the Presidents of the United States, 1953, Dwight D. Eisenhower* (Washington: Government Printing Office, 1960), pp. 813-22.

15. For a discussion of Atoms for Peace as an instrument of foreign policy, see Jack M. Holl, "Eisenhower's Peaceful Atomic Diplomacy: Atoms for Peace in the Public Interest" (Paper delivered before the American Historical Association, Dallas, TX, Dec. 23-30, 1977), p. 1 (hereafter cited as Holl, "Eisenhower's Peaceful Diplomacy").

16. "Message from the President of the United States, "House Document, 83 Cong., 2 sess., no. 328 (Feb. 17, 1954); Richard G. Hewlett, "Industry and the Atomic Energy Commission, 1947-1954" (Paper delivered at a joint session of the Society for the History of Technology and the Organization of American Historians, Chicago, IL, April 27, 1967), pp. 21-22.

17. Joint Committee on Atomic Energy, *Current Statement of the Atomic Energy Commission on the Five-Year Reactor Development Program*, May 4, 1955 (Washington: Government Printing Office, 1955).

18. Holl, "Eisenhower's Peaceful Diplomacy" pp. 9-18; AEC, *Twenty-third Semiannual Report, January 1958* (Washington: Government Printing Office, 1958), pp. 189-221.

19. Robert A. Divine, *Blowing on the Wind, the Nuclear Test Ban Debate 1954-1960* (New York: Oxford University Press, 1978), pp. 3-18; AEC, *Sixteenth Semiannual Report, July 1954* (Washington: Government Printing Office, 1958), pp. 51-5; Richard G. Hewlett and Jack M. Holl, "Nuclear Weapons: A New Reality" (unpublished ms., Historian's Office, 1981), pp. 61-63.

20. "A Report by United States Atomic Energy Commission on Effect of High-Yield Nuclear Explosions," Appendix 7, *Eighteenth Semiannual Report of the Atomic Energy Commission July 1955* (Washington: Government Printing Office, 1955), pp. 147-54; Senate Committee on Armed Services, *Civil Defense Program*, 84th Cong., 1st Sess., Feb. 22, 1955, p. 2; Joint Committee on Atomic Energy, *Health and Safety Problems Associated with Atomic Explosions*, April 15, 1955; AEC, *Major Activities in The Atomic Energy Programs, January-June 1956*, p. 16.

21. Willard F. Libby, "Radioactive Fallout and Radioactive Strontium," Northwestern University, Evanston, IL, Jan. 19, 1956; Joint Committee on Atomic Energy Press Release No. 80, April 18, 1957.

22. AEC, *Twenty-fifth Semi-Annual Report of the Atomic Energy Commission, January 1959* (Washington: Government Printing Office, 1960), pp.

179-80. Richard G. Hewlett, "Nuclear Weapon Testing and Studies Related to Health Effects: An Historical Summary" (unpublished ms., Oct. 1980), pp. 43-44.

23. *Major Activities in the Atomic Energy Program, January-December 1961* (Washington: Government Printing Office, 1962), pp. 161-62; AEC, *Major Activities in the Atomic Energy Programs, January-December 1962* (Washington: Government Printing Office, 1963), p. 234; *Public Papers of Presidents of the United States: John F. Kennedy 1962* (Washington: Government Printing Office, 1963), pp. 186-92.

24. AEC, *Civilian Nuclear Power—A Report to the President—1962*, Nov. 20, 1962.

25. "Annual Message to the Congress on the State of the Union," Jan. 8, 1964; "Commencement Address at Holy Cross College," June 10, 1964, both in *Public Papers of the Presidents: Lyndon B. Johnson*, (Washington: Government Printing office, 1965), pp. 117, 763-764.

26. AEC, *Annual Report to Congress for 1964*, (Washington: Government Printing Office, 1965), pp. 12-14; Hewlett, "The AEC in Retrospect," p. 18; "Remarks Upon Signing Bill Permitting Private Ownership of Nuclear Materials," *Public Papers of the Presidents: Lyndon B. Johnson*, (Washington: Government Printing Office, 1965), p. 1006.

27. AEC, *Civilian Nuclear Power, The 1967 Supplement to the 1962 Report to the President*, February, 1967; AEC, *1974 Annual Report to Congress*, p. 239.

28. Richard M. Nixon, "A Program to Insure an Adequate Supply of Clean Energy in the Future," June 4, 1971, as reprinted in *Executive Energy Documents*, published by the Senate Committee on Energy and Natural Resources, July 1978, pp. 1-12 (Hereafter cited as *Executive Energy Documents*).

29. "Operating and Developmental Functions," AEC *1972 Annual Report to Congress*, pp. 10-12; "AEC Continues Developmental Push for Breeder Reactor," AEC Announcement 0-10, January 29, 1971.

30. AEC, *Major Activities in the Atomic Energy Programs, January-December 1961* (Washington: Government Printing Office 1962), pp. 337-38; Richard G. Hewlett, "The Development of the Nuclear Power Industry" (unpublished ms., Historian's Office, 1974), pp. 13-14; AEC, *Major Activities in the Atomic Energy Programs, January-December 1961*, p. 337-38.

31. *AEC, 1974 Annual Report to Congress*, (Washington: Government Printing Office, 1974), pp. 24-26.

32. *AEC Annual Report to Congress for 1965*, (Washington: Government Printing Office, 1966), p. 151; *Annual Report to Congress for 1966*, (Washington: Government Printing Office, 1967), p. 211; AEC, *1974 Annual Report to Congress*, p. 114.

33. "Atomic Energy Research in the Life and Physical Sciences—1960," A Special Report of the United States Atomic Energy Commission, January 1961, (Washington: Government Printing Office, 1961); AEC, Annual Report to Congress for 1960, (Washington: Government Printing Office, 1961), p. 156-57.

34. Authorization Act for Fiscal Year 1972 (PL. 92-84, Sections 31-33, Aug. 11, 1971; Richard G. Hewlett, "Nonnuclear Energy Research in the Atomic Energy Commission" (unpublished ms., Historian's Office, 1974).

35. Corbin Allardice and Edward R. Trapnell, *The Atomic Energy Commission* (New York: Praegar Publishers, 1974), pp. 131-32.

36. "Reorganization of Atomic Energy Operating Functions," AEC Announcement 216, Dec. 7, 1971.

37. "The Right to be Heard—Laying It on the Line," Remarks given by AEC Commissioner William O. Doub (at 1971 Annual Conference of the Industrial Forum, Oct. 18, 1971); President Richard M. Nixon, Message to the Congress on "A Program to Insure an Adequate Supply of Clean Energy in the Future," June 4, 1971 in *Executive Energy Documents*, p. 1.

38. "Statement by the AEC on Court of Appeals Decision in Calvert Cliffs Litigation," AEC Announcement 0-134, Aug. 4, 1971; AEC *Annual Report to Congress for 1971* (Washington: Government Printing Office, 1972) pp. 1-2, 21-23.

39. "AEC Makes Organizational Changes to Strengthen Its Regulatory Program," Press Release 0-207, Nov. 11, 1971.

40. Richard M. Nixon, "Statement," June 29, 1973 in *Executive Energy Documents*, pp. 49-55; Statement by Dixy Lee Ray, Chairman of the AEC, AEC Press Release R-274, June 29, 1973.

41. *The Nation's Energy Future*, A Report to President Richard M. Nixon, December 1973 (Washington: Government Printing Office, 1973) p. ix; "Proposals to Deal with the Energy Crisis," Jan. 23, 1974, in *Executive Energy Documents*, pp. 119-134; White House Fact Sheet, "Energy Research and Development," Oct. 11, 1973.

APPENDIX I
(Personnel)

Joint Committee on Atomic Energy

CHAIRMEN	*DATES OF SERVICE*
Brien McMahon	1946 -
Burke B. Hickenlooper	1947 - 1948
Brien McMahon	1949 - 1952 (d. 7/28/52)
Carl T. Durham (Acting)	1952 -
W. Sterling Cole	1953 - 1954
Clinton P. Anderson	1954 - 1956
Carl T. Durham	1956 - 1958
Clinton P. Anderson	1959 -
Chet Holifield	1960 - 1961
John O. Pastore	1962 - 1964
Chet Holifield	1965 - 1966
John O. Pastore	1967 - 1968
Chet Holifield	1969 - 1970
John O. Pastore	1970 - 1972
Melvin Price	1973 -

Military Liaison Committee

CHAIRMEN	*DATES OF SERVICE*
Lt. Gen. Lewis H. Brereton, USAF	1946 - 1948
Donald F. Carpenter	1948 -
William Webster	1948 - 1949
Robert F. LeBaron	1949 - 1954
Herbert B. Loper	1954 - 1960
Gerald W. Johnson	1961 - 1962
W.J. Howard	1963 - 1965
Carl Walske	1966 - 1969
Chet Holifield	1970 -
Carl Walske	1971 - 1972
Donald R. Cotter	1973 -

General Advisory Committee

CHAIRMEN	*DATES OF SERVICE*
J. Robert Oppenheimer	1946 - 1952
Isidor I. Rabi	1952 - 1956
Warren C. Johnson	1956- 1959
Kenneth S. Pitzer	1960 - 1961
Manson Benedict	1962 - 1963
L.R. Hafstad	1964 - 1967
Norman F. Ramsey	1968 -
Howard G. Vesper	1969 - 1972
Lombard Squires	1973 -

AEC Commissioners

	From	To
Sumner T. Pike	Oct. 31, 1946	Dec. 15, 1951
David E. Lilienthal, Chairman	Nov. 1, 1946	Feb. 15, 1950
Robert F. Bacher	Nov. 1, 1946	May 10, 1949
William W. Waymack	Nov. 5, 1946	Dec. 21, 1948
Lewis L. Strauss	Nov. 12, 1946	Apr. 15, 1950
Chairman	July 2, 1953	June 30, 1958
Gordon Dean	May 24, 1949	June 30, 1953
Chairman	July 11, 1950	June 30, 1953
Henry DeWolf Smyth	May 30, 1949	Sept. 30, 1954
Thomas E. Murray	May 9, 1950	June 30, 1957
Thomas Keith Glennan	Oct. 2, 1950	Nov. 1, 1952
Eugene M. Zuckert	Feb. 25, 1952	June 30, 1954
Joseph Campbell	July 27, 1953	Nov. 30, 1954
Willard F. Libby	Oct. 5, 1954	June 30, 1959
John Von Neumann	Mar. 15, 1955	Feb. 8, 1957
Harold S. Vance	Oct. 31, 1955	Aug. 31, 1959
John S. Graham	Sept. 12, 1957	June 30, 1962
John Forrest Floberg	Oct. 1, 1957	June 23, 1960
John A. McCone, Chairman	July 14, 1958	Jan. 20, 1961
John H. Williams	Aug. 13, 1959	June 30, 1960
Robert E. Wilson	Mar. 22, 1960	Jan. 31, 1964
Loren K. Olson	June 23, 1960	June 30, 1962
Glenn T. Seaborg, Chairman	Mar. 1, 1961	Aug. 16, 1971
Leland J. Haworth	Apr. 17, 1961	June 30, 1963
John G. Palfrey	Aug. 31, 1962	June 30, 1966
James T. Ramey	Aug. 31, 1962	June 30, 1973
Gerald F. Tape	July 15, 1963	Apr. 30, 1969
Mary I. Bunting	June 29, 1964	June 30, 1965
Wilfred E. Johnson	Aug. 1, 1966	June 30, 1972
Samuel M. Nabrit	Aug. 1, 1966	Aug. 1, 1967
Francesco Costagliola	Oct. 1, 1968	June 30, 1969
Theos J. Thompson	June 12, 1969	Nov. 25, 1970
Clarence E. Larson	Sept. 2, 1969	June 30, 1974
James R. Schlesinger, Chairman	Aug. 17, 1971	Jan. 26, 1973
William O. Doub	Aug. 17, 1971	Aug. 17, 1974
Dixy Lee Ray	Aug. 8, 1972	
Chairman	Feb. 6, 1973	Jan. 18, 1975
William E. Kriegsman	June 12, 1973	Jan. 18, 1975
William A. Anders	Aug. 6, 1973	Jan. 18, 1975

General Managers

Carroll L. Wilson	Dec. 31, 1946	Aug. 15, 1950
Marion Boyer	Nov. 1, 1950	Oct. 31, 1953
Kenneth D. Nichols	Nov. 1, 1953	Apr. 30, 1955
Kenneth F. Fields	May 1, 1955	June 30, 1958
Paul F. Foster	July 1, 1958	Nov. 30, 1958
A. R. Luedecke	Dec. 1, 1958	July 31, 1964
R. E. Hollingsworth	Aug. 11, 1964	Dec. 31, 1973
John A. Erlewine	Feb. 15, 1974	Dec. 31, 1974

APPENDIX I

APPENDIX II

Chronology

DATE	EVENTS
August 1, 1946	Atomic Energy Act of 1946 signed by President Truman.
January 1, 1947	Atomic energy program transferred from the Manhattan Engineer District to the Atomic Energy Commission.
September 1947	Start of construction on first of two new Hanford reactors.
March 1, 1948	Oak Ridge National Laboratory officially established to continue work of Clinton Laboratories established in 1943.
April-May 1948	Operation *Sandstone*, the first AEC nuclear test series conducted at Enewetak Atoll.
March 1, 1949	Announcement by AEC of selection of a site for the National Reactor Testing Station in Idaho.
August 29, 1949	Soviet Union detonated nuclear device.
January 31, 1950	President Truman directs Commission "to continue work on all forms of weapons, including the so-called hydrogen or super-bomb."
June 27, 1950	Truman orders U.S. forces to aid of South Korea.
December 20, 1951	Experimental Breeder Reactor No. 1 (EBR-1) first reactor to produce electric power from nuclear energy.
June 14, 1952	Keel of the world's first nuclear-powered ship, the submarine *Nautilus*, laid at Groton, Connecticut.
November 1952	World's first thermonuclear device detonated by U.S. at Enewetak.
December 8, 1953	Announcement by President Eisenhower of the Atoms-for-Peace program and proposal to establish an international agency to promote peaceful applications of atomic energy.
March 1, 1954	First shot in *Castle* weapon test series fired in Pacific.
August 30, 1954	President Eisenhower signed the Atomic Energy Act of 1954, a major revision of the 1946 Act. The new law made possible greater participation by private industry and more cooperation with other countries in developing the peaceful uses of nuclear energy.
January 10, 1955	Announcement by the AEC of the Power Demonstration Reactor Program, under which the AEC and industry would cooperate in the construction and operation of experimental power reactors.
August 8-20, 1955	First United Nations International Conference on the Peaceful Uses of Atomic Energy, in Geneva, Switzerland.
October 1, 1957	International Atomic Energy Agency inaugurated in Vienna, Austria. AEC Chairman Lewis Strauss announced U.S. offer to make 5,000 kilograms of uranium 235 available to the agency.
December 23, 1957	Full-power operation of the Shippingport Atomic Power Station, the world's first full-scale nuclear power plant, at Shippingport, Pennsylvania.
August 22, 1958	President Eisenhower announced moratorium on weapon testing to begin on October 31.
November 24, 1959	AEC Chairman John A. McCone and Professor Vasily S. Emelyanov signed Memorandum of Cooperation between U.S. and U.S.S.R.
March 1961	Regulatory functions separated from General Manager's Office and placed under a Director of Regulation.
August 31, 1961	Soviet Union broke moratorium and began testing nuclear weapons.
December 10, 1961	Project *Gnome*, the first Plowshare nuclear detonation, conducted in New Mexico.
April 25, 1962	First shot in *Dominic* series conducted at Christmas Island in the Pacific.
August 5, 1963	Limited test ban treaty between U.S., U.K., and U.S.S.R. signed in Moscow.
August 26, 1964	President Johnson signed Private Ownership of Special Nuclear Materials Act.
October 1964	The nuclear-powered surface ships, *Enterprise, Long Beach* and *Bainbridge*, completed "Operation Sea Orbit," a round-the-world cruise without logistic support of any kind.

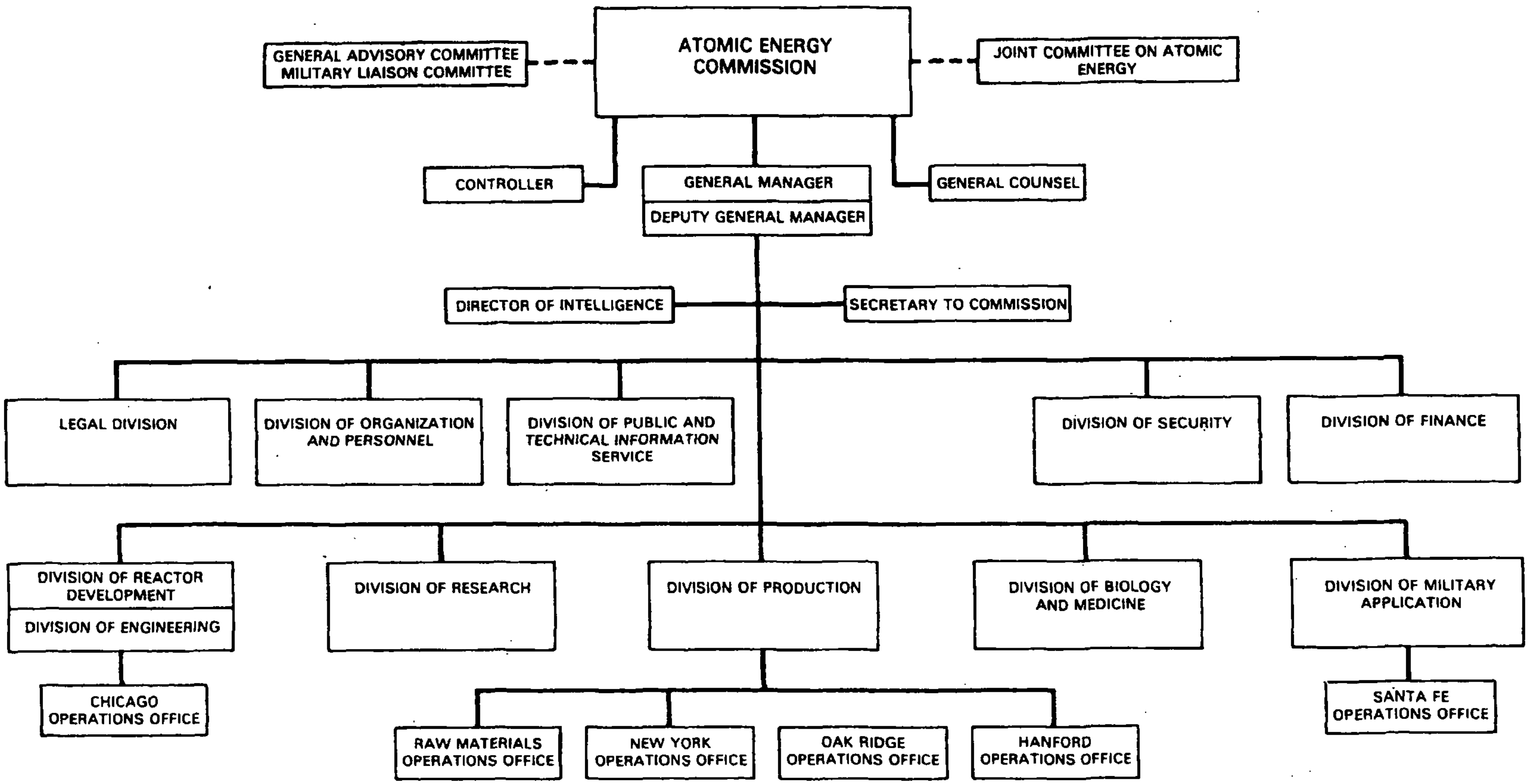
Production, Development, and Fabrication Centers

Burlington-AEC Plant	Burlington, Iowa	Mason & Hanger-Silas Mason Co., Inc.
Feed Materials Plant	Ashtabula, Ohio	Reactive Metals, Inc.
Feed Materials Plant	Fernald, Ohio	National Lead Co.
Feed Materials Plant	Paducah, Ky.	Nuclear Div., Union Carbide Corp.
Hanford Works	Richland, Wash.	Atlantic-Richfield Hanford Co. and United Nuclear, Inc.
Idaho Chemical Processing Plant	INEL, Idaho	Allied Chemical Corp.
Kansas City Plant	Kansas City, Mo.	Bendix Corp.
Mound Laboratory	Miamisburg, Ohio	Monsanto Research Corp.
Nevada Test Site	Mercury, Nev.	Reynolds Electrical & Engineering Co.; EG&G, Inc.; and Holmes & Narver Inc.
Oak Ridge Gaseous Diffusion Plant	Oak Ridge, Tenn.	Nuclear Div., Union Carbide Corp.
Paducah Gaseous Diffusion Plant	Paducah, Ky.	Nuclear Div., Union Carbide Corp.
Portsmouth Gaseous Diffusion Plant	Portmouth, Ohio	Goodyear Atomic Corp.
Pantex Plant	Amarillo, Texas	Mason & Hanger-Silas Mason Co. Inc.
Pinellas Plant	Clearwater, Fla.	General Electric Co.
Rocky Flats Plant	Golden, Colo.	Atomics International Div. Rockwell International Corp.
Savannah River Plant	Aiken, S.C.	E.I. du Pont de Nemours & Co.
Y-12 Plant	Oak Ridge, Tenn.	Nuclear Div., Union Carbide Corp.

APPENDIX IV

Organization Charts

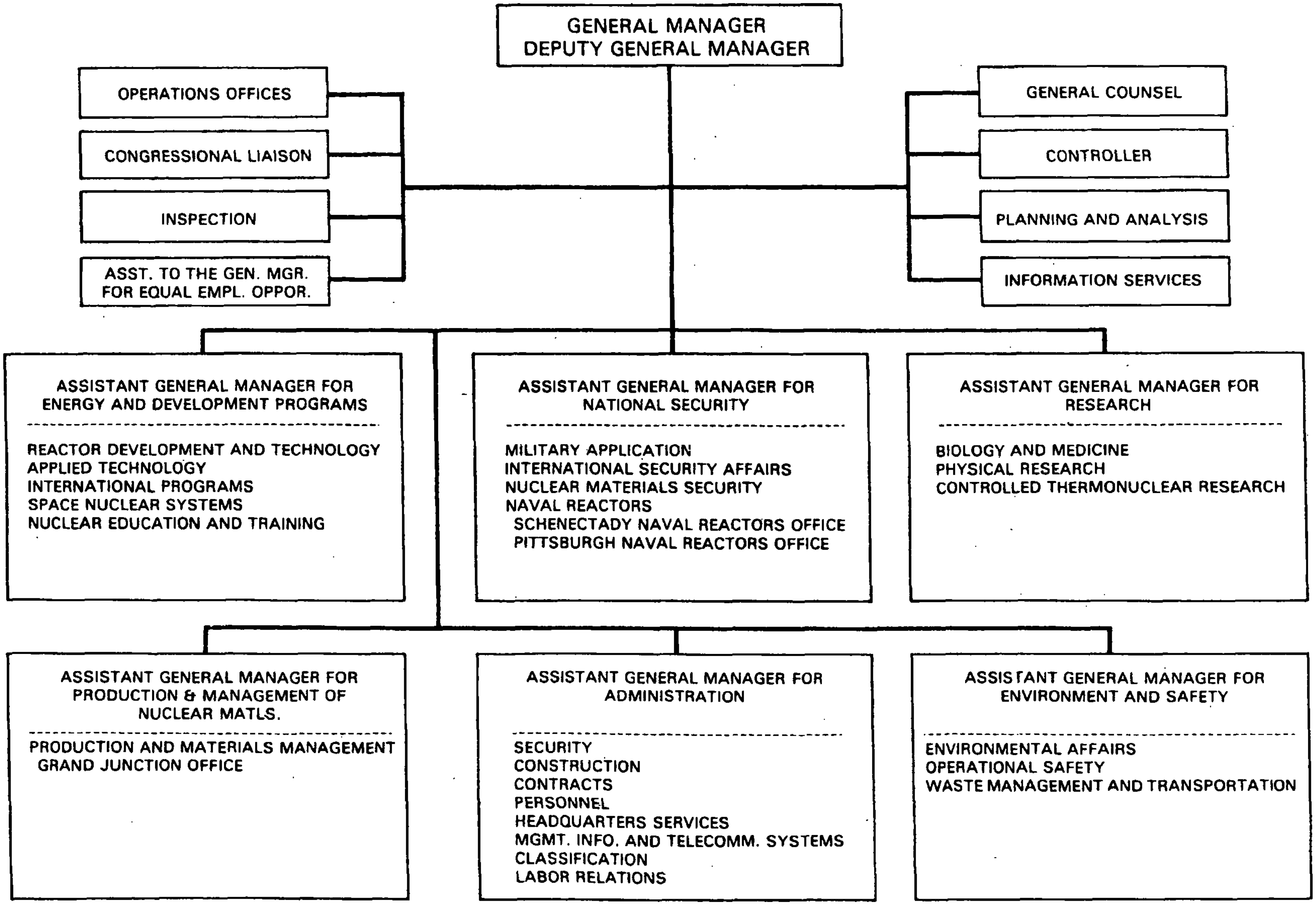
U.S. ATOMIC ENERGY COMMISSION



APPENDIX IV-1

December 1948

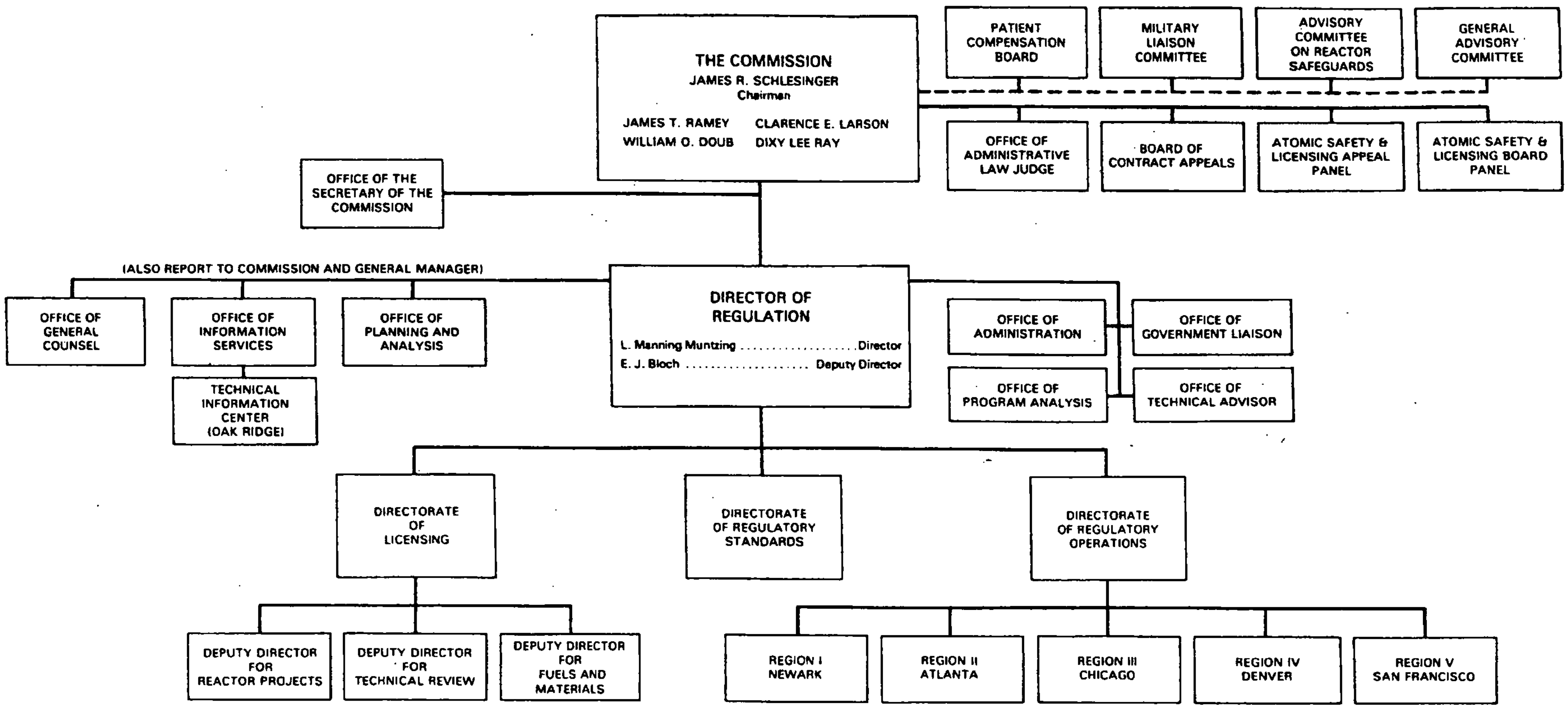
UNITED STATES
ATOMIC ENERGY COMMISSION



December 1971

APPENDIX IV-2

ATOMIC ENERGY COMMISSION
REGULATORY ORGANIZATION

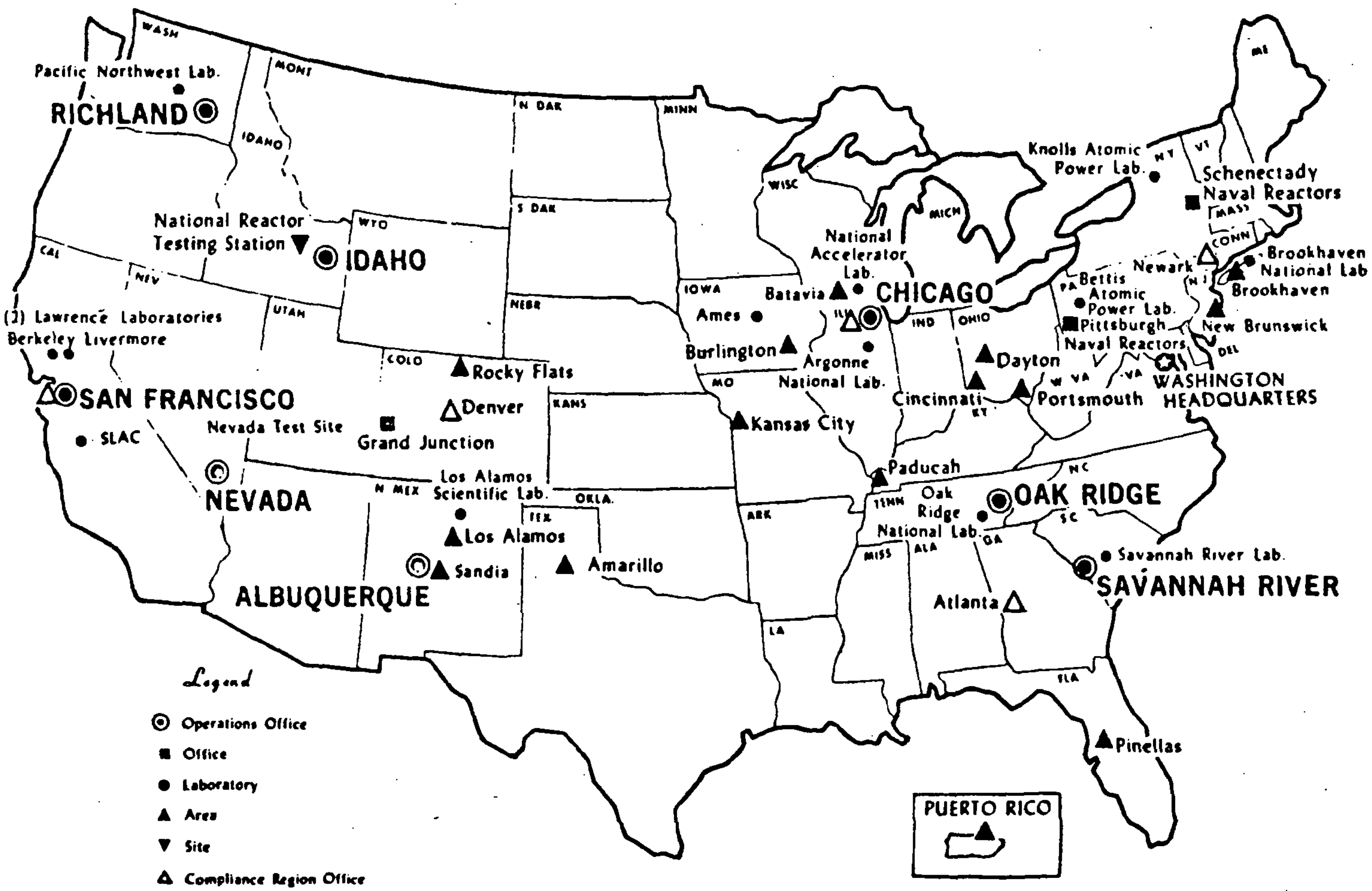


APPENDIX IV-3

August 1972

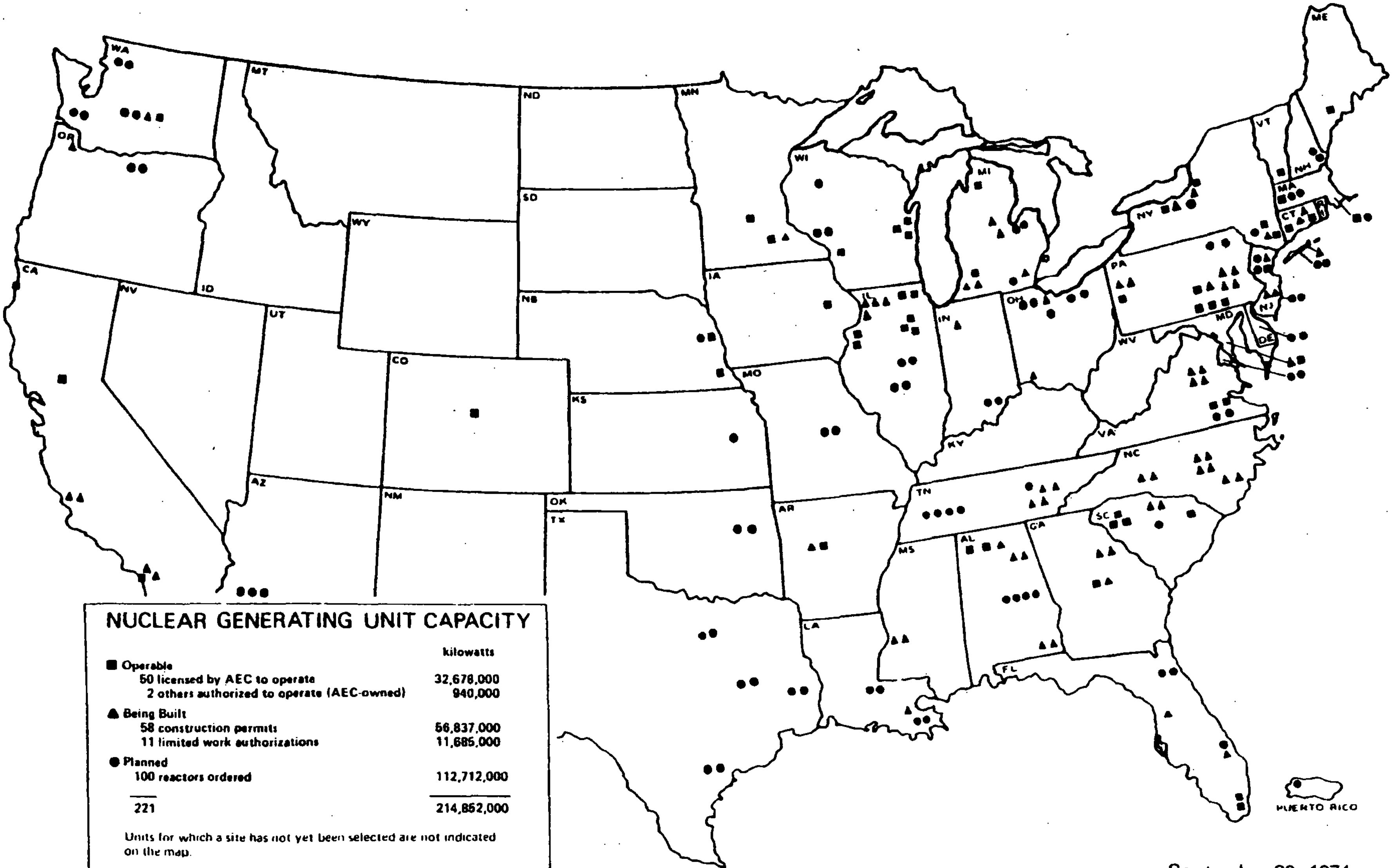
UNITED STATES
ATOMIC ENERGY COMMISSION

OFFICES AND LABORATORIES



December 1973

NUCLEAR POWER REACTORS IN THE UNITED STATES



NUCLEAR GENERATING UNIT CAPACITY

	kilowatts
■ Operable	
50 licensed by AEC to operate	32,678,000
2 others authorized to operate (AEC-owned)	940,000
▲ Being Built	
58 construction permits	56,837,000
11 limited work authorizations	11,685,000
● Planned	
100 reactors ordered	112,712,000
221	214,862,000

Units for which a site has not yet been selected are not indicated on the map.

September 30, 1974

APPENDIX IV-5

APPENDIX V
United States Announced Nuclear Detonations and Early Stockpile Data

1945 - 1974

Event or Series Name	Description	Dates
Trinity	First test of an atomic bomb	July 16, 1945
Hiroshima	First use in combat	August 6, 1945
Nagasaki	Second use in combat	August 9, 1945
Crossroads		June - July 1946
Sandstone		April - May 1948
Ranger		January - February 1951
Greenhouse		April - May 1951
Buster-Jangle		October - November 1951
Tumbler-Snapper		April - June 1952
Ivy		October - November 1952
	Mike, experimental thermonuclear device	October 31, 1952
Upshot-Knothole		March - June 1953
Castle		February - May 1954
	Bravo, experimental thermonuclear device	February 28, 1954
Teapot		February - May 1955
Wigwam		May 14, 1955
Redwing		May - July 1956
Plumbbob		May - October 1957
Hardtack		April - August 1958
Argus		August - September 1958
Hardtack		September - October 1958

NO TESTS CONDUCTED FROM OCTOBER 30, 1958 to SEPTEMBER 1961

Event or Series Name	Description	Dates
Nougat		September 1961 - June 1962
Dominic I		April 1962 - June 1962
Storax		July 1962 - June 1963
	Sedan, excavation experiment	July 6, 1962
Dominic II	Three above ground tests.	July 1962

LIMITED TEST BAND TREATY, AUG. 5, 1963, PROHIBITED NUCLEAR DETONATIONS IN ATMOSPHERE, OUTER SPACE AND UNDER WATER

Event or Series Name	Description	Dates
Niblick		August 1963 - June 1964
Whetstone		July 1964 - June 1965
Flintlock		July 1965 - June 1966
Latchkey		July 1966 - June 1967
Crosstie		July 1967 - June 1968
Bowline		July 1968 - June 1969
Mandrel		July 1969 - June 1970
Emery		October 1970 - June 1971
Grommet		July 1971 - May 1972
Toggle		July 1972 - June 1973
Arbor		October 1973 - June 1974
Bedrock		July 1974 -

Total Announced Detonations by Year

1945	3
1946	2
1947	0
1948	3
1949	0
1950	0
1951	16
1952	10
1953	11
1954	6
1955	15
1956	17
1957	24
1958	55
1959	0
1960	0
1961	9
1962	89
1963	25
1964	28
1965	28
1966	40
1967	28
1968	33
1969	28
1970	30
1971	11
1972	8
1973	9
1974	7
TOTAL	535

Early Nuclear Weapon Stockpile Data

	Fiscal Year			
	1945	*1946*	*1947*	*1948*
Number of nonnuclear components				
1. Gun-type	0	0	0*	2*
2. Implosion-type	2	9	29*	53*
Number of nuclear components				
3. Gun-type	0	0	0	0
4. Implosion-type	2	9	13	50

***Numbers declassified in 1976**

APPENDIX VI

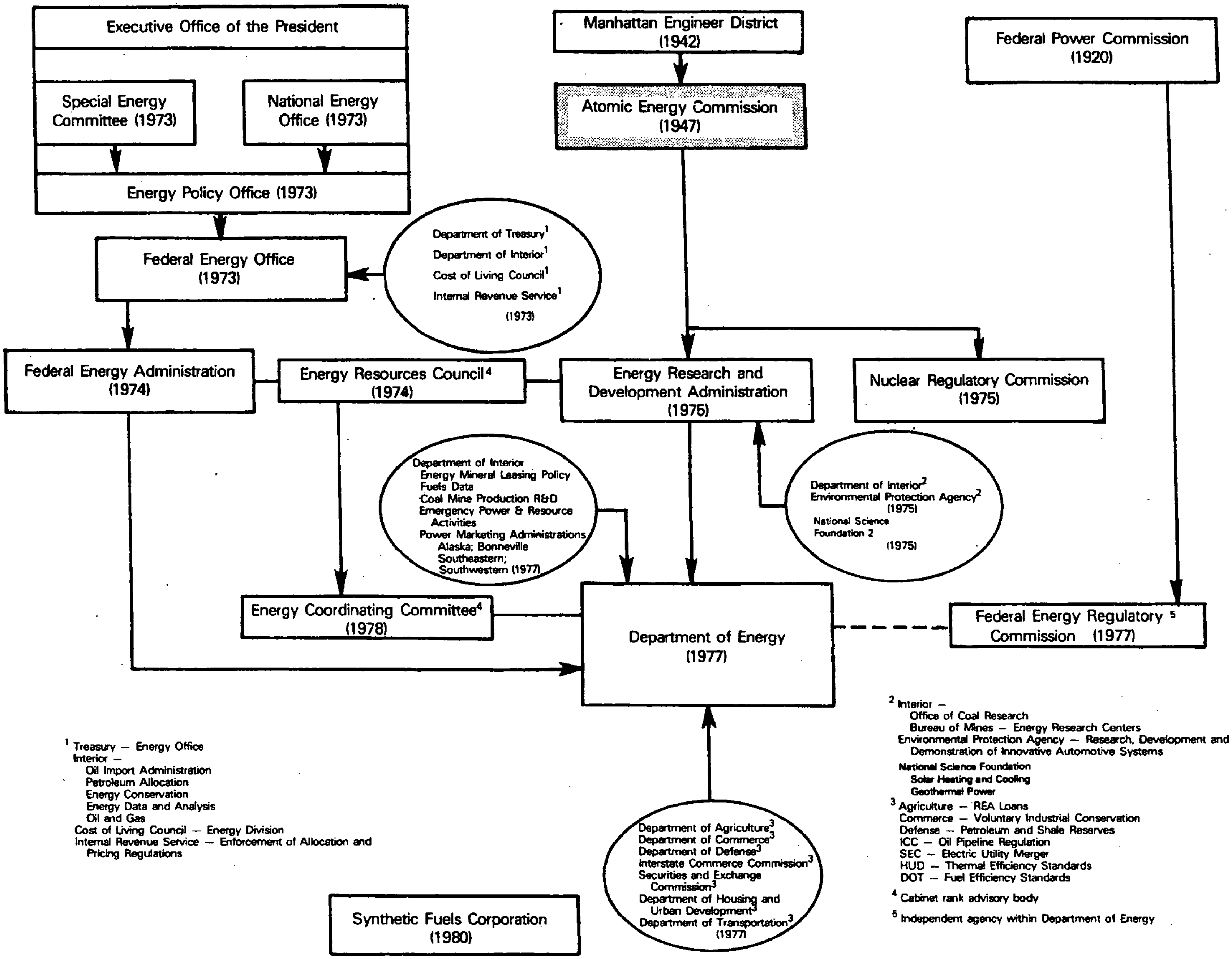
Financial Statistics

U.S. Government Investment in the Atomic Energy Program

(From June 1940 Through January 18, 1975)

	(in millions)
Appropriation Expenditures:	
National Defense Research Council	$ .5
Office of Scientific Research and Development	14.6
War Department (including Manhattan Engineer District)	2,218.3
	2,233.4
Atomic Energy Commission:	
Fiscal years prior to 1966	34,643.8
Fiscal year 1966	2,402.9
Fiscal year 1967	2,263.7
Fiscal year 1968	2,466.6
Fiscal year 1969	2,450.4
Fiscal year 1970	2,455.0
Fiscal year 1971	2,274.7
Fiscal year 1972	2,392.1
Fiscal year 1973	2,393.1
Fiscal year 1974	2,307.5
Fiscal Year 1975 (through January 18)	1,512.6
Total AEC	57,562.4
Total Appropriation Expenditures	59,795.8
Unexpended Balance of Funds in U.S. Treasury January 18, 1975	3,439.9
Total Funds Appropriated	63,235.7
Less:	
Collections paid to U.S. Treasury	58.0
Property and services transferred to other Federal agencies without reimbursement, net of such transfers received from other Federal agencies	462.0
Cost of operations from June 1940 through January 18, 1975	46,562.2
AEC Equity at January 18, 1975 as shown on Balance Sheet	$16,153.5

Institutional Origins of the Department of Energy



[1] Treasury — Energy Office
Interior —
Oil Import Administration
Petroleum Allocation
Energy Conservation
Energy Data and Analysis
Oil and Gas
Cost of Living Council — Energy Division
Internal Revenue Service — Enforcement of Allocation and Pricing Regulations

[2] Interior —
Office of Coal Research
Bureau of Mines — Energy Research Centers
Environmental Protection Agency — Research, Development and Demonstration of Innovative Automotive Systems
National Science Foundation
Solar Heating and Cooling
Geothermal Power

[3] Agriculture — REA Loans
Commerce — Voluntary Industrial Conservation
Defense — Petroleum and Shale Reserves
ICC — Oil Pipeline Regulation
SEC — Electric Utility Merger
HUD — Thermal Efficiency Standards
DOT — Fuel Efficiency Standards

[4] Cabinet rank advisory body

[5] Independent agency within Department of Energy

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83d Congress, 2d Session } JOINT COMMITTEE PRINT

JOINT COMMITTEE ON ATOMIC ENERGY

REPORT

OF THE

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

ON THE

Five-Year Power Reactor Development Program Proposed by the Atomic Energy Commission

MARCH 1954

Printed for the use of the Joint Committee on Atomic Energy

UNITED STATES
GOVERNMENT PRINTING OFFICE
44546* WASHINGTON : 1954

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(Created pursuant to Public Law 585, 79th Cong.)

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WALTER A. HAMILTON, *Staff Member on Reactor Development*

FOREWORD

On July 31, 1953, the Joint Committee on Atomic Energy requested by letter that the Atomic Energy Commission prepare an outline of the objectives it seeks to achieve in the field of reactor development over the next 5 years and of its program for accomplishment of these objectives.

The purpose of this request was twofold: To insure that during the next 5 years the Commission's reactor development program would proceed in an orderly manner toward clear objectives; and to permit the public as well as private industry to have full knowledge of what the Federal Government plans to undertake in this field during the next 5 years so that non-Federal activities may be geared to these plans in the most effective manner.

The Commission submitted its proposed statement of objectives and program in a classified report to the committee dated February 5, 1954, in executive session. Detailed review and discussion of this report has been undertaken by the Research and Development Subcommittee under the chairmanship of Representative Carl Hinshaw.

The report of the subcommittee is attached. Recommendation No. 3 contained in the report has already been carried out in a meeting with the Atomic Energy Commission on March 12. At that meeting, the Commission gave a detailed presentation of the purpose of and the prospects for the pressurized water reactor. Strong assurances were given to the committee that every effort will be made to incorporate into the pressurized water reactor all promising ideas which will help make it more economic and will not unduly delay its completion. In addition, the Commission assured the committee that, whenever possible, the entire 5-year program will be speeded up as a result of any new scientific or engineering advances.

CONTENTS

REPORT FROM THE RESEARCH AND DEVELOPMENT SUBCOMMITTEE OF THE JOINT COMMITTEE ON ATOMIC ENERGY ON THE AEC 5-YEAR POWER REACTOR DEVELOPMENT PROGRAM

On February 5, 1954, the chairman of the joint committee referred to the Subcommittee on Research and Development for review and evaluation the 5-year reactor development program proposed by the Atomic Energy Commission in response to the letter request from the committee on July 31, 1953. This program incorporates the plans for full-scale construction of an atomic powerplant known as the pressurized water reactor which will produce 60,000 kilowatts of electricity.

The proposed 5-year program calls for a research and development program at a cost of $8.5 million per year, and five specific reactor development projects. These projects, their total estimated costs over the entire 5 years, and the dates for estimated completion of plants on an experimental scale are shown below:

Project	Estimated cost [1]	Estimated completion	Experimental scale
	Million		
1. Pressurized water reactor	$85	1957	Full.
2. Boiling water reactor	17	1956	Medium.
3. Sodium graphite reactor	10	1955	Medium.
4. Homogeneous reactor	47	1956–8	Medium.
5. Fast breeder reactor	40	1958	Medium.
Total	199	5 years	

[1] All cost estimates are conditional on annual congressional appropriations.

The subcommittee has held 4 meetings reviewing this program as follows:

- February 5, 1954: Dr. L. R. Hafstad, AEC Chief of Reactor Development.
- February 24, 1954: Dr. A. T. Weinberg, technical director, Oak Ridge National Laboratory.
- March 4, 1954: Dr. C. Starr, Atomic Energy Research Division manager, North American Aviation Co.
- March 5, 1954: Dr. W. H. Zinn, director, Argonne National Laboratory.

In addition the subcommittee addressed pertinent questions concerning the program to the following nuclear scientists and engineers:

- Dr. Hans Bethe, Cornell University
- Mr. Walker Cisler, president, Detroit Edison Co.
- Dr. Karl Cohen, Walter Kidde Nuclear Laboratories, Inc.
- Mr. William E. Dean, Chief of Power Economics Branch, TVA
- Dr. Enrico Fermi, University of Chicago
- Dr. L. R. Hafstad, AEC, Chief of Reactor Development
- Mr. Murray Joslin, Commonwealth Edison Co. of Chicago
- Dr. Kenneth Kingdon, Knolls Atomic Power Laboratory, General Electric Co.
- Mr. John R. Menke, Nuclear Development Associates, Inc.
- Adm. E. W. Mills, Foster Wheeler Corp.

Dr. I. I. Rabi, Columbia University (chairman, GAC)
Dr. C. Starr, Atomic Energy Research Division manager, North American Aviation Co.
Dr. Edward Teller, University of California
Dr. Charles Thomas, Monsanto Chemical Co.
Dr. A. T. Weinberg, technical director, Oak Ridge National Laboratory
Dr. Eugene P. Wigner, Princeton University
Dr. W. H. Zinn, director, Argonne National Laboratory

The testimony and the letter replies are summarized briefly below.

1. *Concept of the program.*—The idea of setting out a specific program for reactor development is generally regarded as a sound step toward achievement of economic atomic power. Some criticism of the administrative direction of reactor development activities by the Atomic Energy Commission in the past has been expressed by witnesses and correspondents on the grounds that the Commission did not formulate a specific development program earlier on its own initiative.

2. *Selection of these five approaches.*—Out of the large number of possible approaches—perhaps 80 or more—the 5 particular approaches selected by the Commission for its program are generally regarded by those who have expressed their views to the subcommittee as the ones most likely to lead to economic power. There is real confidence that atomic power can be produced at a cost competitive with fossil fuels such as coal and oil within the next decade by exploring these five approaches.

3. *Scale of the program.*—Disagreement as to how fast each project can be pushed profitably was expressed by witnesses. On the whole, the Commission's estimate of the amount of effort which should be devoted to each project is within the range generally approved by those consulted. Strong statements have been received from all witnesses and correspondents in support of speeding up any of these projects whenever scientific and engineering findings may warrant. It was generally felt that larger budgets than those planned for these programs at this time would probably not speed up accomplishment appreciably.

4. *Relative merits of the five projects.*—The 5 projects were divided by most of those consulted into 3 categories: *Short term*, meaning ready for large experimental testing in 2 or 3 years with a good chance of mechanical success; *middle term*, meaning ready for testing on a large scale within 5 years; and *long term*, meaning ready for large experimental testing in not less than 5 years unless some unexpected technical break-through occurs during the next 5 years. The following is the listing under these categories on which most witnesses agreed:

Short term —Pressurized water reactor (formerly CVR)
Sodium graphite reactor (North American)
Middle term—Boiling water reactor (Argonne)[1]
Long term —Homogeneous reactor (Oak Ridge)
Fast breeder reactor (Argonne)

[1] A description of the boiling rector experiment prepared by Dr. W. H. Zinn, Director, Argonne National Laboratory, is attached to this report.

The short term approaches are thought to be least likely ever to produce competitive and low-cost atomic power and the long term most likely to do so.

The consensus of opinion for achievement of economically competitive atomic power as expressed by the witnesses and correspondents is as follows: (No. 1 is most promising, No. 5 least promising.)

No. 1 Homogeneous reactor
No. 2 Fast breeder reactor
No. 3 Boiling reactor
No. 4 Sodium graphite reactor
No. 5 Pressurized-water reactor

Strong emphasis was placed by witnesses before the subcommittee on the enthusiasm of the participants in any project as a large factor in early achievement of the goal of economic atomic power. The proponents of each particular type of reactor proposed for pilot testing appear to have enthusiasm in the prospects for achievement of economic power by the approaches which they advocate. There is apparently little optimism about the chances of producing economic power at an early date along the route of the pressurized-water reactor.

5. *Pressurized water reactor.*—This is the only full-scale plant proposed by the Commission for construction at this time, although it is not as large as might be necessary to achieve maximum economy with this design. However, it is as large as is necessary to get operating experience and prove the design. Most witnesses and correspondents seem to feel that the other approaches will benefit from information and experience gained in the construction and operation of any large-scale plant, including PWR. It is clearly of conservative design and has a poor long-term prospect for producing low-cost atomic power. On the other hand, it is the one approach now ready for full-scale construction as a demonstration of the generation of electricity from atomic energy. The achievement of economic atomic power by this approach will require the very greatest engineering skill, scientific ingenuity, and continuous research and study after the plant starts operating.

The pressurized water reactor might also contribute substantially to carrying out the President's international cooperation proposal. It uses as fuel uranium slightly enriched in the isotope-235. With relatively minor redesign it would operate on natural uranium if heavy water were to be used as a coolant and moderator instead of natural water. Plants of this type could be built in foreign countries with United States assistance at an earlier date than the more novel plants using highly enriched fuels. Thus we believe electric power could be provided at competitive prices in many parts of the world in the next 10 years. Later on, as technology improves, possibly more efficient reactors, using enriched fuels, could also be made available.

As a demonstration of the serious intent of the United States to develop peacetime uses of atomic energy for both ourselves and our allies and as a tool to help gain operating experience on a full-scale plant, the continuation of construction of one large-scale plant such as the pressurized water reactor is important.

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CONCLUSION

The proposed program is the subject of controversy not in its concept but in its estimates of scale of effort and priority of projects. This controversy is the direct result of the natural and desirable optimism of the various project proponents for their own approaches. The most serious criticism which might be leveled at this program is that it overlooks some profitable approaches completely or distorts the levels of effort unduly. No such criticism appears warranted.

RECOMMENDATIONS

1. The joint committee should support the proposed 5-year program for reactor development.
2. The program as a package should be reviewed at least annually to insure that the approaches being followed are still in proper balance and that every advantage is being taken of new developments.
3. A meeting should be held with the Commission before any further action on the pressurized water reactor is undertaken in order to insure that both the committee and the Commission are in agreement on its continuation, appreciate its limitations, and have a clear conception of what it can be expected to accomplish.

Approved March 17, 1954, and reported to the full committee by the subcommittee.

Carl Hinshaw,
Chairman of the Subcommittee.
William F. Knowland.
John W. Bricker.
John O. Pastore.
James E. Van Zandt.
Carl T. Durham.
Melvin Price.

Approved March 23, 1954, and adopted by the full committee.

Sterling Cole, *Chairman.*

CONGRESS OF THE UNITED STATES,
JOINT COMMITTEE ON ATOMIC ENERGY,
July 31, 1953.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington, D. C.

(Attention: Mr. Lewis L. Strauss, Chairman.)

GENTLEMEN: The joint committee is about to conclude its executive and open hearings in which it has explored some of the problems involved in definition of a Federal policy on atomic power development in private enterprise.

Our hearings have made clear that the entire atomic power development problem is one of considerable complexity. With this thought in mind, it has occurred to us that there are certain steps which the Atomic Energy Commission might take during the next few months which would be particularly helpful, not only to the joint committee in its examination of these problems, but also to the many other interested parties.

1. Even though the Commission has concluded that the time has not yet arrived when "any industrial, commercial, or other non-military uses of fissionable material of atomic energy has been sufficiently developed to be of practical value," as set forth in section 7 (b) of the act, it might, nevertheless, be of considerable assistance if the Commission were to prepare an estimate of the "social, political, economic, and international effects of such use" as now appear. This estimate would be helpful in our further consideration of the problem even though it is appreciated that such an estimate might be of an interim nature if the circumstances envisioned by the act have not, in fact, fully developed at this time.

2. There have been a substantial number of references by witnesses during our hearings to the indefiniteness of Commission plans for research and development in the field of atomic power components, pilot plants, and prototypes. It would seem appropriate that plans for Commission activity should be set forth in a concise manner so that all interested companies, groups, organizations or individuals can henceforth have no doubt about the Federal program under the existing act. I have in mind here that a 3- to 5-year program consisting of specific reasearch and development projects—perhaps including construction items—might be set forth so that others could adjust their plans accordingly. Even though appropriations are determined on a year-to-year basis, it should be possible to carry out planning and programing over a longer term.

3. As you note in your letter of June 2 (1953), policy decisions on some aspects of the nuclear power program "will necessarily be subject to revision from time to time as experience and technical progress dictate." Nevertheless, the particular policy problems are important matters in the growth of private industrial participation. Your policy decisions on these five matters would be of real interest, not only to the joint committee, but to many of the companies, groups, and individuals who have recently testified on this subject.

Thank you very much for your attention to these matters.

Sincerely yours,

STERLING COLE, *Chairman.*

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington D. C., March 12, 1954.

Hon. STERLING COLE,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. COLE: In accordance with Mr. Strauss' instructions before he left town, I am forwarding herewith a copy of the draft for an unclassified version of the reactor development program. It was from this draft that the summary sent to you on March 5 was taken. * * *

Sincerely yours,

K. D. NICHOLS, *General Manager.*

ABSTRACT OF UNCLASSIFIED MATERIAL FROM CLASSIFIED AEC REPORT TO THE JCAE, "PROGRAM PROPOSED FOR DEVELOPING NUCLEAR POWERPLANT TECHNOLOGY" [3]

The Atomic Energy Commission program for the development of nuclear powerplant technology is based on a 5-way approach to the problem of attaining economically competitive power from nuclear fuels.

This program, which involves 1 full-scale experimental power project, already underway, and 4 prototype or pilot size power reactor projects, was described in detail in a classified report recently submitted to the joint committee.

The Commission plan calls for a developmental effort, including 5 different types of experimental power reactor systems in the civilian power reactor field. It is expected to take from 4 to 6 years to carry out the program.

All the reactor development expenditures have produced a large amount of technology applicable to the design and construction of civilian industrial nuclear powerplants. Many studies by the AEC and its contractors made on the basis of this technology lead to a program of research, development, construction, and operation of reactors along five major technical approaches:

(1) Pressurized water, which calls for the building of the country's first full-scale nuclear powerplant, the pressurized water reactor, now under development by Westinghouse Electric Corp. This plant's power output will total about 264,000 kilowatts of heat from which the plant will produce at least 60,000 kilowatts of electricity net, not including power for operating auxiliary equipment.

(2) Boiling water, which explores further the concept of boiling water in a reactor to create steam for a turbine directly. This concept appears promising according to preliminary experiments by Argonne National Laboratory. An experimental boiling water reactor, with an output of 20,000 kilowatts of heat and 5,000 kilowatts of electricity, will be fabricated after the necessary research and development.

[3] The joint committee was informed on March 19, 1954, that the Commission had approved this draft as final on that date.

(3) Sodium graphite, which is along the line of extensive investigations by North American Aviation, Inc., for the AEC. A sodium reactor experiment, to produce 20,000 kilowatts of heat and not be equipped with a turbogenerator, will be the first reactor of the sodium-graphite type.

(4) Fast breeder, which will take the next steps in developing a practical power reactor that will also breed new fissionable material, that is, produce as much as it consumes or more. Research and development will continue; an experimental breeder reactor No. 2, producing 62,500 kilowatts of heat, is to be built as a scale-up from the original experimental breeder reactor, which has an output of only 1,400 kilowatts. This first EBR demonstrated breeding on a very small scale and produced the country's first power from nuclear fuel in token amounts and on an experimental, uneconomic basis. Argonne National Laboratory is the developer of both EBR's.

(5) Homogeneous, which will further the development of reactors containing fuel in a water solution. First, homogeneous reactor experiment No. 2, with an output of 5,000 kilowatts of heat, will be fabricated as a scale-up from the 1,000-kilowatt first homogeneous reactor experiment, the country's second nuclear power plant, located at Oak Ridge National Laboratory. Like EBR No. 1, HRE No. 1 is a very small, uneconomic, experimental powerplant. A turbogenerator and a chemical processing plant are included in the HRE No. 2. Next, homogeneous thorium reactor is projected as a scale-up to 65,000 kilowatts of heat with the addition of production of uranium 233 from thorium. Turbogenerator and chemical processing plants for the liquid fuel and for the thorium blanket are included. Considerable research and development will be necessary for both reactor projects.

In addition to these major projects, the AEC plans to continue its program of general research and development in exploration of other types of reactors on which less work has been done, and to advance technology in such fields as reactor physics, radiation effects on materials, shielding, fuel elements and their materials, instrumentation and control, coolants, and heat transfer. These general investigations also include the recovery of uranium, plutonium, and thorium from used fuel, treatment and disposal of highly radioactive reactor wastes, and utilization of the radioactive fission products of the wastes.

Plans also call for continuing the military programs. In the past, submarine and airplane reactor research and development, construction, and operation have made valuable contributions toward the development of civilian nuclear power, and it is reasonable to expect additional contributions from these sources in the future.

FINANCING PRIMARILY BY GOVERNMENT

The program outlined calls for financing primarily by the Government. Except for the pressurized water reactor, it consists of small, experimental reactors. All these units will produce technical and cost information which will make possible more accurate evaluation of the future of nuclear power. It is hoped that the new technology will encourage industry to take over an increasing share of the financing of further research and development and to consider with increasing favor the actual construction of pilot or full-scale power plants. The progress of this program and the extent and growth of industrial effort will assist in determining the course of future work.

Consisting largely of small, experimental reactors, the program is designed to provide a foundation upon which future work toward industrial nuclear power can be undertaken by Government or industry. It is based on the assumption that the law will be changed to make industrial participation in reactor development more attractive.

Thus the program implements the AEC Statement of Policy on Nuclear Power Development, issued May 26, 1953, which recognized—

> * * * a responsibility of the Commission to continue research and development in this (nuclear power) field and to promote the construction of experimental reactors which appear to contribute substantially to the power reactor art and constitute useful contributions to the design of economic units.

The statement also expressed the—

> * * * conviction of the Commission that progress toward economic nuclear power can be further advanced through participation in the development program by qualified and interested groups outside the Commission.

The public hearings of the Joint Committee on Atomic Energy in the summer of 1953 brought out the fact that the cost of developing competitive nuclear power is at the present time too great for industry to carry. However, a number of industrial firms are already sharing in certain research and development projects with the AEC, and others are financing their own studies of reactor technology. Private financing thus far has been only a small fraction of total reactor development costs.

ESTIMATING NUCLEAR POWER COSTS

Economic evaluations by the Commission and its contractors show that the probability of producing electricity from nuclear fuel at a cost competitive with electricity from coal, oil, or gas is good. The estimates generally indicate that if the goal of economic nuclear power is pursued with vigor, costs can be brought down—in an established nuclear power industry—until the cost of electricity from nuclear fuel is about the same as the cost of electricity from conventional fuels, and this within a decade or two. This does not mean that such low-cost nuclear power will be obtained from the very first plants which might be built but that it may well come from succeeding plants which, as a result of experience with the first, it should be possible to construct and operate more economically.

At the same time it should be remembered that even the program outlined may not be sufficient to determine conclusively whether power can be produced cheaply enough from nuclear fuel to be of general use. There are five different types of reactors in the program, because it has not yet been learned which is the ideal or even the best choice. It will require all the ingenuity of the AEC staff, the Commission's contractors, and private industry working together to get costs down, but it is reasonable to assume that eventually this will be done.

Though the estimates which have been made are the best that can be obtained at the present time, they are merely paper evaluations and are subject to considerable uncertainty. Architect-engineering work has not been done yet for a full-scale industrial nuclear powerplant. The estimates will become more dependable as the development program improves technology and results in more detailed plans and specifications.

Assumptions on which the costs are estimated include reasonably conventional location of nuclear plants—not location on large exclusion areas. Neither real estate prices for large exclusion areas near customers nor the cost of long distance transmission from remote areas can be borne if competitive costs are to be attained.

It is further recognized that the establishing of a nuclear power industry is dependent upon solution of a number of nontechnical problems. These include the problems of patent rights, of the lease or sale of fissionable materials, of the licensing of producers of these materials, of Government purchase of byproduct fissionable material, and accounting assumptions such as length of amortization period and amount of interest. These factors are not within the scope of the technical report.

The reactor development program will be reviewed annually in the light of accomplishment during the preceding year, and revised as necessary. Results sought in research and development cannot be guaranteed within estimated expenditure. Also, some technical avenues may turn out to be more promising, others less promising, than they now appear.

AREAS FOR COST REDUCTION

The problem of developing nuclear reactors for the economic generation of electric power is largely one of reducing costs for capital investment and fuel.

The capital cost of a nuclear plant must be reduced considerably below estimates based on current technology. The "per kilowatt cost" of a nuclear powerplant that can be built today or in the very near future will be perhaps several times the "per kilowatt cost" of a conventional plant of the same power output.

For practical nuclear powerplants of the future, a construction cost goal of $50 to $70 kilowatt of heat, roughly equivalent to about $200 per kilowatt of electricity, is sought. Then the cost of constructing a nuclear plant will be about the same as for a conventional plant.

The basic hope for making nuclear power competitive rests on the possibility of making the fuel very inexpensive—certainly bringing its cost below 3 mills per kilowatt-hour of electricity, which is about the average cost of fuel for conventional power.

To achieve this low fuel cost, technical advances sought include—

(1) Higher burnup per fuel cycle, that is, burning more fuel before it must be removed from the reactor for chemical processing. Alloying offers one possibility for reducing radiation damage so that fuel elements will last longer and withstand higher burnup.

(2) Lower cost of chemically processing and fabricating fuel elements. Partial processing without complete removal of radioactivity is attractive. Simple methods of fabricating this mildly radioactive material are being investigated.

(3) Higher thermal efficiency, that is, conversion of a larger percentage of heat energy into electrical energy. Achievement depends on higher reactor temperature. The first pioneering nuclear plants have low efficiencies—17 percent for the experimental breeder reactor No. 1 and 14 percent for the homogeneous reactor experiment No. 1. Design concepts for large water-cooled plants provide substantially higher figures, while estimates for full-scale liquid metal reactors approach 35 percent, which is approximately the efficiency of large, new conventional power plants.

In addition to reducing fuel costs, the program is aimed at developing types of reactors and modes of operation safe enough to make large exclusion areas unnecessary.

PRESSURIZED WATER REACTORS

The pressurized water reactor, a conversion from a project for a reactor for a large naval ship, will be a full-scale nuclear central station of moderate power—at least 60,000 kilowatts of electricity—and should be in operation within 3 or 4 years. It is not expected to be competitive with conventional power plants, but it will give information that can be obtained only from a large plant, such as reliability, period of amortization, and operating and maintenance costs.

This project is the next step in carrying forward the pressurized water approach to nuclear power. A number of early reactors were water cooled and this technology was advanced considerably more by the recent work of Westinghouse Electric Corp. on the submarine thermal reactor and on the large ship project.

Westinghouse is the principal contractor for the pressurized water reactor, responsible for research and development, and fabrication of the reactor itself and auxiliary equipment. The Westinghouse contract does not include the turbine and generator portions of the plant or the plant's operation. Research and development is well under way. Only slight enrichment of the uranium fuel is necessary to achieve a critical mass with ordinary (light) water moderator and coolant. Nuclear experiments are being conducted to determine the amount of uranium fuel needed, its exact enrichment, the shape of the fuel elements, and methods of fabrication. Like STR, this reactor will make use of the new metals, zirconium and hafnium, and their alloys.

Among contributions this project will make to pressurized water technology are developing and testing of fuel elements for long irradiation cycle and advancing the physics of slightly enriched uranium fuel in ordinary water. The project will demonstrate that a relatively large pressure vessel can be built according to specifications required for reactor operation. A system will be developed and demonstrated for charging and discharging compactly located fuel elements through a pressure shell. A system for the control of a reactor composed of very closely spaced fuel elements will be developed and operated.

By comparison with the submarine thermal reactor, the pressurized water reactor will operate at appreciably higher fuel temperature, coolant temperature, and steam pressure. Preliminary specifications call for a fuel temperature well over 600° F., coolant temperature between 500° and 600°, and steam pressure of about 600 pounds per square inch. The PWR core will be about 6 feet in diameter and 7½ feet high and will require a pressure vessel about 9 feet in diameter and 28 feet high. A fuel charge will consist of 15 to 20 tons of slightly enriched uranium, that is, uranium containing 1.5 to 2 percent of the 235 isotope rather than natural uranium which contains only 0.7 percent of this isotope. A pressure of 2,000 pounds per square inch will keep the cooling water from boiling.

Other preliminary specifications include reactor power, 264,000 kilowatts of heat; maximum heat flux, 350,000 British thermal units per square foot per hour; average power density, 45 kilowatts of heat per liter; and average specific power, 1,000 kilowats of heat per kilogram of fissionable material.

EXPERIMENTAL BOILING WATER REACTOR

Some years ago use of a reactor as the direct source of steam for the turbine was suggested as an attractive way of making power. This arrangement would eliminate the need for a heat exchanger (steam boiler) outside the reactor and permit appreciable reduction in pumping power, and hence should lead to lower capital costs. However, it was thought that boiling in the core would cause continual changes in reactivity and might result in unstable operation.

In the summer of 1953, experiments with a small temporary reactor, conducted by Argonne National Laboratory at the National Reactor Testing Station in Idaho, demonstrated that these fears are not justified. It may be possible to design boiling reactors which will operate in a stable, self-regulating manner, and which in the event of trouble will shut themselves down without serious damage. These developments constitute a major contribution toward safe power reactors.

An experimental boiling water reactor of about 20,000 kilowatts of heat and 5,000 kilowatts of electricity is planned to explore further the possibilities revealed by the investigations in 1953. Specifications are being established by the Argonne Laboratory. The boiling reactor will be fueled with enriched uranium and moderated and cooled with ordinary (light) or heavy water. The uranium enrichment is necessary to make any natural uranium-light water reactor critical. Enrichment is also needed for a heavy water reactor of small size, like the EBWR, but not for a large boiling reactor.

An important purpose of the experimental boiling water reactor is to determine whether it can be operated without significant deposit of radio-activity in the turbine, the condenser, and the feed water pumps. Such deposits might cause major maintenance problems in case of equipment failure.

Assuming success with this boiling reactor, tentative specifications for a full-scale central station plant of this type have been estimated. However, EBWR is not expected to provide nuclear data on the critical mass of the large reactor or on the proper spacing of its fuel. Such information would be obtained from critical experiments.

The Atomic Energy Commission is selecting an architect-engineering contractor and a site for the facilities required for experimental boiling water reactor. The schedule calls for completion of the reactor and facilities during the latter part of calendar year 1956.

SODIUM REACTOR EXPERIMENTS

The program for advancing the technology of the sodium-cooled, graphite-moderated type of reactor centers about a preliminary design for a full-scale power plant. This design uses metallic fuel elements of either slightly enriched uranium or a combination of thorium and uranium 233.

With slightly enriched uranium fuel, the full-scale reactor is expected to have a regeneration ratio of about 0.9, producing plutonium as a byproduct. Charged with uranium 233 and thorium, the reactor should have a ratio slightly greater than one and thus operate as a power breeder, producing more uranium 233 than it consumes.

Although concepts incorporated in the full-scale design have been determined to be feasible by North American Aviation, Inc., the chief contractor developing this type of reactor, many features of the proposed plant and its operating procedure have not been tested in reactor practice. Neither are the upper limits known for fuel and coolant temperatures, burnup, and other operating variables. Moderate changes in some of these variables, such as increasing maximum uranium metal temperature from 1,200° to 1,400° F. and maximum coolant temperature from 1,000° to 1,250° F., will have appreciable effect on the cost of power.

A small sodium reactor experiment is planned to obtain information needed for evaluating the possibilities. This unit will have a heat power level of about 20,000 kilowatts, but it will not be equipped for generating electricity. The heat produced will be exhausted to the atmosphere through a relatively inexpensive sodium-to-air heat exchanger.

The sodium reactor experiment will resemble the design for a full-scale plant in important respects. For example, both designs call for tank-type reactors, both have the entire reactor structure below ground level, and both use similar fuel arrangements.

Tests possible with the SRE include fuel element performance, maximum permissible fuel element and structure temperature, and corrosion and radio-active transfer. The reactor's temperature and specific power will be increased gradually to determine performance limitations. Test "loops" circulating sodium can be installed in the SRE to determine the effect of radiation on aspects of sodium-graphite technology.

The schedule for the sodium reactor experiment calls for completion of fabrication and beginning of experimental operation in calendar year 1956.

EXPERIMENTAL BREEDER REACTOR NO. 2

Two years of operating experience with the experimental breeder reactor at the National Reactor Testing Station provides the basis for scaling up to a larger unit, called experimental breeder reactor No. 2.

The scale up planned is from 1,400 to 62,500 kilowatts in heat power output and from 170 to 15,000 kilowatts in electrical generating capacity. Fuel and coolant temperatures will be substantially higher and steam pressure will be correspondingly greater. In fact, the temperatures and steam pressure will be the same for EBR No. 2 as are now visualized for a full-scale power-breeder reactor.

The new reactor will also be similar to a large central station unit in power density, control, and fuel-handling features. It will include pumps, heat exchangers, valves, flow meters, and other "hardware" of sizes suitable for a full-scale powerplant. In addition, as an experimental reactor, EBR No. 2 will test advanced ideas for long-range application such as variations in core and blanket concentration, in fuel-handling techniques, in power-cycle conditions, and in component design.

Operation of the first EBR, now designated No. 1, will continue to contribute to the fast-breeder research and development program valuable information on physics, radiation damage, chemical processing, and fabrication techniques. A neutron source reactor is in operation at Argonne National Laboratory to provide neutrons for reactor physics measurements on subcritical core arrangements. Results are being used to design a critical assembly for construction at the testing station in Idaho during the current calendar year. The critical assembly will provide information on such factors as critical mass, breeding ratio, and power distribution in the core.

Plans call for a mechanical mockup to be built at Argonne during fiscal year 1955 to test heat transfer and mechanical components under simulated operating conditions. Components to be tested include loading and unloading devices, control mechanism, heat exchangers, boilers, and superheaters.

EBR No. 2 probably will be loaded first with uranium 235 and later with plutonium. The blanket in each case will consist of natural or depleted uranium whose uranium 238 will be transmuted into plutonium. Because of physical constants, greater production of plutonium is expected with plutonium fuel than with uranium 235 fuel. However, the purpose of this experimental reactor is to test engineering features rather than produce a maximum amount of fissionable material.

Facilities must be built for developing, manufacturing, and processing partly used uranium and plutonium fuel elements and the irradiated uranium blanket containing plutonium.

Startup of experimental breeder reactor No. 2 is planned for calendar year 1958.

HOMOGENEOUS REACTOR EXPERIMENT NO. 2

An experimental reactor designated homogeneous reactor experiment No. 2 is to be the next major step in developing homogeneous type reactors which have their fuel and moderator in a water solution. Potential advantages of this type include low-cost chemical processing, elimination of fuel element fabrication and handling, and simplified reactor design.

The homogeneous reactor experiment, now designated No. 1, at Oak Ridge National Laboratory, has demonstrated that a 1,000-kilowatt reactor, circulating uranyl sulfate fuel solution at nearly 500° F. under 1,000 pounds per square inch pressure and at a power density of 30 kilowatts of heat per liter, will operate with stable power output. HRE No. 1 has also shown that the reactor can be operated and maintained safely after its fuel solution becomes highly radioactive from fission products and while a mixture of hydrogen and oxygen is formed by irradiation-produced decomposition of the solution water.

HRE No. 1 will be dismantled early in calendar year 1954 and HRE No. 2 assembled in the same building. The new reactor should be in operation by the summer of 1956.

Homogeneous reactor experiment No. 2 will have a heat output of about 3,000 kilowatts as compared with 1,000 for its predecessor. Its primary purpose is to produce a simplified, mechanically reliable plant which will demonstrate operability and reliability over a long period under conditions closely simulating those of a full-scale reactor. The plant will include chemical processing equipment for the purification of the fuel solution by removal of fission products.

The homogeneous development also seeks more information on the effect of irradiation on the corrosion of materials and on the chemical stability of the fuel solution. A long series of corrosion tests without irradiation has demonstrated the compatibility at elevated temperatures of a dilute uranyl sulfate solution with a number of materials. Quantitative data of the effects of varying temperature, salt concentration, acidity, and solution velocity have also been obtained.

Corrosion and stability tests under irradiation will utilize the low intensity testing reactor at Oak Ridge and the materials testing reactor at the testing station. The equipment required for the tests includes closed "in-pile loops" of piping, pumps, and instruments which will circulate fuel solution past samples of different materials while they are under intense neutron bombardment in the test reactors.

HOMOGENEOUS THORIUM REACTOR

As the next step in developing homogeneous reactors, scale up to about 65,000 kilowatts of heat, of which about 16,000 will be converted into electricity, is planned for the homogeneous thorium reactor. This reactor is also aimed at demonstrating the production of uranium 233 from a blanket of thorium. The physical constants of the uranium isotopes and of thorium and plutonium make the generation of uranium 233 from thorium attractive for thermal reactors in which fission is primarily by slow, or thermal, neutrons, whereas the production of plutonium from uranium 238 can be accomplished most readily in a fast reactor.

Though the core of the homogeneous thorium reactor will not be as large in diameter as that of a full-scale plant, it is planned to have the same blanket thickness and concentration of thorium as a large central station reactor of this type. Two chemical plants, one for removing fission products from the fuel solution and the other for separating the uranium 233 from the thorium blanket, are contemplated as integral parts of the nuclear powerplant.

Following development and design, construction is tentatively scheduled to begin during fiscal year 1958 with completion in fiscal year 1959. The HTR probably will start operating with uranium 235, which eventually can be replaced with uranium 233 produced in the blanket.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington 25, D. C., March 12, 1954.

Hon. STERLING COLE,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. COLE: Attached is the statement of Dr. Zinn's which Mr. Strauss said you had asked about.

Dr. Zinn brought the statement with him to Washington in response to a request from a member of your staff, with a view to having it declassified. The statement has been revised to permit its publication.

Sincerely yours,

K. D. NICHOLS, *General Manager.*

STATEMENT BY DR. WALTER H. ZINN CONCERNING AN EXPERIMENT USING THE BOILING REACTOR PRINCIPLE

The Argonne National Laboratory has carried out for the Atomic Energy Commission certain experiments which it is expected will have a vital bearing on the question of the safety of operation of industrial power reactors. Since safety is an important factor in the evaluation of the use of atomic energy for the generation of economically competitive electricity, it has been decided to make this information generally available. The experiments were done during the summer of 1953 at the National Reactor Testing Station, Arco, Idaho. A team of scientists and engineers from the Argonne Laboratory at Lemont, Ill., and the staff of the experimental breeder reactor project in Idaho carried out the work. Principal members of the team were S. Untermyer, J. R. Dietrich, D. C. Layman, H. V. Lichtenberger, and W. C. Lipinski, working under the laboratory director, Walter H. Zinn, as leader.

The experiment consisted of setting up and operating a nuclear reactor and then imposing conditions on the reactor which would make it "run away." This means that the power of the machine was caused to rise precipitously and was allowed to continue to rise indefinitely. Under such conditions it had been assumed in the past that the core of the reactor would melt and that this would permit the escape of radio-active fission products. It is this particular assumed circumstance which has governed decisions concerning locations of nuclear reactors and which has required an uninhabited, restricted area surrounding them of an acreage which is determined by the power of operation. This particular reactor was moderated by water and cooled by water. The experiment showed that power excursions of very large magnitude and which took place quite rapidly did not produce melting of the fuel and no radioactive contamination of the surroundings whatsoever resulted. The favorable effects observed were anticipated and are due to the particular design of the reactor, which is so arranged that the formation of steam quenches the nuclear reaction. In experiments in which the power was allowed to rise to many thousand watts in a fraction of a second, the steam formation process nevertheless quenched the nuclear reaction completely long before a dangerous temperature was induced.

The experiments were carried out in such a way that visual evidence of the formation of steam and the motion of water was obtained. The most vigorous tests to which the reactor was subjected involved conditions which it would be hard to imagine occurring in any combination of accidental events in an operating power reactor. The visual results were quite spectacular.

It is believed that this mechanism if applied to the design of power reactors may constitute an inherent safety mechanism which will make it impossible for the nuclear reaction, itself, to create dangerously high temperatures. The experiment is an example of the way in which research and development can contribute to the solution of the safety problem. Design and experimentation can be expected to show that there are other types of reactors for which safety is not a major problem.

The reactor also was operated successfully under conditions in which steam was continuously formed and ejected from the reactor. This suggests that it may be possible to construct powerplants in which the reactor not only releases heat but converts it to steam for use in a turbine. In some designs of water-cooled power reactors, the heat is released to water which is circulated to a boiler where steam is produced for use in a turbine. Economies might result from the elimination of the boiler and the production of steam directly from the reactor. This possibility requires further exploration and such work is being undertaken by the Argonne National Laboratory.

March 5, 1954.

APPENDIX

APPENDIX A

The Development of Nuclear Power for Peaceful Purposes

Remarks prepared by Henry D. Smyth, member, United States Atomic Energy Commission, for delivery at the national meeting of the American Institute of Chemical Engineers, Washington, D. C., March 9, 1954

I. INTRODUCTION

The structure of modern industrial society depends on plentiful supplies of energy. There is never enough. We are always seeking new sources. Yet, we have not tapped the most generous sources of energy that nature has supplied to us—the winds, the tides, the rays of the sun. We have not yet learned how to harness these great natural forces.

Fifteen years ago a new natural force was discovered, the fission of uranium. Within the first 2 months of 1939 the idea of uranium fission was suggested, communicated, proved experimentally, and published. The speed and importance of this discovery constitute one of the most spectacular events in the history of science. It involved men of many nations, free communication, high imagination, and precise experiment.

In a world at war, the potential use of nuclear fission in bombs meant that vast sums of money were soon available for its exploitation. In 1945, only 6 years later, an atomic bomb marked the end of the Second World War.

We are now engaged in an effort to harness this same atomic energy for peaceful purposes. It is a great effort and, indeed, should be so, for success in it may materially change the lives and conditions of men. The accident of history has placed the major responsibility for this effort on the Government of the United States. As its agent, the Atomic Energy Commission has brought together an array of scientific and engineering talent never before equaled. Private industry already is carrying a major share of our enterprise under contract to the Government and is now becoming more and more active on its own initiative. This is as it should be.

Those of us engaged in this effort believe we shall be successful. We are so confident of success that we do not begrudge the years and the skill and the millions of dollars that are being spent to make available to man the kind of energy that heats the stars. But the road to success will be a long one. We know that it will have many dead ends and wrong turnings and many dull and dreary stretches. The barriers to be surmounted or bypassed are formidable.

By now we think we know what these barriers are, what kinds of problems have to be solved if nuclear power is to be significant in our economy. We should know these problems, for it is now 15 years since nuclear fission was discovered, 10 years since the first large-scale nuclear reactor was started, and 5 years since the Atomic Energy Commission announced its first program of nuclear reactors aimed at power. Energy from nuclear powerplants will be just like energy from coal-burning powerplants. Except for special purposes, the sole criterion of comparison will be cost.

Let me outline the problems we foresee. It is from men like you that their solutions will come. The problems of reactor development today are best explained in terms of those which faced the designers of the first great reactors at Hanford. These problems are so fundamental that they will continue to be of major importance even though the emphasis may shift from time to time. Once I have defined the problems, I shall outline our present state of knowledge and the next major steps we are planning for their solution.

II. THE GENERAL PROBLEMS OF A NUCLEAR POWER REACTOR

Let me recall to you the three major facts of nuclear fission. They are; first, that enormous amounts of energy are released; second, that the products of fission are radioactive; and third, that fission is caused by neutrons and results in the production of further neutrons thereby making a chain reaction possible.

These basic facts confront the designers of reactors with a series of technical questions which can be grouped in five general areas. These general areas which have to be considered are, first of all, what we call neutron economy; second, the effects of nuclear radiations; third, heat transfer or removal; fourth, control and instrumentation; and fifth, chemical processing of fuel both before and after it goes into the reactor. Let me go into some detail about these five areas.

1. *Neutron economy*

It is evident that the first requirement of a nuclear reactor is that the nuclear chain reaction shall occur. In other words, if a uranium nucleus in a structure containing uranium does undergo fission, it must produce neutrons in sufficient quantity to cause other nuclear fissions in the vicinity and to set up a self-propagating nuclear chain reaction. Actually the number of neutrons produced by a single fission is not very large. On the average, for every neutron used up in producing a fission about two and a half new neutrons are released, a net gain of one and a half neutrons per fission. At first sight, this would appear plenty to produce a multiplication of fissions. Unfortunately, from the point of view of neutron economy, all the neutrons produced in a single fission are not absorbed in uranium 235 to produce additional fissions.

There are, in fact, four things that can happen to the neutrons that are produced in the fission process. First of all, since neutrons are extremely penetrating, they may simply escape to the outside environment. A second way in which they disappear is by capture by uranium 238 without causing fission. A third possibility is that they may be captured by impurities in the uranium or by the structural materials that have to be introduced for cooling or other purposes. The fourth possible process that can occur is, of course, the capture of neutrons by uranium 235 resulting in fission. If the fourth process produces more neutrons than are lost by the first three processes, the chain reaction occurs. Otherwise, it does not. Evidently, in a given arrangement the first three processes may have such a high probability that the extra neutrons created by fission will be insufficient to keep the reaction going.

One obvious way to reduce the probability of the escape of neutrons is to increase the amount of uranium present. The more uranium there is, the more likely it is that the neutrons will be absorbed in it and cause fission rather than escape. This leads, of course, to the concept of critical mass which is familiar to many of you and which I will not discuss any further.

The second process we need to minimize is the capture of neutrons by uranium without producing fission. There are several things that can be done to minimize this process. Two of them depend on the great effect which the speed of the neutrons has on the probability of their absorption in uranium 238. This probability is reduced by using a slowing down material, called a moderator, and arranging the uranium in a lattice. Another way to reduce nonfission capture by uranium is to eliminate part or all of the uranium 238 isotope, since it contributes very little to the fission process and does absorb many neutrons. Of course, in the Hanford reactors, this was not desirable because one of the objectives of the Hanford reactors was to produce plutonium by absorption of neutrons in uranium 238.

To reduce the third process, the nonfission capture of neutrons by impurities or structural materials requires that the uranium itself be very highly purified in the first place and that structural materials be used which have a low capacity for the absorption of neutrons. This last consideration puts many restrictions in the path of the designer of a nuclear chain reactor.

2. *The effects of nuclear radiation*

The effects of nuclear radiation have several aspects that the designer needs to keep in mind. Perhaps the most important one technically is the fact that the constant bombardment of structural materials and of uranium itself causes changes in their properties. A piece of uranium, a piece of steel or aluminum in a nuclear reactor is continually bombarded by neutrons, by gamma radiation, and to some extent by other nuclear radiations. The result of such bombardment may be a change of shape, an embrittlement, a change in thermal conductivity, or of almost any other property of the material. The rate of corrosion of a material is affected by the presence of nuclear radiation.

Nuclear radiation is dangerous to health. Consequently, the whole reactor structure must be surrounded by a shield which will not be penetrated by the neutrons and other radiation. Radiation is present not only while the reactor is running, but induces a lasting radioactivity in the materials of the reactor. In particular, fuel elements in the reactor become highly radioactive, and when they are unloaded for chemical processing, they have to be handled by remote control. It is unsafe for any personnel to handle them directly. Similarly, maintenance must be held to an absolute minimum, and actual direct access of the operators to the heart of the reactor must be avoided.

3. Heat transfer or removal

The principal interest in establishing a nuclear reaction is because the fission processes release such enormous amounts of energy, millions of times the amounts of energy released in chemical reactions in corresponding amounts of material. To be sure, the Hanford reactors were not designed for the purpose of producing energy but for the purpose of producing plutonium. Nevertheless, the production of large amounts of energy is inescapably associated with the fission process, and therefore, the designers of the Hanford reactors had to provide some means of removing that energy. It was a simpler problem for them than for the designers of a reactor intended to produce energy. The Hanford designers had merely to get rid of the energy in some way.

The designers of a power reactor must extract the energy in a form which can be put to use. Nevertheless, many of the problems are the same. They differ from ordinary heat transfer problems for reasons that have already been suggested; namely, that the choice of materials is limited by neutron economy, that corrosion effects may be enhanced by the radiation present, and finally that the replacement of parts is difficult or impossible because of the health dangers involved. In a power-producing reactor, the temperature should be as high as possible so that the heat energy removed can be converted into useful power efficiently. This is a real difficulty as we shall see later on and is one point where the Hanford designers had a considerable advantage.

4. Control

When the first reactors were designed, the question of control was a very critical one. No one knew very certainly whether or not it would be possible to prevent the reactor from running away with itself. We do not want to have a reactor heat up to the point where it will melt and destroy itself. We wish to avoid this for two reasons: First, we don't want to lose the reactor; and second, we don't want to spew radioactive material all over the countryside. By now, we have had enough experience so that we are not very concerned about essential difficulties of control. We are perfectly sure that we can build a reactor which we can control. In fact, as I shall mention later, some types of reactor are self-controlling. There does remain, however, a problem of convenience, efficiency, and cost in designing the proper controls to start, stop, or maintain at a desired operating level the nuclear chain reaction.

5. Chemical processing of fuel

Ideally, we would like to put into a nuclear reactor a certain amount of uranium and leave it there until all the uranium had been converted into heat energy and fission products. If that were possible, we would be concerned with chemical processing only in preparing the fuel. Unfortunately, the difficulties both of neutron economy as affected by the growth of fission products and of the corrosion or radiation damage of structural materials or fuel elements make it quite out of the question to consume more than a fraction of a nuclear charge in any know design of reactor. After a certain length of time—and one of the problems in the design of reactors is to make that length of time as great as possible—it is necessary to remove the fuel. It is too valuable to throw away, since it will probably still contain some 90 percent or more of the fissionable material. Consequently, we have to reprocess it chemically, separating out the fission products, and refabricating the uranium into new fuel elements. This turns out to be one of the most costly processes in the whole business of operating a reactor for power.

I believe it is possible that the nuclear power industry will stand or fall economically depending on the success which chemists and chemical engineers have in developing cheap processes for purifying and refabricating nuclear fuel.

III. THE HANFORD REACTORS

I have been speaking of the general technical problems of reactor design. To be more concrete, let me recall briefly in specific terms how these problems are met in the Hanford reactors.

For neutron economy, the reactor is large. It uses graphite as a moderator, and the natural uranium fuel elements are arranged in a lattice. Both graphite and uranium are very highly purified. Cooling channels and protecting coatings of the uranium fuel elements are aluminum of minimum dimensions.

To shield operating personnel, the reactor is surrounded by heavy composite walls and all control and operation are from outside the shields. To reduce corrosion of the aluminum, the cooling water is purified and the temperatures held relatively low. To avoid corrosion or distortion of the uranium, it is canned in aluminum and not left in the reactor very long.

Heat is removed by large volumes of Columbia River water with relatively low exit temperature. The water is then held in retention basins before returning to the river.

Control is by neutron absorbing rods that move in and out of the reactor. The position of the rods is recorded at the control desk and varied by the operators or automatically in response to instruments.

Chemical procesing by a solvent extraction process is done in a separate plant to which the fuel elements are transported in shielded railroad cars, with all operations remotely controlled.

Fundamentally, it is the low exit temperature of the cooling water and the short life of the fuel elements that make this plant impracticable as a power source.

IV. BREEDING

Uranium 235 is the isotope of uranium in which fission occurs most readily. Unfortunately, it is present in natural uranium only 1 part to 140. Natural uranium is none too plentiful, and to be able to use only seven-tenths of a percent of it is frustrating. Neutrons absorbed in the other uranium isotope, uranium 238, lead to the production of plutonium and plutonium is readily fissionable. This fact early suggested the possibility that a reactor could simultaneously produce heat energy from the uranium 235 in natural uranium, and produce plutonium from the uranium 238, and that then the plutonium could be used as fuel for further production of energy. It was even suggested that the plutonium produced might be greater in quantity than the uranium 235 burned up. Such a process is called a breeding process since more fuel can be produced than would be burned.

This is, of course, a very fascinating idea. It turns out, however, that it may not be so very important whether actually more material is produced than is burned. It is obviously possible to produce some plutonium, since that is what the Hanford reactors are for and it should be possible to take that plutonium and use it as fuel for power reactors. Whether the amount of plutonium produced is slightly less or slightly greater than the amount of uranium 235 burned up is not very important. We do, however, make a distinction in nomenclature whereby we call a reactor that produces plutonium in smaller quantity than uranium burned a converter and one where the quantity produced is greater than that of uranium burned a breeder. In either case, it should be possible eventualy to convert the fission energy of both isotopes of uranium to useful power. In the case of the converter, there would be some loss; in the case of the breeder, the losses in the reactor would be zero, but in either case, there will be losses in chemical processing so that the difference is not very significant. The difference, however, between using just the uranium 235 and evenutally using all of the uranium in natural uranium is enormous and may well make the difference between an ample supply of nuclear fuel for many years to come and a rather scanty one.

V. THE FIRST ATOMIC ENERGY COMMISSION REACTOR PROGRAM

When the Atomic Energy Commission took over the plant and equipment of the Manhattan District in January 1947, the problems that I have been reviewing were already clear. Although the Commission's first responsibility was to prosecute the atomic weapons program with vigor, it soon turned to the possibility of atomic power, both for special military purposes and for ultimate peacetime uses. Early in 1949, Dr. Bacher, my predecessor as the scientific member of the Commission, made a speech in which he outlined the ways in which the Commission was attacking the problems I have reviewed. Essentially, the program consisted of a plan to build four major reactors. Let me describe three of these that have been finished at our Idaho test site and why they were built.

The first of them was the so-called materials testing reactor, MTR. It was aimed primarily at getting information on the effects of radiation on uranium fuel elements or other materials that might be used as tubes for cooling water, or as coolants, or containers for uranium fuel elements. The object of this reactor then was to provide very high intensity radiation in a machine so designed that many experimental samples could be placed in it. It has now been running for about 2 years, and it has in fact proved exceedingly useful. Incidentally, it also was a novel kind of reactor and therefore was in itself a step toward the development of new types of reactors.

The second reactor built at Idaho was the so-called experimental breeder reactor, EBR. As the name implies, it was specifically aimed at demonstrating whether or not breeding was possible. It has demonstrated that breeding is possible and has had a number of other incidental interesting results.

The third reactor was a special purpose one aimed at providing power for a submarine. You have heard a great deal about that one and about the submarine in which a similar reactor is now being installed.

In all three of these reactors, the neutron economy problem was solved by using uranium from which much of the uranium 238 isotope has been extracted. Whether or not in the long run, this is the kind of reactor we will build for power purposes will be largely a question of economics. Personally, I doubt it, but I do not doubt the wisdom of having built these three reactors and the value of the results we have obtained from them.

A more modest undertaking initiated later is the homogeneous reactors experiment at Oak Ridge. From the atomic point of view, the homogeneous reactor is misnamed. In reality, one can think of it as a lattice where the spacing is very small and the size of the fuel elements is of atomic dimension. To put it more simply, and in terms that will be more familiar to you, the homogeneous reactor is a solution of uranyl sulphate in water. The water serves as the moderator, and the uranyl sulphate molecules serve as the fuel elements in which the chain reaction is set up.

The immediate and obvious advantage of the homogeneous reactor is that fuel fabrication and processing is enormously simplified. The solution is pumped continuously through the reactor chamber and then cooled in outside heat exchangers, and some of it can be continually led off for purification and then reintroduced into the circulating stream of combined fuel and moderator. One of the interesting features of the homogeneous reactor is that it turns out to be self-regulating. As the temperature of the reactor rises, its reactivity decreases and therefore it controls itself. One difficulty that was anticipated in the homogeneous reactor was that the water itself would be dissociated by the radiation. This does occur, but it has been found possible to recombine the hydrogen and oxygen formed without too great difficulty.

In addition to the results obtained with the 3 reactors I have been discussing, and the homogeneous reactor experiment, there has, of course, been an extensive program of study of the various associated problems in the laboratory. These range from fundamental studies of what causes radiation damage, or of the absorption probabilities of various materials for neutrons of various energies, to component testing in heat loops, and experimental fabrication of fuel elements. Some of these studies use the various low-power research reactors that have been built.

One of the most interesting experiments that has been done was carried out last summer at the Idaho test site by Dr. Zinn, director of our Argonne Laboratory, and his associates. We had long worried about what would happen to a water-cooled reactor if the flow of water should be cut off. We were afraid if the water supply was cut off or if the temperature of the reactor rose too rapidly boiling would occur and that this might have disastrous results. Dr. Zinn decided to make a direct approach to this problem and built a small reactor with the deliberate intention of producing boiling. When it was set up at the Idaho testing station, it had an arrangement in it which suddenly ejected the control rods so that the power generated by the chain reaction went up in a fraction of a second from a few watts to many thousands of watts. This had the expected effect on the water. It boiled. It boiled so violently in fact that it was ejected from the reactor in a small geyser. Repeated trials showed that in every case the boiling reduced the power of the reactor so rapidly that no serious damage was done.

This particular experiment illustrates very well the reasons for choosing an isolated area as a site for experimental reactors. It was not only that some of the reactors might be inherently dangerous, but it was felt that an experimental reactor, one built primarily for the purpose of obtaining information, should be operated to extremes, and that it was desirable to have them in an isolated location for that reason. In other words, if you want to get as much information as you can out of a reactor, you need to push it to the point where it might conceivably run into trouble.

VI. RESULTS OF THE PAST FIVE YEARS AND PRESENT STATUS OF THE ART

Let me summarize some of the major results that we have obtained in the last 5 years either directly from the reactors we have built and operated or from laboratory work. I will take them in terms of the 5 general areas that I enumerated at the start. So far as neutron economy is concerned we have learned a great deal about the probabilities of various nuclear events, including the relationship between the probability of fission and the energy of the neutrons. (This, for example, was tested in the experimental breeder reactor.) We have found that we can use a number of different substances as moderators, specifically beryllium, light water, and heavy water in addition to the familiar graphite.

As to the effects of radiation, the MTR has, of course, been of the greatest value as one might expect since it was designed for that purpose. But we also have the benefit of studying the fuel elements that have been in the EBR and in the submarine thermal reactor. "These," too, have been valuable. We have made a great variety of alloys and have tested various fuel elements. In particular, the submarine thermal reactor has shown that fuel elements sheathed in zirconium will resist corrosion and radiation effects over considerable lengths of time and represent a great improvement over the aluminum sheathed fuel elements in the Hanford reactors. Radiation effects have also been studied in a variety of coolants including sodium and heavy water.

In the matter of heat transfer we have found we can remove the heat from a reactor by circulating molten sodium-potassium alloy through it. This is the system of heat removal used in the EBR. We have also done a great deal of work on pure sodium as a possible coolant and are using it in the second type of submarine reactor now under construction. We have also found that we can use a cooling system of pressurized water. This is the system used in the submarine thermal reactor. We have run reactors at much higher temperatures than we were ever able to run them at Hanford, and therefore, we have moved in the direction of efficient use of the energy from nuclear fission.

As to control and instrumentation, the most striking results have been those already mentioned where we have found that certain types of reactors are in fact self-regulating as a result of boiling or near boiling as the temperature rises. The only other result I will mention is the use of hafnium as a material for control rods. Hafnium is present as an impurity in zirconium and has to be removed before zirconium cladding can be used for fuel elements because it absorbs neutrons. For the same reason it is very useful as a control material.

In the matter of chemical processing, perhaps it is fair to say that most of the work has been accomplished in the laboratory, although we have had experience with actual processing of the various types of fuel elements in the new reactors, none of which is exactly like those at Hanford. We have also proved that the homogeneous reactor will work, at least on a small scale, and we, therefore, know that that is one direction in which to hope for improvement.

In the matter of costs, we still have much work to do. None of the reactors that we have actually put up is cheap, either to build or to operate. The submarine thermal reactor probably costs somewhere around fifteen hundred or two thousand dollars per kilowatt to build, which is to be compared with the cost of a modern steam plant somewhere around a hundred and eighty dollars per kilowatt. But the submarine thermal reactor does prove one overall major result: namely, that it is possible to build a reactor for the production of power that will run for at least reasonably long times continuously and efficiently.

VII. QUESTIONS STILL TO BE ANSWERED

The fundamental question still to be answered is whether a power producing uranium reactor can be built which will compete with other sources of energy. The answer to that question will be found in the choice of some one of the kinds of reactors we have already built or thought about. None of them has yet been proved to be the ideal or even the best choice. The homogeneous reactor, for example, does simplify chemical processing, but it requires enriched fuel and it is not yet certain that the corrosion problems can be solved. The breeder has not yet been proved on any large scale so that we do not know at all how expensive that may be. The submarine thermal reactor uses such expensive materials for cladding the fuel elements that it is almost certainly not competitive, even though we may be able to produce zirconium at lower and lower costs. It also uses enriched material. And so it goes all through the list.

VIII. PROPOSED 5-YEAR PROGRAM

In the last few months we have been reviewing the results that we have obtained up to the present time and planning what would be best to do over the next few years in order to arrive at an economical solution of the problem of nuclear power. We have decided that there are six programs that we should pursue. One of these is the general program that we must obviously continue, the program of research on fundamental properties of materials, on nuclear reactions, on components that might go into the reactors of the future, and on chemical processes. This work will be continued principally in our Argonne and Oak Ridge Laboratories. In addition to this general research and development work, we wish to build five reactors of varying size and cost. The Commission has recently submitted to the Joint Committee on Atomic Energy a special report on the reactor program prepared at the request of the committee.

The first of these reactors in our new program has already been publicly announced. It is the so-called PWR reactor which is designed to generate at least 60,000 kilowatts of electric power. It will use slightly enriched uranium as fuel, ordinary water as a moderator and coolant. The reactor will be operated under reasonably high pressure and temperature, not nearly so high as are used in modern steam plants, but as high as we feel safe in terms of our present knowledge. Specifically, the water in the reactor will be under 2,000 pounds per square inch pressure and at a temperature between 500° and 600° Fahrenheit. Steam will be delivered to the turbine at about 600 pounds per square inch. The temperature is limited by the corrosion of the fuel elements and piping and container, and the pressure is limited by the strength and size of the vessel in which the reactor must be contained. One of the difficult problems in this reactor will be that of getting control mechanisms to operate in a high-pressure vessel. Principally, we hope to learn from this reactor how such a plant may stand up under ordinary operating conditions of central-station electric powerplant, and how much it costs to build and operate it. We have no expectation that this reactor will produce power as cheaply as a modern coal-burning plant, but we hope to learn how costs can be cut in later plants.

The second new reactor which we wish to build is a breeder of intermediate size. It will not be of direct interest from the point of view of economic power, but it will be much larger and more nearly a power producing, continuously operating reactor than the small experiment we have been running out in Idaho. The scaleup planned is from 1,400 to 62,500 kilowatts of heat, and from 170 to 15,000 kilowatts of electric power. Temperatures and steam pressure will be increased to values appropriate to a full-scale power-breeder reactor. Auxiliaries such as pumps, heat exchangers, valves, etc., will be of sizes suitable to a full-scale reactor.

Our third step is based on the boiling experiment that I have already described. It will be an attempt on an intermediate scale actually to use boiling of the water as a method of heat extraction. We hope in this way to get a very cheap method of getting the heat out of the reactor and possibly of eliminating one step between the coolant in the reactor and the turbines which turn the generator. It is planned to feed the steam generated in the reactor directly to the turbines. Present plans call for 20,000 kilowatts of heat and 5,000 kilowatts of electric power.

The fourth reactor which we intend to build is a larger version of the homogeneous reactor. Again, it will be a step in the direction of a practical power-producing unit and should give us information about corrosion, chemical processing, and operating conditions that cannot be obtained with the small machine now in use at Oak Ridge. Present specifications call for only 3,000 kilowatts of heat in this reactor experiment compared to 1,000 in the present experiment. The next step, already planned, calls for 65,000 kilowatts of heat in a homogeneous reactor which will breed uranium 233 in a blanket of thorium surrounding the chain-reacting core.

The fifth reactor experiment which we plan to build is a little different from any that I have described. I have mentioned that the breeder reactor uses sodium-potassium alloy as a coolant. You all know that the Hanford reactors use graphite as a moderator. We hope to be able to combine these two materials, getting the advantage of high temperature without high pressure from the sodium coolant. To test this combination, we will build a reactor generating about 20,000 kilowatts of heat but without any electric-generating plant attached.

In addition to these new proposals, we shall continue several other programs already underway. These include the so-called intermediate submarine reactor now under construction at West Milton, N. Y., near Schenectady, and the development of a reactor to propel aircraft. Though the aims of both of these projects are special, they will undoubtedly contribute to the general technology.

IX. COSTS

It is evident that we can build powerplants which will convert the energy release in nuclear fission into electrical energy to be fed into transmission lines. The question that has not been answered and may not be conclusively answered even by the program I have outlined is whether this power can be produced cheaply enough to be of general use. The Atomic Energy Commission believes that it can be done and this is the opinion also of the several private industrial groups who have been studying the problem for several years at the invitation of the Commission. At present, the power delivered by the submarine reactor at our Idaho plant costs about 10 times as much as it would if we bought it from the Idaho Power Co. From this figure you can see that it will require all the ingenuity of our staff, our contractors, and private industry working together to get costs down, but it is reasonable to assume that eventually this will be done.

X. INDUSTRIAL PARTICIPATION

These private industrial groups I have mentioned are interested in more than just cost studies. They have assigned able members of their staffs to design studies of nuclear powerplants and in some cases are doing considerable amounts of research at their own expense. But it is a mistake to think that private industry can or will pick up the burden of development of nuclear powerplants in the present state of the art. It is a field in which knowledge and competence are still largely confined to Government laboratories and in which the financial risks are still too great for private industry to carry alone.

The Commission hopes for greater and greater participation by industry both technically and financially and for a gradual transfer of the nuclear power part of the Commission's responsibilities to private enterprise. To discuss the many problems of such a transfer would need another speech. Personally, I feel they are just about as difficult as the technical problems of getting cheap nuclear power. Time, money, and thought will be needed for both sets of problems. I believe they can be solved.

XI. CONCLUSION

To establish a nuclear power industry in this country will be a great achievement. If power becomes cheaper and more plentiful, our material standard of living will be raised. In other countries the effect may be even greater. By the accident of history the first use of this great new discovery has been in the development of weapons of war, weapons of appalling magnitude. The nations of the world have today the means to destroy each other. They also have, in this same nuclear energy, a new resource which could be used to lift the heavy burdens of hunger and poverty that keep masses of men in bondage to ignorance and fear. Toward this peaceful development of nuclear power we have, all of us, a high obligation to work with all the ingenuity and purpose we possess.

APPENDIX B

[Atomic Energy Commission press release, March 14, 1954.]

AEC and Duquesne Light Co. to Negotiate on Atomic Power Plant

Lewis L. Strauss, Chairman of the Atomic Energy Commission, announced today that a proposal submitted for participation by the Duquesne Light Co. of

Pittsburgh, Pa., in the construction and operation of the Nation's first full-scale central station nuclear power plant is the most favorable to the Government and that the AEC is negotiating a formal agreement with the company. The Duquesne Co. submitted 1 of 9 major proposals to the Commission.

Under the Duquesne proposal the company would—

1. Furnish a site for the entire project and build and operate a new electric generating plant at no cost to the Government.
2. Operate the reactor part of the plant and bear the labor costs thus entailed.
3. Assume $5 million of the cost of research, development, and construction of the reactor portion of the plant.
4. Pay the Commission at the rate of 48.3 cents per million B. t. u.'s of steam used in the turbines for first year; the rate increasing annually until it reaches 60.3 cents in the fifth year.
5. Waive any reimbursement by the Government of costs incident to termination of the contract.

The Chairman estimated that, including revenues from the sale of steam generated by the reactor, the company's proposal would reduce by an estimated $30 million the expenditures the Government would have to make during the period of construction and 5 years of operations if it undertook the full cost of the project.

The proposed plant site is on land presently owned by the company in the greater Pittsburgh area. The reactor design will incorporate safety features developed through 10 years of experience with reactor operation.

The Westinghouse Electric Corp. has a contract with AEC to develop, design, and construct the reactor portion of the plant. The reactor is expected to generate sufficient heat to produce a minimum of 60,000 kilowatts of salable electricity in addition to meeting the electricity requirements of the plant itself. The actual capacity of the reactor may turn out to be somewhat greater than the minimum of 60,000 kilowatts design and foreseeing this possibility the company would design its generating plant with some reserve capacity.

It is not expected that this first plant will produce electric power at costs competitive with power from conventional fuels. The project has been undertaken, in order to gain more design and technological experience than could be obtained otherwise, such as from a smaller plant, and to provide firm cost estimates for the future.

This type of reactor, known as the pressurized water reactor (PWR), will be cooled and moderated by ordinary water under pressure. The fuel will be slightly enriched uranium, that is, it will have a slightly greater concentration of uranium 235 than occurs in nature. This type of reactor was selected because research and development on it is more advanced than on other types. Several early reactors were water cooled and this technology also was advanced to a very great extent by the work of Westinghouse on the submarine thermal reactor developed to power the submarine *Nautilus* and on the large naval vessel reactor project.

The Duquesne Light Co. supplies electric power to the greater Pittsburgh district, one of the world's largest industrial centers. Since last October the company has engaged in nuclear power reactor studies under the AEC's industrial participation program. Preceding its entry into this study, the company arranged to have some 40 of its engineers attend a special course on atomic energy at the Carnegie Institute of Technology.

In announcing the negotiations with Duquesne for participation in the PWR project, Mr. Strauss pointed out that this project represents only one of several approaches to the development of technology and equipment for economical electric power production from atomic reactors. He called attention to the announcement by Dr. Henry D. Smyth, member of the Commission, in an address March 9 to the American Institute of Chemical Engineers, of other approaches which the Commission has concluded should be undertaken, including breeder, boiling water, homogeneous, and sodium-graphite reactor projects.

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1258990

THIS INDENTURE, made the 30th day of October nineteen hundred and fifty-four,

BETWEEN LOUIS F. PALERMO and MARIE C. PALERMO, his wife, and DOMENICK DI PIETRO and JENNIE DI PIETRO, his wife, residing at 286 Bleakley Avenue, Buchanan, Westchester County, State of New York,

party of the first part, and CONSOLIDATED EDISON COMPANY OF NEW YORK, INC., a domestic corporation of 4 Irving Place, New York, N.Y.,

party of the second part,

WITNESSETH, that the party of the first part, in consideration of ten dollars and other valuable consideration paid by the party of the second part, does hereby grant and release unto the party of the second part, the heirs or successors and assigns of the party of the second part forever,

ALL that certain plot, piece or parcel of land, with the buildings and improvements thereon erected, situate, lying and being in the Village of Buchanan, Town of Cortlandt, County of Westchester, State of New York, BEGINNING at a point on the westerly side of the Proposed Extension of First Street at the most northeasterly corner of the land now or formerly of the Village of Buchanan as shown on a "Map of Property Belonging to Charles Jacoby" dated Oct. 15, 1948 made by J. Wilbur Irish, P.E. & L.S., and filed as Map No. 6771 on Feb. 9, 1949 in the Westchester County Clerk's Office; running thence South 54 degrees 07 minutes West along the northerly line of the said land of the Village of Buchanan 898.07 feet to the most northwesterly corner of said land; thence North 35 degrees 53 minutes West 625 feet, more or less, along the land now or formerly of Josephine Migliore, to the land now or formerly of the Patrick King Estate; thence along the said land of the Patrick King Estate the following courses and distances: N 10° 12' E 88.53 feet; N 19° 23' E. 27.03 feet; N 28° 00' E 32.18 feet; N 37° 06' 30" E 148.39 feet; N 32° 43' 40" E 158.67 feet; N 13° 14' 40" E 82.91 feet; N 7° 47' E 38.38 feet; N 1° 38' E 101.04 feet; N 6° 57' W 13.97 feet; N 24° 50' W 85.13 feet; to a point on the southerly side of Broadway and the land now or formerly of Ed. Newman; thence along the said land of Ed. Newman S 53° 10' 40" E 100 feet; N 36° 49' 20" E 50 feet; N 53° 10' 40" W 100 feet, to the southerly side of Broadway; thence N 36° 49' 20" E along the southerly side of Broadway 276 feet; thence on a curve to the right having a radius of 25 feet a distance of 42.21 feet to the westerly side of the said Proposed Extension of First Street; thence the following courses and distances along the said Proposed Extension of First Street: S 46° 26' 20" E 222.83 feet; on a curve to the right having a radius of 300 feet a distance of 130.42 feet; S 21° 31' 50" E 449.21 feet; on a curve to the left having a radius of 300 feet a distance of 152.77 feet; S 50° 42' 30" E 185.45 feet; and on a curve to the right having a radius of 140 feet a distance of 36.22 feet, to the point or place of beginning; be all of the said courses, distances and dimensions more or less; and containing 16.78 acres, more or less.

TOGETHER with all right, title and interest, if any, of the party of the first part of, in and to any streets and roads abutting the above described premises to the center lines thereof; TOGETHER with the appurtenances and all the estate and rights of the party of the first part in and to said premises; TO HAVE AND TO HOLD the premises herein granted unto the party of the second part, the heirs or successors and assigns of the party of the second part forever.

AND the party of the first part covenants that the party of the first part has not done or suffered anything whereby the said premises have been encumbered in any way whatever, except as aforesaid.

AND the party of the first part, in compliance with Section 13 of the Lien Law, covenants that the party of the first part will receive the consideration for this conveyance and will hold the right to receive such consideration as a trust fund to be applied first for the purpose of paying the cost of the improvement and will apply the same first to the payment of the cost of the improvement before using any part of the total of the same for any other purpose.

The word "party" shall be construed as if it read "parties" whenever the sense of this indenture so requires.

IN WITNESS WHEREOF, the party of the first part has duly executed this deed the day and year first above written.

IN PRESENCE OF:

[signature]

[signature] L.S.
Louis F. Palermo

[signature] L.S.
Marie C. Palermo

[signature] L.S.
Domenick Di Pietro

[signature] L.S.
Jennie Di Pietro

USIR STAMPS ATTACHED $9.90 NOV 12 1954

LIBER 5392 PAGE 30

STATE OF NEW YORK, COUNTY OF Westchester ss:

On the 30th day of October, 1954, before me personally came LOUIS F. PALERMO, MARIE C. PALERMO, DOMENICK DI PIETRO and JENNIE DI PIETRO, to me known to be the individuals described in and who executed the foregoing instrument, and acknowledged that they executed the same.

John Christian Tittle
JOHN CHRISTIAN TITTLE
Notary Public
Qualified Westchester County
Commission Expires March 30, 1956

STATE OF NEW YORK, COUNTY OF ss:

On the day of 19 , before me personally came

to me known to be the individual described in and who executed the foregoing instrument, and acknowledged that executed the same.

The foregoing instrument was endorsed for record as follows: The property affected by this instrument is situate in the TOWN OF CORTLANDT

County of Westchester, N. Y. A true copy of the original DEED

RECORDED NOV. 12, 1954 at 11:45 AM at request of INTER-CO. T. G. & M. CO.

FEE: $ 4.10 No. 46969 EDWARD L. WARREN, County Clerk.

Title No. W46267 and (Pcl #5)

LOUIS F. PALERMO,
MARIE C. PALERMO,
DOMENICK DI PIETRO and
JENNIE DI PIETRO

TO

NOV 12 1954
11.45 A.M.

Bargain and Sale Deed
WITH COVENANT AGAINST GRANTOR'S ACTS

The land affected by the within instrument lies in Section ... in Block ... on the Land Map of the County of Westchester

RECORDED AT REQUEST OF

STANDARD FORM OF ... TITLE UNDERWRITERS

RECORDED AT REQUEST OF
Inter-County Title Guaranty and Mortgage Company
199 MAIN STREET WHITE PLAINS, N. Y.
RETURN BY MAIL TO

RESERVE THIS SPACE FOR USE OF RECORDING OFFICE

WESTCHESTER COUNTY CLERK'S OFFICE
DIVISION OF LAND RECORDS

12/1/54 INDIAN POINT to ConEd

Standard N.Y.B.T.U. Form 8007-3-54-15M—Bargain and Sale Deed, with Covenant against Grantor's Acts—Individual or Corporation

LIBER 5398 PAGE 340

USIR STAMPS ATTACHED $247.50 DEC 2 - 1954

THIS INDENTURE, made the 1st day of December, nineteen hundred and fifty-four

BETWEEN INDIAN POINT REALTY CORPORATION, a corporation organized and existing under the laws of the State of New York, having its office and principal place of business at 152 West 42nd Street, City, County and State of New York,

party of the first part, and CONSOLIDATED EDISON COMPANY OF NEW YORK, INC., a domestic corporation duly organized and existing under and by virtue of the ~~Transportation Corporations~~ Laws of the State of New York, having its principal office at #4 Irving Place, Borough of Manhattan, City, County and State of New York,

241 acre parcel A

party of the second part,

WITNESSETH, that the party of the first part, in consideration of

ONE HUNDRED AND 00/100 ($100.00)- - - - - - - - - - - - - - - - - dollars,

lawful money of the United States, and other good and valuable consideration paid by the party of the second part, does hereby grant and release unto the party of the second part, ~~the heirs or~~ its successors and assigns of the party of the second part forever,

ALL that certain plot, piece or parcel of land, with the buildings and improvements thereon erected, situate, lying and being in the Town of Cortlandt, County of Westchester and State of New York, and described as follows:

FIRST PLOT: ALL that certain lot, piece or parcel of land situate, lying and being in the Town of Cortlandt, County of Westchester and State of New York, bounded northwesterly and northeasterly by the Hudson River and a creek or cove called Lent's Cove, southeasterly by a street or road called Broadway and southwesterly by land late of Maria M. Lyell and land late of Thomas J. Bonner and more particularly bounded and described as follows:

BEGINNING at a point on the northerly side of Broadway in the line between the land hereby described and land late of Maria M. Lyell, which line is the new division line created by indenture executed by Benjamin Tatham & wife and Maria Mercia Lyell, dated April 14, 1866 and recorded in the office of the Register of Westchester County March 5th, 1867 in Liber 627 of Deeds at page 30, running thence with the said new division line north fifty-seven degrees west in a straight line to the high water mark of the Hudson River, to said creek or cove called Lent's Cove, thence easterly and southeasterly along the high water mark of said creek or cove following the windings and turnings of the shore to Broadway, thence southwesterly along Broadway to the point or place of beginning.

SECOND PLOT: ALL that certain lot, piece or parcel of land, situate, lying and being in the Town of Cortlandt, County of Westchester, State of New York, bounded and described as follows:

BEGINNING at a point on the westerly side of a street or highway known as Broadway, distant 790 feet northerly from the land now or late of John Henry at the northeasterly corner of land conveyed by Maria M. Lyell to Dain & Avery, recorded in the office of the Register of Westchester County, in liber 981 cp 343; thence running westerly and parallel with the northerly side of said land now or late of Henry, 830 feet; thence southerly and parallel to said Broadway 774 feet to a point 16 feet northerly from said northerly side of said Henry's land; thence westerly in a straight line parallel with and always, 16 feet northerly from the northerly side of said Henry's land to the Hudson River; thence with said River in the northerly direction to the land now or late of Benjamin Tatham; thence on an easterly course to the westerly side of Broadway; thence in a southerly direction to the point or place of beginning.

RIDER I - Continuation of Description

THIRD PLOT: ALL that certain lot, piece or parcel of land, situate, lying and being in the Town of Cortlandt, County of Westchester, State of New York, bounded and described as follows:

BEGINNING at a point, three hundred and twenty (320) feet South, fifty-one (51) degrees, fifteen (15) minutes East, from the southeast corner of land conveyed by Hudson River Day Line to New York Trap Rock Corporation, by deed dated January 28, 1947 and recorded in the office of the Register of Westchester County; thence North fifty-one (51) degrees, fifteen (15) minutes West, three hundred and twenty (320) feet to the southeast corner of said lands of or late of New York Trap Rock Corporation; thence along the southeasterly property line of said lands North thirty-three (33) degrees, fifteen (15) minutes East, five hundred and seventy-five (575) feet to a point which is fifty (50) feet northwesterly from the edge of the woods; thence continuing along the southeasterly property line of said lands North forty-one (41) degrees, seventeen (17) minutes East, four hundred and twenty-five (425) feet to a point which is fifty (50) feet northwesterly from the edge of the woods; thence in a straight line in a southeasterly direction to a point at a southeast corner of lands late of Indian Point Corporation which is distant nine hundred and eighty-four (984) feet from the place of beginning and which is on a line passing through the point of beginning and parallel to a street or highway known as Broadway; thence running along said straight line parallel to a street known as Broadway in a southwesterly direction nine hundred and eighty-four (984) feet to the place of beginning.

TOGETHER with all the right, title and interest of the party of the first part of, in and to Broadway, to the center lines thereof, in front of and adjoining said premises.

BEING the same premises conveyed by Indian Point Corporation to Indian Point Realty Corporation by deed dated March 25, 1953 and recorded in the office of the County Clerk of the County of Westchester, Division of Land Records, in Liber 5195 of Deeds at page 408.

Containing within said description 241.9 acres more or less.

SUBJECT to:

1. Zoning regulations and ordinances and building restrictions and regulations of the city, town or village in which the premises lie.

2. Agreement between Hudson River Day Line and Hudson River Boat Company, Inc., dated April 6, 1949, recorded August 8, 1949, in the office of the County Clerk of the County of Westchester (Division of Land Records) in Liber 4767 of Deeds at page 390.

3. Easement granted by Indian Point Corporation to Algonquin Gas Transmission Company, dated September 19, 1951, recorded October 23, 1951, in Liber 5035 of Deeds at page 146.

EXCEPTING the premises released from the lien of a mortgage made by Maria M. Lyell to Samuel Knox and Francis T. Smith as executors of the Last Will and Testament of Amos C. Stearns, deceased, which is bounded and described as follows:

BEGINNING at a point on the westerly side of a street or highway known as Broadway, distant 800 feet northerly from the northerly line of land now or late of John Henry; thence westerly and parallel with the northerly line of said land now or late of John Henry, 830 feet; thence southerly parallel with said Broadway 784 feet to a point 16 feet northerly from said northerly side of said Henry's land; thence westerly in a straight line and parallel with and all ways 16 feet northerly from the northerly side of said Henry's land 300 feet; thence northerly parallel with said Broadway 984 feet; thence easterly parallel with the northerly line of said Henry's land 1130 feet to said westerly side of said Broadway; thence southerly along the westerly side of said Broadway 200 feet to the point or place of beginning.

ALSO excepting from the parcel second above described, the following parcel bounded and described as follows:

BEGINNING at a point in the division line between lands late of the Hudson River Day Line and lands of the New York Trap Rock Corporation at the high water mark of the Hudson River, and running thence South fifty-one (51) degrees fifteen (15) minutes East, one thousand four hundred and twenty (1420) feet along said division line to a point which is North fifty-one (51) degrees fifteen (15) minutes West, and three hundred and twenty (320) feet from a corner in the division line; thence North thirty-three (33) degrees fifteen (15) minutes East, five hundred and seventy-five (575) feet to a point which is fifty (50) feet northwesterly from the edge of the woods on the lands of Hudson River Day Line; thence North forty-one (41) degrees seventeen (17) minutes East, four hundred and twenty-five (425) feet to a point which is fifty (50) feet northwesterly from the edge of the woods; thence North twenty-six (26) fifty-two (52) minutes East, five hundred and seventy-five (575) feet to a point which is fifty (50) feet northwesterly from the edge of the woods; thence along the same course North twenty-six (26) degrees fifty-two (52) minutes East, one hundred (100) feet to a point; thence in a straight line approximately five hundred and thirty (530) feet to a point on the high water mark of the Hudson River, which point is one thousand (1000) feet southerly from the southerly side of the more southerly of two docks; thence along the high water mark of the Hudson River to the point of beginning, which course, if a single straight line, would be south sixty-one (61) degrees no minutes West, two thousand and fifty (2050) feet; containing about forty-one and one-half ($41\frac{1}{2}$) acres.

BEING the same lands conveyed by Hudson River Day Line to New York Trap Rock Corporation by deed dated January 28, 1947, and recorded in the office of the County Clerk of the County of Westchester, Division of Land Records in Liber 4497 of Deeds at page 148.

ALSO excepting from the parcel second above described, the following parcel bounded and described as follows:

BEGINNING at a point, three hundred and twenty (320) feet South, fifty-one (51) degrees, fifteen (15) minutes East, from the southeast corner of land conveyed by Hudson River Day Line to New York Trap Rock Corporation, by deed dated January 28, 1947 and recorded in the office of the Register of Westchester County; thence North fifty-one (51) degrees, fifteen (15) minutes West, three hundred and twenty (320) feet to the southeast corner of said lands of or late of New York Trap Rock Corporation, thence along the southeasterly property line of said lands North thirty-three (33) degrees fifteen (15) minutes East, five hundred and seventy-five (575) feet to a point which is fifty (50) feet northwesterly from the edge of the woods; thence continuing along the southeasterly property line of said lands North forty-one (41) degrees, seventeen (17) minutes East, four hundred and twenty-five (425) feet to a point which is fifty (50) feet northwesterly from the edge of the woods; thence in a straight line in a southeasterly direction to a point at a southeast corner of lands late of Indian Point Corporation which is distant nine hundred and eighty-four (984) feet from the place of beginning and which is on a line passing through the point of beginning and parallel to a street or highway known as Broadway; thence running along said straight line parallel to a street known as Broadway in a southwesterly direction nine hundred and eighty-four (984) feet to the place of beginning.

TOGETHER with all right, title and interest, if any, of the party of the first part of, in and to any streets and roads abutting the above-described premises to the center lines thereof.

TOGETHER with the appurtenances and all the estate and rights of the party of the first part in and to said premises.

TO HAVE AND TO HOLD the premises herein granted unto the party of the second part, the heirs or successors and assigns of the party of the second part forever.

AND the party of the first part covenants that the party of the first part has not done or suffered anything whereby the said premises have been incumbered in any way whatever, except as aforesaid.

AND the party of the first part, in compliance with Section 13 of the Lien Law, covenants that the party of the first part will receive the consideration for this conveyance and will hold the right to receive such consideration as a trust fund to be applied first for the purpose of paying the cost of the improvement and will apply the same first to the payment of the cost of the improvement before using any part of the total of the same for any other purpose.

The word "party" shall be construed as if it read "parties" whenever the sense of this indenture so requires.

IN WITNESS WHEREOF, the party of the first part has duly executed this deed the day and year first above written.

IN PRESENCE OF:

INDIAN POINT REALTY CORPORATION

By: Emanuel D. Kelman
President

LIBER 5398 PAGE 344

STATE OF NEW YORK, COUNTY OF NEW YORK ss:

On the 1st day of December 1954, before me personally came EMANUEL D. KELMANS to me known, who, being by me duly sworn, did depose and say that he resides at No. 184 Barnard Road, New Rochelle, New York; that he is the President of Indian Point Realty Corporation, the corporation described in and which executed the foregoing instrument; that he knows the seal of said corporation; that the seal affixed to said instrument is such corporate seal; that it was so affixed by order of the board of directors of said corporation, and that he signed his name thereto by like order.

Mildred S. Hudock

MILDRED S. HUDOCK
NOTARY PUBLIC, STATE OF NEW YORK
No. 60-6894250
Qualified in Westchester County
Term Expires March 30, 1956

STATE OF NEW YORK, COUNTY OF ss:

On the day of 19 , before me personally came the subscribing witness to the foregoing instrument, with whom I am personally acquainted, who, being by me duly sworn, did depose and say that he resides at No. ; that he knows to be the individual described in and who executed the foregoing instrument; that he, said subscribing witness, was present and saw execute the same; and that he, said witness, at the same time subscribed h name as witness thereto.

The foregoing instrument was endorsed for record as follows: The property affected by this instrument is situate in the TOWN OF CORTLANDT County of Westchester, N. Y. A true copy of the original DEED RECORDED DEC. 2, 1954 at 1:15 PM at request of INTER-CO. T. G. & M. CO.

FEE: $ 8.60 No. 50139 EDWARD L. WARREN, County Clerk.

U. S. Internal Revenue Stamps Affixed
STATUTORY FORM AA—Deed with Full Covenants—(Corporation)

W4626 LIBER 5419 PAGE 283

F. 3485 12-53-10M City Title Insurance Company

THIS INDENTURE, made the 31st day of January nineteen hundred and fifty-five, between King Properties, Inc.

a corporation organized under the laws of the state of New York having its principal place of business at ~~Peekskill, Westchester County, New York~~ c/o John De Angeli, 165 Broadway, New York, N.Y., party of the first part, and Consolidated Edison Company of New York, Inc., a corporation organized under the laws of the State of New York, having its principal place of business at 4 Irving Place, Borough of Manhattan, City, County and State of New York

residing at

, party of the second part:

WITNESSETH, that the party of the first part, in consideration of Ten (10.00)- - - - - - - - - - - - - - - - Dollars, lawful money of the United States, and other good and valuable considerations paid by the party of the second part, does hereby grant and release unto the party of the second part, its successors and assigns forever,

ALL that tract or parcel of land situate at Verplancks Point, Town of Cortlandt, County of Westchester, State of New York, bounded and described as follows: BEGINNING on the easterly side of Broadway at the corner of land of estate of William Bleakley deceased and Maria Lydell; running thence along lands of said Bleakley in a southerly direction by the various bearings of a crooked line to the southwesterly corner of the land hereby conveyed; thence north fifty four degrees west sixteen chains and fifty two links along lands of Thomas McGlynn to the westerly side of Broadway; thence with the westerly side of Broadway north fourty four degrees east thirty seven chains and seventy five links; thence at a right angle crossing Broadway one chain and twenty three links to the place of beginning. Containing thirty one acres and one rod of land more or less. Excepting therefrom however, so much of said premises as were conveyed to John McClosky for burial purposes.

BEING the same premises conveyed to Ellen T. King, late of the Town of Cortlandt, County of Westchester, State of New York, by Thomas N. Avery and Eliza N. Avery, his wife, by deed dated January 16th, 1896, and recorded in the office of the Register (now County Clerk's) of Westchester County, in Liber 1418 of Deeds, page 197 on the 27th day of January, 1896.

SUBJECT TO covenants and restrictions of record if any, not rendering title unmarketable and to any state of facts an accurate survey would show, not rendering title unmarketable.

SAID premises known on the Tax Maps of the Town of Cortlandt and Village of Buchanan, Westchester County, New York as Section 6, Block 32, Lot 37.

SAID premises lying on the East side of Broadway, north of the Roman Catholic Cemetery, opposite lands known as Indian Point Park.

U.S.I.R. STAMPS ATTACHED 8/3 30 FEB - 1 1955

Recorded See L. 5538 Page 464

TOGETHER with all right, title and interest of the party of the first part of, in and to the land lying in the streets and roads in front of and adjoining said premises.

TOGETHER with the appurtenances and all the estate and rights of the party of the first part in and to said premises.

TO HAVE AND TO HOLD the premises granted unto the party of the second part, its successors and assigns forever, AND the party of the first part covenants as follows:

First.—That the party of the first part is seized of the said premises in fee simple and has good right to convey the same;

Second.—That the party of the second part shall quietly enjoy the said premises;

Third.—That the said premises are free from encumbrances, except as aforesaid;

Fourth.—That the party of the first part will execute or procure any further necessary assurance of the title to said premises;

Fifth.—That the party of the first part will forever warrant the title to said premises;

Sixth.—That, in compliance with Section 13 of the Lien Law, it will receive the consideration for this conveyance and will hold the right to receive such consideration as a trust fund to be applied first for the purpose of paying the cost of the improvement and that it will apply the same first to the payment of the cost of the improvement before using any part of the total of the same for any other purpose.

IN WITNESS WHEREOF, the party of the first part has caused its corporate seal to be hereunto affixed, and these presents to be signed by its duly authorized officer the day and year first above written.

KING PROPERTIES, INC.

By [signature]
President

Attest: [signature: Charles F. King]
TREASURER

STATE OF NEW YORK, COUNTY OF Westchester

On the 28 day of January 19 55 before me personally came JOHN J. KING to me known, who, being by me duly sworn, did depose and say that he resides at No. 162 Hawthorne Avenue, Yonkers, New York; that he is the President of King Properties, Inc., the corporation described in and which executed the foregoing instrument; that he knows the seal of said corporation; that the seal affixed to said instrument is such corporate seal; that it was so affixed by order of the board of directors of said corporation, and that he signed his name thereto by like order.

JOHN F. D'ANGELI
NOTARY PUBLIC, STATE OF NEW YORK
No. 41 8893450
Qualified in Queens County
Certs. filed with N. Y., Kings, Bronx & Westchester Co. Clerks, N. Y., Kings, Bronx & Queens Co. Registers
Term expires March 30, 1955

The foregoing instrument was endorsed for record as follows: The property affected by this instrument is situate in the TOWN OF CORTLANDT County of Westchester, N. Y. A true copy of the original DEED RECORDED FEB. 1, 1955 at 1:40 PM at request of INTER-CO. T. G. & M. CO.

FEE: $ 4.10 No. 4678 EDWARD L. WARREN, County Clerk.

U. S. Internal Revenue Stamps Affixed
STATUTORY FORM AA—Deed with Full Covenants—(Corporation)

W46267

LIBER 5419 PAGE 281

LIBER 5338 PAGE 404

City Title Ins...

1322

THIS INDENTURE, made the 31st day of January nineteen hundred and fifty-five, between

King Properties, Inc.

a corporation organized under the laws of the state of New York
principal place of business at ~~Peekskill, Westchester County, New York~~
c/o John De Angelis 165 Broadway, New York, N.Y. , party of the f...

and Consolidated Edison Company of New York, Inc., a corporation organized under the laws of the State of New York, having its principal place of business at 4 Irving Place, Borough of Manhatt..., City, County and State of New York

residing at , party of the s...

WITNESSETH, that the party of the first part, in consideration of Ten (10.00)- - - - - - - - - - - - - - - - lawful money of the United States, and other good and valuable considerations by the party of the second part, does hereby grant and release unto the party of the second part, its successors and assigns...

ALL that tract or parcel of land situate at Verplancks Point, Town of Cortlandt, County of Westchester, State of New York, bounded and described as follows: BEGINNING on the easterly side of Broadway at the corner of land of estate of William Bleakley deceased and Maria Ly..., running thence along lands of said Bleakley in a southerly direction by the various bearings of a crooked line to the southwesterly corner of the land hereby conveyed; thence north fifty four degrees west sixteen chains and fifty two links along lands of Thomas McGlynn to the westerly side of Broadway; thence with the westerly side of Broadway north fourty four degrees east thirty seven chains and seventy five links; thence at a right angle crossing Broadway one chain and twenty three links to the place of beginning. Containing thirty one acres and one rod of land more or less. Excepting therefrom however, so much of said premises as were conveyed to John McClosky for burial purposes.

BEING the same premises conveyed to Ellen T. King, late of the Town of Cortlandt, County of Westchester, State of New York, by Thomas N. Avery and Eliza N. Avery, his wife, by deed dated January 16th, 1896, and recorded in the office of the Register (now County Clerk's) of Westchester County, in Liber 1418 of Deeds, page 197 on the 27th day of January, 1896.

SUBJECT TO covenants and restrictions of record if any, not rendering title unmarketable and to any state of facts an accurate survey would show, not rendering title unmarketable.

SAID premises known on the Tax Maps of the Town of Cortlandt and Village of Buchanan, Westchester County, New York as Section 6, Block 32, Lot 37.

SAID premises lying on the East side of Broadway, north of the Roman Catholic Cemetery, opposite lands known as Indian Point Park.

U.S.I.R. STAMPS ATTACHED $ 13.20 FEB -1 1955
U.S.I.R. STAMPS ATTACHED $ 13.20 DEC 22 1955

TOGETHER with all right, title and interest of the party of the first part of, in and to the land lying in the street in front of and adjoining said premises.

TOGETHER with the appurtenances and all the estate and rights of the party of the first part in and to said...

TO HAVE AND TO HOLD the premises granted unto the party of the second part, its successors and as...

5419/
5338/404

AND the party of the first part covenants as follows:

First.—That the party of the first part is seized of the said premises in fee simple, and has good right to convey the same;

Second.—That the party of the second part shall quietly enjoy the said premises;

Third.—That the said premises are free from incumbrances, except as aforesaid;

Fourth.—That the party of the first part will execute or procure any further necessary assurance of the title to said premises;

Fifth.—That the party of the first part will forever warrant the title to said premises;

Sixth.—That, in compliance with Section 13 of the Lien Law, it will receive the consideration for this conveyance and will hold the right to receive such consideration as a trust fund to be applied first for the purpose of paying the cost of the improvement and that it will apply the same first to the payment of the cost of the improvement before using any part of the total of the same for any other purpose.

IN WITNESS WHEREOF, the party of the first part has caused its corporate seal to be hereunto affixed, and these presents to be signed by its duly authorized officer the day and year first above written.

[Corporate seal: KING PROPERTIES, INC. INCORPORATED 1941 NEW YORK]

Attest:

[signature] TREASURER

KING PROPERTIES, INC.

By [signature]
President

STATE OF NEW YORK, COUNTY OF Westchester ss:

On the 28 day of January 19 55 before me personally came JOHN J. KING to me known, who being by me duly sworn, did depose and say that he resides at No. 162 Hawthorne Avenue, Yonkers, New York; that he is the President of King Properties, Inc., the corporation described in and which executed the foregoing instrument; that he knows the seal of said corporation; that the seal affixed to said instrument is such corporate seal; that it was so affixed by order of the board of directors of said corporation, and that he signed his name thereto by like order.

[signature]

JOHN F. D'ANGELI
NOTARY PUBLIC, STATE OF NEW YORK
No. 41-2996450
Qualified in Queens County
Certs. filed with N. Y., Kings, Bronx & Westchester Co. Clerks, N. Y., Kings, Bronx & Queens Co. Registers
Term expires March 30 1955

Recorded in the Office of the Clerk of the County of Westchester
Division of Land Records) on Feb 1 1955
at 1:40 P M. in Liber 5419 Page 283 of Deeds.
Witness my hand and Official Seal

[signature]
Clerk

LIBER 5538 PAGE 406

STATE OF NEW YORK, COUNTY OF WESTCHESTER

On the 15thday of December, 1955, before me personally came JOHN J. KING, to me known, who, being by me duly sworn, did depose and say that he resides at No. 162 Hawthorne Avenue, Yonkers, New York; that he is the President of King Properties, Inc., the corporation described in and which executed the foregoing instrument; that he knows the seal of said corporation; that the seal affixed to said instrument is such corporate seal; that it was so affixed by order of the board of directors of said corporation, and that he signed his name thereto by like order.

JOHN F. DeANGELIS
NOTARY PUBLIC STATE OF NEW YORK
No. [illegible]
Qualified in Queens County
Term expires March 30, 1957

The foregoing instrument was endorsed for record as follows: The property affected by this instrument is situate in the TOWN OF CORTLANDT County of Westchester, N. Y. A true copy of the original DEED RE-RECORDED DEC. 22, 1955 at 10:39 AM at request of INTER-CO. T. G. & M. CO.

FEE: $ 5.75 No. 61397 EDWARD L. WARREN, County Clerk.

UNITED STATES ATOMIC ENERGY COMMISSION

MAJOR ACTIVITIES

IN THE

ATOMIC ENERGY PROGRAMS

January–December 1961

UNITED STATES GOVERNMENT PRINTING OFFICE : JANUARY 1962

capacity as an unsolicited project of the third round type. (The two companies had previously announced their intention of submitting such a proposal during April 1960.) The proposal by Southern California Edison covers operation of the nuclear power plant, while plant development, design, and construction would be carried out by Westinghouse and its subcontractor, the Bechtel Corp. Nuclear fuel services for the plant would be supplied by Westinghouse. Financial assistance by the Commission would total about $17 million, including research and development assistance and waiver of fuel use charges.

Under the proposal, the estimated capital cost of the plant to Southern California Edison would be $78 million, and commercial operation would begin by early 1965. However, the Edison proposal is contingent, among other things, upon the company's obtaining a satisfactory long-term lease of a site on the Marine Corps reservation at Camp Pendleton in Southern California. At year's end, the site question still had not been resolved.

Consolidated Edison Thorium Reactor

Construction of the privately financed uranium oxide-thorium oxide Consolidated Edison Co. reactor was essentially completed at Indian Point, N.Y., in December. Initial criticality is expected by early 1962. Full power operation of the 255,000 ekw pressurized water plant, which includes 104,000 kilowatts from an oil-fired superheater, is scheduled for the spring of 1962. The Indian Point plant will provide important operating data for large water-cooled reactor systems and technical data on the use of a fuel mixture of thorium and uranium 235. It will be the second large-scale nuclear power plant to be put into operation without financial assistance from the Commission; Dresden was the first. A public hearing to consider the issuance of a provisional operating license was held on December 7–20, 1961, and recessed to January 3, 1962.

Saxton Nuclear Experimental Reactor

Construction work was essentially completed in December on the privately financed 3,250 ekw developmental reactor of the Saxton Nuclear Experimental Corp. at Saxton, Pa. The small pressurized water plant was designed and built by the Westinghouse Electric Corp. It will be operated primarily for research and development and will be connected to an existing turbine generator for production of electrical power at the Saxton steam generating station of Pennsylvania Electric Co., about 20 miles southeast of Altoona. Design power operation is expected to be achieved in March 1962. A provisional operating license was issued November 15, 1961.

APPENDIX 8

License Applications Filed and Actions Taken

SUMMARY OF LICENSING ACTIONS

Facilities [a]	Permits and Licenses Issued: Sept. 1, 1954 to Dec. 31, 1957	Jan. 1, 1958 to Dec. 31, 1958	Jan. 1, 1959 to Dec. 31, 1959	Jan. 1, 1960 to Dec. 31, 1960	Jan. 1, 1961 to Dec. 31, 1961	Permits and licenses in effect as of Dec. 31, 1961
Power Reactors						
Construction permits	5	0	0	5	1	7
Construction permit amendments and orders	1	4	5	2	4	---------
Licenses to operate	1	0	1	1	1	4
License amendments, authorizations and orders	1	7	7	7	22	---------
Test Reactors						
Construction permits	1	2	0	0	0	0
Construction permit amendments and orders	1	0	1	1	0	---------
Licenses to operate	0	0	2	0	1	3
License amendments and authorizations	0	0	3	6	6	---------
Research Reactors						
Construction permits	[b] 20	[c] 11	[d] 15	14	7	[e] 15
Construction permit amendments and orders	5	9	15	12	8	---------
Licenses to operate (including acquire and operate)	28	19	9	11	9	54
License amendments	16	17	34	29	76	---------
Reactor Exports						
Research Reactor Licenses	16	5	11	3	2	([f])
Test Reactor Licenses	0	2	0	0	1	([f])
Power Reactor Licenses	0	1	1	0	1	([f])
License amendments	6	14	10	14	9	---------
Critical Experiment Facilities						
Construction permits	10	4	1	2	0	1
Construction permit amendments and orders	2	2	1	3	2	13 ---------
Licenses to operate	6	5	3	2	0	13
License amendments	1	10	16	14	11	---------
Production Facilities						
Construction permits	0	0	0	0	1	1
Construction permit amendments and orders	0	0	0	0	0	---------
Licenses to operate	0	0	0	0	0	0
Import licenses	0	0	0	1	0	---------
Operator licenses	148	215	176	222	[h] 203	[h] 686
Operator license amendments and renewals	21	67	81	141	[h] 157	---------
Special Nuclear Material licenses	151	115	73	85	[h] 116	[h] 449
SNM license amendments and renewals	92	156	194	249	[h] 268	[h] 449
Source Material licenses issued or renewed [g]	4, 541	1, 303	1, 168	1, 061	[h] 508	[h] 600
Source Material export licenses	2, 456	676	721	696	[h] 221	([f])

[a] Applications to construct and operate are filed simultaneously; conversions from construction permits to licenses to operate are made upon satisfactory completion of construction.

[b] Permits authorize construction of 36 reactors and modification of 2 reactors.

[c] Permits authorize construction of 38 reactors.

[d] Permits authorize construction of 13 reactors and modification of 2 reactors.

[e] Permits authorize construction of 24 reactors.

[f] Export licenses terminate upon completion of shipment.

[g] Under amendment to Part 40, Licensing of Source Material, effective Feb. 13, 1961, a license is no longer required with respect to activities (except export) relating to possession of unrefined and unprocessed ore containing source material. Exports to non-Soviet bloc destinations of up to three pounds of source material at any one time and any quantity of incandescent gas mantles are authorized by general license under Part 40 as amended.

[h] Data as of Nov. 30, 1961.

Facility License Applications [a]

Applicant and Location of Facility	Description of Facility	Date Filed	Status
POWER REACTORS			
Carolinas Virginia Nuclear Power Associates, Inc., Parr, S.C.	17,000-kilowatt, vertical pressure tube, heavy water moderated and cooled reactor.	July 9, 1959	Construction permit issued May 4, 1960.
Commonwealth Edison Co., Dresden Station, Grundy County, Ill.	180,000-kilowatt, dual cycle, boiling water reactor.	Apr. 1, 1955	Construction permit issued May 4, 1956; 45-day limited license for 1-megawatt (thermal) operation issued September 28, 1959; amended November 5, 1959 to expire December 10, 1959; amended November 16, 1959 for 315-megawatt (thermal) operation after December 10, 1959; amended June 2, 1960 for operation at power levels up to, but not in excess of, or at steady state power level of 630 megawatts (thermal); amended October 14, 1960 for steady state operation at 630 megawatts (thermal); reactor shut down in November 1960 due to control rod difficulties; 100-kilowatt operation authorized March 31, 1961; 630-megawatt (thermal) operation authorized May 27, 1961; license amended June 9, 1961 to include revised technical specifications.
Consolidated Edison Co. Westchester County, New York.	163,000-kilowatt, pressurized water (plus 112,000 kw of conventional superheater capacity).	Mar. 22, 1955 (date of application).	Construction permit issued May 4, 1956; amended August 4, 1961 to approve final design of reactor.
Consumers Power Co., Big Rock Point, Charlevoix County, Mich.	75,000-kilowatt, high power density, single cycle, boiling water reactor.	Jan. 18, 1960	Construction permit issued May 31, 1960.
Florida West Coast Nuclear Group, Inc., Polk County, Fla.	50,000-kilowatt, high temperature, gas-cooled, heavy water moderated, pressure tube reactor.	Dec. 10, 1959	Application withdrawn by letter of June 26, 1961.
General Electric Co., Alameda County, Calif.	3,000 to 5,000-kilowatt developmental boiling water reactor, designated the Vallecitos Boiling Water Reactor (VBWR).	Jan. 10, 1956 (date of application).	Construction permit issued May 14, 1956; license issued for criticality tests July 29, 1957; for power operation, Aug. 31, 1957; license amendment authorizing operation at power levels to 50.000 kw. (thermal) issued Jan. 30, 1959; amended July 6, 1960 to authorize operation with certain internal modifications and with new fuel arrangements; amended Nov. 5, 1960 to authorize G.E. to make changes within technical specifications described in license amendment provided no unreviewed safety questions is involved; VBWR shut down in Feb. 1961 pending replacement of certain reactor components; resumption of operation authorized Apr. 13, 1961.

[a] For applications withdrawn prior to 1961, see Appendix 9, Annual Report to Congress for 1960.

NUREG-75/002

Final

environmental statement

related to operation of

INDIAN POINT NUCLEAR GENERATING PLANT UNIT NO. 3

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.

DOCKET NO. 50-286

February 1975

Volume I

UNITED STATES NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION

This document is Volume One of a two volume report.
Both volumes are available from

National Technical Information Service
Springfield, Virginia 22151

Price for Printed Copy:

Volume I – $17.25
Volume II – $10.25

Price for Microfiche: $2.25 per Volume

SUMMARY AND CONCLUSIONS

This Environmental Statement was prepared by the U. S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation.

1. This action is administrative.

2. The proposed action is the issuance of a license to Consolidated Edison Company of New York, Inc., for the operation of the Indian Point Nuclear Generating Plant, Unit No. 3 (Docket No. 50-286), located in the State of New York, Westchester County, Village of Buchanan, 24 miles north of the New York City boundary line.

   The Indian Point Station will have three Units, with each employing a pressurized water reactor to produce a total of 6,675 megawatts thermal (MWt). Indian Point Unit No. 3 will produce up to 3,025 MWt. A steam turbine-electrical generator will use this heat to provide 965 net megawatts of electrical power (MWe). A design power level of 3,216 MWt (1,033 MWe) is anticipated at a future date and is considered in the assessment in this Statement. Just north of Unit No. 3 is Indian Point Unit No. 1 (Docket No. 50-3), which produces 890 MWt (net 265 MWe) and Unit No. 2 (Docket No. 50-247), which yields 2,758 MWt (net 873 MWe).

   During initial operation, the exhaust steam from each Unit will be condensed by once-through cooling water withdrawn from the Hudson River through separate intakes and discharged into the river via a common discharge canal and submerged multiport outfall structure.

   Although the present action is the issuance of an operating license for Unit No. 3, this Statement considers the environmental impacts from simultaneous operation of all three Units. A Final Environmental Statement has been issued for Unit No. 2. Furthermore, in view of the proximity to the Indian Point site of existing and presently proposed power plants on the Hudson River, the cumulative environmental benefits and impacts of the plants within a 30-mile reach of the river have been assessed. The proposed action is interrelated to other actions taken by other Federal agencies such as the Environmental Protection Agency, in regard to granting or denying application for discharge permits under the National Pollutant Discharge Elimination System (NPDES) instituted through the Federal Water Pollution Control Act Amendments of 1972, and the Federal Power Commission, in licensing of other facilities on the Hudson River. The States that will be affected by this proposed action include New York, New Jersey, and possibly Connecticut and other New England states. In New York State, Westchester and Rockland Counties, and in New Jersey, Bergen County are the counties particularly affected by this proposed action.

Since issuance of the Draft Environmental Statement (DES) on Indian Point Unit No. 3 (October 1973), the Atomic Safety and Licensing Appeal Board ruled on the environmental issues requiring closed-cycle cooling for Indian Point Unit No. 2 (ALAB-188). This Board required the licensee to terminate once-through cooling at Unit No. 2 by May 1, 1979, and thereafter to operate Unit No. 2 with a closed-cycle cooling system. However, it required the staff to take a fresh look at certain of the staff's positions and reconsider portions (ecological sections) of the Final Environmental Statement (for Unit No. 2) to which they relate. Such a reassessment of the issues in contention relative to the staff's recommendation on closed-cycle cooling was made in preparing this Final Statement and included holding several meetings with the applicant, its consultants, the State of New York, and intervenors in order to exchange information about current ecological research results which have been utilized in this Statement.

3. Summary of principal environmental impacts, including beneficial and adverse effects, follows:

   a. Indian Point Unit No. 3 will produce an average annual generation of 6.26×10^9 kWhr of electricity, which will provide support of $8.8 billion of regional product in 1980. (pp. XI-45 to 58)

   b. About 35 acres of 239 acres of land formerly used as an amusement park, and later zoned for heavy industry, have been converted to industrial use. (p. V-1)

   c. The applicant's plans to develop an 80-acre forested park with a freshwater lake and to build a new visitors' center, nature trails, gardens and public facilities will enhance the value of the site to the general public. A 14-acre area, transferred by the applicant to the Village of Buchanan, now includes a playing field and the remainder will be developed into a marina. (pp. V-1 to 2)

   d. No additional land area was used for the right-of-way of the transmission lines from Unit No. 3 to the nearby Buchanan Substation from which the power is distributed to the applicant's service system; however, the present transmission facilities will be upgraded to improve the applicant's capability of distributing power to its customers. Transmission towers from Unit No. 3 of the Buchanan Substation were designed in accordance with Federal guidelines. (pp. IV-3 to 4)

e. Areas disturbed during construction will be improved by landscaping and planting after Unit No. 3 is built. (p. V-2)

f. About 4,585 cubic feet per second (cfs) or 2,058,000 gallons per minute (gpm) of water for cooling and service water systems will be withdrawn from the Hudson River and increased in temperature by about 15F° during passage through the steam condensers and heat exchangers of Units Nos. 1, 2 and 3. This heated water from all the Units will be combined and released into the Hudson River at a velocity of about 10 feet per second (fps) through a 270-foot long, submerged multiport discharge structure. Unit No. 3 will use a total of 1,933 cfs of river water for once-through cooling which will be raised in temperature by about 17F°. (pp. III-3 to 14)

g. The staff assessment of thermal discharges from once-through cooling of all three Units, based on mathematical modeling for the near and far field, and utilizing the New York State thermal criteria, indicates that: (pp. V-37 to 41)

(1) When the ambient temperature is about 80°F, compliance with the New York State 90°F maximum surface temperature criterion is possible but is marginal.

(2) Under certain conditions, the thermal discharges in the vicinity of Indian Point, on a tidal average basis, will exceed the New York State thermal criterion requiring that no more than one half of the vertical cross-sectional area of the river shall experience a temperature rise of 4F°.

(3) Under certain conditions, the thermal discharges in the vicinity of Indian Point, on a tidal average basis, will exceed the New York State criterion requiring that no more than two-thirds of the surface width of the river shall experience a temperature rise of 4F°.

(4) Based on a statistical analysis of hydrological and meteorological conditions, the staff estimated that the New York State 4F° surface temperature rise criterion may be exceeded for as many as 30 consecutive days during one out of every

I. INTRODUCTION

The Consolidated Edison Company of New York, Inc. (applicant) has applied to the Atomic Energy Commission for an operating license for Unit No. 3 (Docket No. 50-286) of the Indian Point Nuclear Generating Plant (or Station). The 239-acre site, on the eastern bank of the Hudson River in an industrial area near Peekskill, and about 24 miles north of the New York City northern boundary line, is located in the Village of Buchanan in upper Westchester County, New York, and contains two existing nuclear-powered Units. Unit No. 1 produces 265 megawatts electrical (MWe) and Unit No. 2 produces 873 MWe. Unit No. 3 will use a Westinghouse pressurized-water reactor, rated at 3,025 megawatts thermal (MWt), to produce a net rated output of 965 MWe. A design power level of 3,216 MWt or 1,033 MWe is anticipated in the future. Important information related to Unit No. 3 is given in Table I-1. Additional data regarding the thermal and electrical power for the Plants are given in Table III-1. All three Units will initially use the Hudson River for once-through cooling. In addition, the power output from the three Units will be transmitted to the Buchanan substation, 2,100 ft east of the Units, and from there onto existing transmission facilities owned by the applicant.

In regard to the status of the construction and operation of the three Units on the site, the applicant received a Provisional Operating License DPR-5 for Unit No. 1 on March 26, 1962, and applied for a full-term license on November 10, 1969. Unit No. 1 has been shut down since October 31, 1974, in order to have an emergency core cooling system installed. On September 28, 1973, the applicant received Amendment No. 4 to the Facility Operating License No. DPR-26 to operate Unit No. 2 at 100% steady-state power. This license has since been amended by Amendment No. 5 in accordance with the Atomic Safety and Licensing Appeal Board's Memorandum and Order (ALAB-174) dated January 29, 1974, and Amendment No. 6 in accordance with the Appeal Board's Decision (ALAB-188) dated April 4, 1974. A construction permit CPPR-62 for Unit No. 3 was issued to the applicant on August 13, 1969. The applicant resubmitted to the Commission an amended application for an operating license for Unit No. 3 on April 13, 1973. Construction of Unit No. 3 will be completed in the early part of 1975 and commercial power operation is anticipated during the latter half of 1975.

This Statement has been prepared with consideration of the incremental impacts on the Hudson River ecosystem produced by operation of Indian Point Unit No. 3 with the applicant's proposed once-through cooling system over those produced by existing power plants, including Indian Point Units Nos. 1 and 2.

Table I-1. Important parameters related to Indian Point Nuclear Generating Plant Unit No. 3

Power plant	
Thermal power, MWt	
Rated	3,025
Maximum calculated	3,216
Electrical output, MWe	
Rated gross turbine-generator	1,001
Rated net	965
Maximum calculated net	1,033
Heat discharge, Btu/hr	
At rated power	6.940×10^9
At maximum calculated power	7.490×10^9
Water flow rates, gpm (cfs)	
Cooling water	840,000 (1,871)
Service water	30,000 (67)
Total	870,000 (1,938)
Water velocities, fps	
Intake	0.8–2.0
Discharge (design velocity at discharge port)	10
Fuel weight, lb UO_2	215,800
Equilibrium fuel enrichment, wt % U-235	3.2
Plant site	
Distance north of New York City boundary line, miles	24
Area, acres	
Site	239
Occupied by plant (all 3 units)	35
Location of plant on Hudson River, mile point	43
Characteristics of Hudson River at plant site	
Width, ft	4,500–5,000
Maximum depth, ft	85
Approximate cross-sectional area, ft^2	170,000
Ambient temperatures, °F	
Maximum	79–81
Minimum	32
Freshwater flow, cfs	
Maximum	68,000
Minimum	3,500
Maximum tidal flow, cfs	300,000
Average tidal range, ft	2.9
Maximum salinity, ppt	8
Population (1970 Census)	
Nearby cities	
Peekskill	18,881
West Haverstraw	8,558
Haverstraw	8,198
Croton-on-Hudson	7,523
Stony Point	6,270
Nearby counties	
Westchester	894,406
Rockland	229,903
Orange	221,657
Putnam	56,696

In this Environmental Statement, the staff's Final Environmental Statement[1] (FES) for Unit No. 2, as amended, and the applicant's Environmental Report[2] (ER) and Supplements for Unit No. 3 are cited extensively. Therefore, their full titles and documentation are given only in the list of references for the Introduction. A third document, the applicant's Environmental Report[3] and Supplements for Unit No. 2, will be treated similarly to prevent ambiguity. Throughout the Statement, these references will be given in the line of text, either in short form or as abbreviations, followed by citations to pages, sections, appendices, etc.:

FES, IP-2	Final Environmental Statement for Unit No. 2
ER, IP-2	Environmental Report and three Supplements for Unit No. 2
ER, IP-3	Environmental Report and twelve Supplements for Unit No. 3

Independent calculations and sources of information were also used as a basis for the assessment of environmental impact. In addition, some of the information was gained from visits by the staff to the Indian Point site and surrounding areas in February and November 1973 and in June and August 1974.

Meetings with the New York State Department of Conservation and other State agencies occurred in February 1973, and discussions with the intervenors have taken place during the same meetings between the applicant and the staff mentioned above. These various discussions among the parties in the hearing have been beneficial in the staff's preparation of the FES. In addition, the various reports on the applicant's research program have provided extensive information on the Hudson River environment.

A. SITE SELECTION

The Indian Point site was committed to nuclear power generation as early as 1956, when the construction permit for Unit No. 1 was issued by the Commission. The site was further committed in 1966 when the construction permit for Unit No. 2 was issued, and in 1969 when the construction permit for Unit No. 3 was issued. This commitment and the following factors were the major considerations in the selection of the Indian Point site for Unit No. 3: (1) low population density in the nearby area; (2) the geology of the site; (3) extremely remote danger of flooding; (4) short distances to load centers; (5) existing transmission rights-of-way; (6) availability of the Hudson River water for cooling purposes; and (7) scarcity of suitable sites. Each Unit utilizes the Hudson River as the water supply and the receiving water body for discharged wastes. Experience had been gained from operation of Unit

No. 1 regarding the discharges of thermal, chemical, and radioactive effluents and their effects on the environment, and studies have been carried out on the impact of incremental amounts of these discharges. All liquid and gaseous effluents discharged from the Units to the environment shall be required to meet Federal, State, and local regulations. Suitable sites for large power plants are becoming increasingly scarce in the New York area. Limitations of the availability of the above-mentioned requirements have restricted the applicant in selecting suitable sites to build power plants to serve the applicant's service area.

B. APPLICATIONS AND APPROVALS

Table I-2 lists the applications filed by the applicant and the approvals received to date from various governing bodies or agencies for Unit No. 3 as well as for the other two Units. For those applications which have been granted, the date of issuance is included. The letters granting the permits are presented in Appendix I of the applicant's Suppl. No. 1 to the Environmental Report for Unit No. 2 and Appendix H in the Environmental Report for Unit No. 3.

1. Past Environmental Approvals

The applicant has also conferred with the Westchester County Department of Planning[4] in establishing the Indian Point site for construction of nuclear power plants. The Department of Planning comments on the fact that the site is zoned for industrial use, including the use of nuclear power generation, which is consistent with the overall land use development planned for Westchester County. It also strongly endorses the applicant's policy of making part of the site available for public use and for recreational purposes. The State of New York Atomic Energy Council has similarly expressed the opinion, consistent with that of the Department of Planning, that nuclear power development may have resulted in an improved land usage (ER, IP-3, p. 6-2).

The Advisory Council on Historic Preservation[5] has commented on the effect of the nuclear power plant undertaking on the Stony Point Battlefield Reservation, a National Register property, and concluded that the probable effect upon this Reservation cannot be judged to be sufficiently adverse to warrant Council comment.

On September 14, 1967, the Hudson River Valley Commission (HRVC),[6] which encourages projects that enhance the preservation and development of the historic, natural, and scenic resources of the Hudson River Valley and recognizes the need for full development of the commercial, industrial, and other resources, stated its unanimous

Table I-2. Approvals related to the Indian Point Station

Agency	Subject	Date of issuance	Approval
Atomic Energy Commission	Unit No. 1 construction permit	May 4, 1956	CPPR-1
	Unit No. 1 provisional operating license	Mar. 26, 1962	DPR-5
	Unit No. 2 construction permit	Oct. 14, 1966	CPPR-21
	Unit No. 2 facility operating license to load fuel and conduct subcritical testing	Oct. 19, 1971	DPR-26
	Unit No. 2 facility operating license to conduct tests up to 50% of rated power	Apr. 20, 1973 Apr. 27, 1973	DPR-26, Amendments 1 and 2
	Unit No. 2 facility operating license to operate up to 50% of rated power	Aug. 9, 1973	DPR-26, Amendment 3
	Unit No. 2 facility operating license for 100% of rated power	Sept. 28, 1973	DPR-26, Amendment 4
	Unit No. 3 construction permit	Aug. 13, 1969	CPPR-62
Department of the Army, Corps of Engineers	Construction of wharf, screenwells, and discharge tunnel; installation of pipes; dredging and placing of fill	Apr. 3, 1957	Permit No. 5236
	Construction of dike in Lents Cove	Jan. 8, 1960	Permit No. 5891
	Placement of fill	Feb. 23, 1966	Permit No. 7184
	Revised plans to place fill; construction of discharge channel extension wall and screenwell structure; dredging and placing of fill	Mar. 15, 1966	Permit No. 7184-A
	Revised plans for discharge structure	Jan. 19, 1967	Permit No. 7184-B
	Installation of screenwell cofferdam and discharge canal	Sept. 29, 1967	Permit No. 7562
	Dredging at Lents Cove	Dec. 11, 1967	Permit No. 7589
	Revised plans for discharge structure and installation of steel outfall section consisting of 12 submerged openings	Nov. 24, 1970	Permit No. 7562-A
	Sect. 13 permit to discharge and control thermal, chemical, and other wastes	Applied for June 24, 1971; converted to Sect. 402 permit	
Hudson River Valley Commission	Installation of screenwell cofferdam and discharge canal	Sept. 14, 1967	Letter of approval
	Dredging at Lents Cove	Dec. 7, 1967	Letter of approval
	Changes in discharge canal	Mar. 26, 1971	Letter of approval

Table I-2 (continued)

Agency	Subject	Date of issuance	Approval
New York State Water Resources Commission	Dumping of rock spoil in Hudson River	Feb. 4, 1966	Permit No. 8-1-66
	Construction of extension of discharge canal to separate discharge from intake to a point 300 ft south of present location	Mar. 2, 1966	Permit No. 8-4-66
	Dredging for concrete screen-well construction	Apr. 13, 1966	Permit No. 8-11-66
	Installation of screenwell cofferdam and discharge canal	June 22, 1967	Permit No. 8-31-67
	Dredging at Lents Cove	Nov. 30, 1967	Permit No. 8-78-67
	Extension of discharge canal 98 ft downriver and protection with sheet piling	June 30, 1970	Permit No. 8-22-70
New York State Department of Environmental Conservation	Redesigned outfall structure including sluice gates	Dec. 10, 1970	
	Construction of modified outfall structure to change openings from 18-ft depth to 12-ft depth	Nov. 4, 1971	
	Discharge of chemical cleaning solutions	Nov. 13, 1970	Temporary; no longer used
	Discharge of chemical cleaning solutions	Feb. 10, 1971	Temporary; no longer used
	Water quality certification for Units Nos. 1 and 2 under Sect. 21(b) of WQIA of 1970	Dec. 7, 1970	
	Water quality certification under Sects. 401 and 402 of FWPCAA of 1972 for testing period for Units Nos. 1 and 2	Apr. 24, 1973	
	Water quality certification under Sect. 401 of FWPCAA of 1972 for full power operation of Units Nos. 1 and 2	Sept. 24, 1973	
New York State Department of Health	Sewage disposal system	June 10, 1959	
	Construction of 214-ft cooling water discharge channel	Aug. 22, 1966 (expired Aug. 22, 1971)	
	Construction of fossil-fired service boilers	Apr. 12, 1968	Permit No. HA-680101
	Construction of an effluent channel with a submerged diffuser	May 19, 1970	

Table I-2 (continued)

Agency	Subject	Date of issuance	Approval
Westchester County Department of Planning	Use of land for industrial purposes	Nov. 9, 1970	
Village of Buchanan, Building Department			
	Unit No. 2		
	Excavation	Dec. 1, 1965	Permit No. 373
	Intake screenwell	May 16, 1965	Permit No. 381
	Turbine room, water bay, and discharge water tunnel	May 24, 1965	Permit No. 387
	Primary auxiliary building and waste holdup tank pit	Sept. 28, 1966	Permit No. 404
	Fuel storage building	Sept. 28, 1966	Permit No. 405
	Containment building	Sept. 28, 1966	Permit No. 406
	Control room	Feb. 18, 1967	Permit No. 411
	Unit No. 3		
	Excavation	June 16, 1967	Permit No. 421
	Demolition of existing storage and office buildings	July 10, 1967	Permit No. 425
	Installation of screenwell cofferdam and discharge canal	July 11, 1967	Permit No. 427
	Control house	May 28, 1968	Permit No. 458
	Containment building	May 28, 1968	Permit No. 459
	Turbine building	May 28, 1968	Permit No. 460
	Fuel-storage building	July 15, 1968	Permit No. 463
	Primary auxiliary building	Feb. 24, 1969	Permit No. 473
	Waste-holdup tank	Aug. 25, 1969	Permit No. 491
	Service building	Aug. 26, 1969	Permit No. 492

IV. ENVIRONMENTAL IMPACT OF SITE PREPARATION AND PLANT CONSTRUCTION

A. SUMMARY OF CONSTRUCTION STATUS

Construction at the Indian Point site has been almost continuous since 1956, when construction began on Unit No. 1. Construction of Unit No. 1 was completed in 1962. Construction of Unit No. 2 began in 1965 and was completed in April 1973, after which this plant achieved criticality on May 22, 1973. Construction of Unit No. 3 began in 1969, is currently about 92% complete, and is scheduled for completion in 1975. Unit No. 3 is estimated to be ready for fuel loading by the early part of 1975 and for power operation by the last half of 1975. The applicant has received all the necessary Federal, State, and local permits and licenses for the necessary construction work as described in Chapter I.

B. IMPACTS ON LAND USE

1. Onsite Construction

The site was formerly the Indian Point amusement park, which was abandoned when the use of the park decreased. The applicant purchased the abandoned site in the mid-1950's for use as a site for a power plant. The site was zoned for heavy industrial use.

About two-thirds of the 239-acre site has been affected by construction-related activities for all three Units. Upon completion of construction, about 35 acres, or 15%, of the 239-acre site will be utilized by permanent buildings and facilities.

During construction of Unit No. 3, few impacts of any significance on land use resulted, because no changes were needed for rebuilding or relocating highways, railroad lines, or gas lines. Most access lines and roads were built during the construction of Units Nos. 1 and 2. A permanent access road through the site starts at the corner of Bleakley Avenue and Broadway, a few blocks away from the New York-Albany Post Road (NYS Highway 9). Heavy equipment was shipped into the site via this access road from existing highways, expressways, and railroads or up the Hudson River by barge. Much of the construction work and impacts have been limited to the confines of the site itself.

Erosion in areas disturbed by construction will be reduced through continuous efforts to landscape and carry out vegetative measures on the site as construction work is being completed. The major effect of construction of Unit No. 3 is to delay the restoration of the areas of the site disturbed during construction of the other Units.

III. THE PLANT

A. GENERAL

The Indian Point Nuclear Generating Plant consists of three Units. Unit No. 1 uses nuclear and oil-fueled components in combination to produce a net output of 265 MWe. It has been in commercial operation since October 1962 and has generated a cumulative total of 13,557,495 MWhr gross (as of December 6, 1974). Unit No. 2 uses nuclear fuel and has a net rated capacity of 873 MWe. On September 28, 1973, the applicant received a license to operate Unit No. 2 up to 100% of steady state power. The gross generation of power has amounted to 10,764,100 MWhr as of December 6, 1974. Unit No. 3, with construction about 92% complete in the fall of 1974, also uses nuclear fuel and has a net rated capacity of 965 MWe.

Waste heat from Units Nos. 1, 2, and 3 is dissipated by once-through cooling with water from the Hudson River. In Unit No. 3, cooling water is withdrawn from the Hudson River at a maximum rate of 840,000 gallons per minute (gpm) through six pumps at full capacity of 140,000 gpm each and six service water pumps of 5,000 gpm each for a total of 30,000 gpm for service water purposes. Upon passing through three condensers, the circulating cooling water is heated to about 15 F° above the background river water temperature and discharged into a common discharge canal with Units Nos. 1 and 2. The heated water is then discharged into the Hudson River through a submerged multiport discharge structure at a minimum velocity of 10 feet per second (fps). Dilution of the thermal discharges takes place by jet entrainment and by diffusion, with heat dissipation eventually occurring by surface heat exchange into the atmosphere.

B. EXTERNAL APPEARANCE

The containment buildings and turbine buildings are the major structures on the site (Fig. III-1). As viewed from the river, the turbine building for Units Nos. 1 and 2 is on the left (north) and that for Unit No. 3 on the right (south). The containment buildings are just behind and extend above the turbine buildings with Unit No. 2 on the left (north), Unit No. 3 on the right (south), and the smaller building for Unit No. 1 in the middle.

Only the Unit No. 1 stack and the upper parts of the three containment vessels are visible from Broadway and parts of Peekskill. For the most part, the Plant structures present an appearance similar to other industrial structures in the area. The appearance

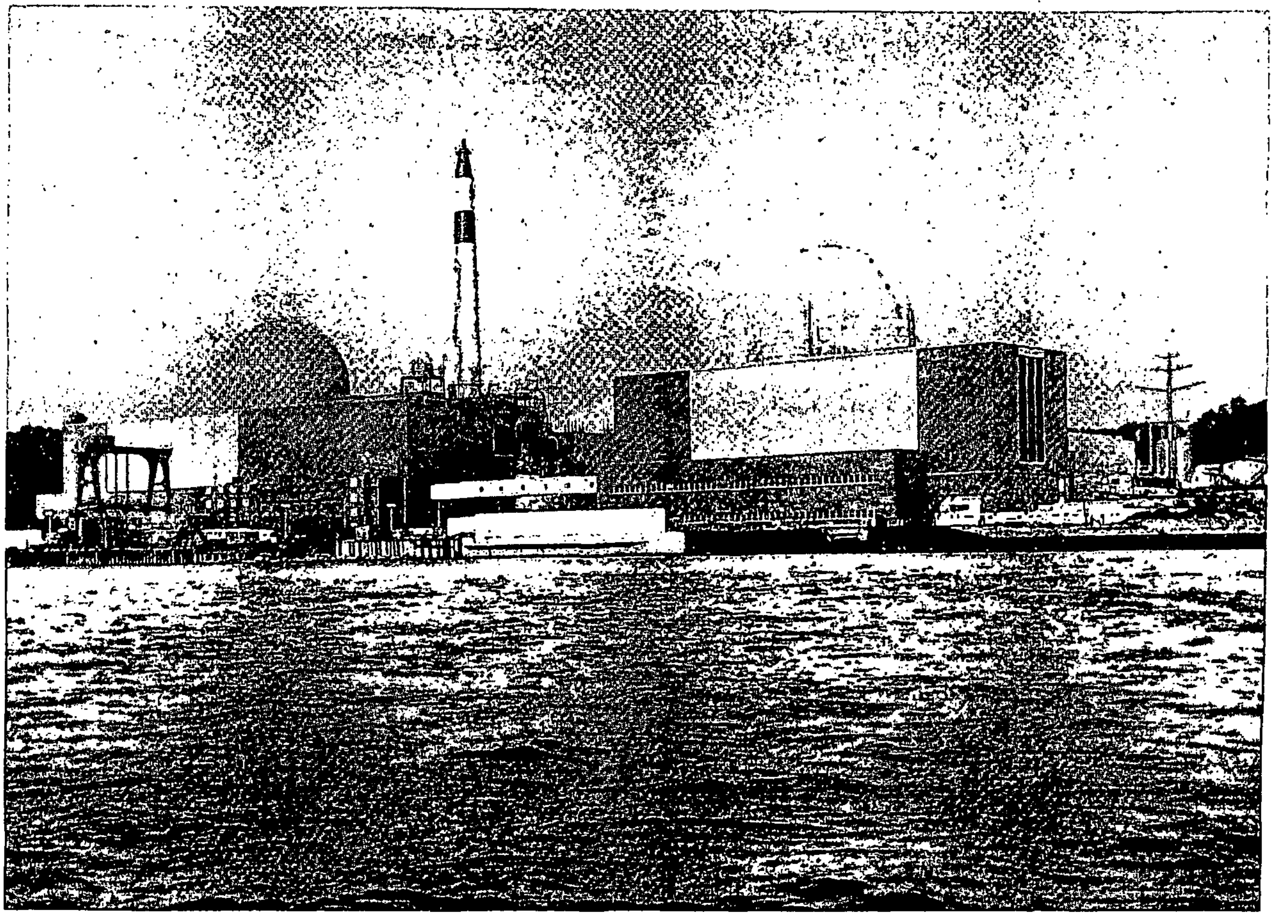

Fig. III-1. Photograph showing construction of Indian Point Unit No. 3.

of the Plants would be decidedly changed if an alternative closed-cycle cooling system as recommended by the staff in Sect. XI were installed.

C. TRANSMISSION LINES

Transmission facilities uniquely identifiable with Unit No. 3 consist of a truss framed into the turbine-generator building, four tubular-steel transmission poles (three double-circuit poles and one single-circuit pole) located within site boundaries, and two tubular-steel terminal structures at the Buchanan substation, 2,100 ft east of the site. Power from Unit No. 3 as well as from Units Nos. 1 and 2 will be transmitted on existing transmission facilities through the Buchanan substation to other substations to the New York City area and other highly populated sections around the metropolitan area in the applicant's service area on transmission lines shown in Fig. X-1 and described in Table X-2.

D. REACTOR AND STEAM-ELECTRIC SYSTEMS

All three Units utilize pressurized light-water nuclear reactors. Their descriptions have been given in detail in the applicant's *Final Facility Description and Safety Analysis Reports*[1,2] and have been summarized in the applicant's Environmental Reports (ER, IP-2, Sect. 2.1.2 and ER, IP-3, Sect. 3) and in the staff's Final Environmental Statement for Unit No. 2 (FES, IP-2, Sect. III.D). The license application for Unit No. 3 is for a power rating of 3,025 MWt as compared with 2,758 MWt for Unit No. 2. The power levels for the three Units are summarized in Table III-1. The rated capacity is the capacity which is the basis for the license application. The maximum guaranteed capacity is the maximum output for which the vendor guarantees the turbine generators. The maximum calculated (design) capacity is the ultimate capacity that the applicant plans to achieve ("stretch" level).

Steam is generated to drive tandem-compound turbine-generator units located in adjacent secondary-system buildings. There is one turbine-generator for each Unit, and the turbine assemblies for Units Nos. 2 and 3 are essentially identical, each consisting of one high-pressure and three low-pressure turbines on a single shaft. Each of the low-pressure turbines exhausts into a separate single-pass condenser (with divided water boxes) cooled by water from the Hudson River.

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Legislative Document (1959) No. 46

STATE OF NEW YORK

MESSAGE OF THE GOVERNOR

in relation to

Use of Atomic Energy for Peaceful Purposes

and

Atomic Energy Law and Establishment of Office of Atomic Development

STATE OF NEW YORK

EXECUTIVE CHAMBER

ALBANY, *February* 17, 1959

To the Legislature:

The development and use of atomic energy for peaceful purposes is a matter of important concern to the economic growth, and the health and safety, of the people of the State.

The full nature of the opportunities foreshadowed by man's ability to control nuclear fission and fusion are still beyond our power to visualize—just as our modern agricultural economy was beyond the vision of those who, thousands of years ago, first found it possible to domesticate animals and cultivate edible crops from planted seed.

New York should be the leader among the states in encouraging the development and use of atomic energy within the State as fully as possible, consistent with the health and safety of workers and the public as well as with the powers and responsibilities of the Federal Government and the governments of other states.

It was in New York that the atom was split for the first time in this hemisphere, in 1939. New York is now the headquarters of more organizations having an interest in atomic energy than are located in any other state. To encourage these and other organizations to make New York the center of their atomic activities, the State must be alert in providing the regulatory climate, the trained personnel, and the incentives most conducive to private atomic development.

1. *The Need for State Action*

For sixteen years the pace and direction of nuclear development have been largely determined by the Federal Government and by military considerations. Yet, the health of our citizens and the vigorous development of our industry are fully as much a State and local concern as they are a Federal responsibility. Furthermore, the peaceful uses of atomic energy in industry, hospitals and laboratories are, at the least, as many and significant as are the military.

The health, the safety, the economic growth of our people are vitally involved in atomic development. Expansion of our industry and increased individual well-being are among the rewards for the State which fosters private initiative and leadership in these matters.

The need for a more coordinated and affirmative State roll in atomic affairs is widely recognized. The Federal Atomic Energy Commission, members of the Congressional Joint Committee on Atomic Energy, the Council of State Governments, the Joint Federal-State Action Committee created by President Eisenhower and the state governors, members of the State Bar Association and the Association of the Bar of the City of New York, and other leading citizens have urged an increased assumption of atomic energy responsibility by the State.

2. *Recommendation for Atomic Energy Law and Office of Atomic Development*

Accordingly, I urge the early adoption of a New York State Atomic Energy Law and the creation within the Executive Department of an Office of Atomic Development, headed by a Director.

A law creating such an Office would provide both the legal framework and the momentum to accelerate atomic development programs. While one cannot blueprint now all the specific steps the State might take to encourage atomic developments, there is no need to do so in the initial legislation.

I recommend that the initial State atomic energy legislation have at least five major objectives:

First—Encouragement of the resourceful use of nuclear science and nuclear knowledge by private enterprise and nonprofit organizations for the fullest possible development of the economy of the State and the well-being and safety of our people.

Second—Encouragement and support for nuclear science and education so that the State will be in the forefront as a center of nuclear knowledge and activity.

Third—Wider and better understanding of atomic energy, its prospects and hazards, through studies, surveys and reports.

Fourth—Agreement with the Federal Government to clarify those areas of government support, inspection or regulation which are primarily a State or local function—to the end that the Federal and State objectives will be mutually advanced.

Fifth—Closer coordination of those departments, municipalities and agencies within the State dealing with one or more aspects of atomic energy—to foster the optimum use of atomic energy under regulation that will be harmonious, and not burdensome, in its application.

3. *Development Activities of the Office*

Each of these five objectives involves important State concerns. I place special emphasis, however, on the need for resourceful planning and incentives for the development of atomic energy and increased use of it by private enterprise within this State.

In the industrial use of atomic energy, there is already evidence that New York State is losing the leading position it once enjoyed. According to a recent survey by the Atomic Industrial Forum, the State of California in 1958, for the first time, surpassed New York in the number of industrial users of radioactive material.

This trend must and can be reversed. A new Office of Atomic Development, such as I propose, is one of the necessary steps.

An essential part of the development function of the Office will be close cooperation with the Federal Government. The Director of the new Office must seek to clarify with the Federal Government the areas of primary State responsibility in the atomic field. He must also determine what, if any, opportunities for the encouragement of atomic development are not now receiving the attention they merit at either the Federal, State or local levels of government. He should also represent the State at hearings before the Congressional Joint Committee on Atomic Energy in Washington, such as those to be held next May on Federal-State relationships in the promotion and regulation of peaceful uses of atomic energy. The Director should, moreover, be directly responsive and responsible to the Governor, and thus work at the highest levels of the State administration.

To be successful, the Director will have to be knowledgeable in a complex area, have the respect of industry, labor and federal officials, and be capable of pioneering in a rapidly evolving field. To attract a man of the required specialized competence, adequate compensation must be provided.

The initial staff of the Office can be small. It must, however, have a high order of skill. The Office should also be able to draw on the specialized facilities and services of existing State departments and agencies.

4. *Coordinating Activities of the Office*

The new Office should also coordinate the many atomic energy activities of government departments or agencies in the State. Similar coordination must be maintained with the other states.

Coordination, particularly in a field as intricate and specialized as atomic energy, is difficult but essential. A way must be found to avoid overlapping or contradictory regulations and procedures. Yet coordination does not and should not mean shifting to the new Office operating or program responsibilities of the agencies.

As an approach to this problem of coordination, I suggest that the new atomic law require the departments, agencies and political subdivisions (including municipalities) of the State (1) to keep the Director fully and currently informed of their activities relating to atomic energy, and (2) to submit all proposed rules, regulations and ordinances relating primarily and directly to atomic energy to the Director for a reasonable period prior to their becoming effective.

I also propose that there be a Coordinating Council to advise and assist the Director in his coordinating function. I propose that the Council be made up principally of representatives of those departments or agencies whose activities and programs are most involved. The Council would be expanded as other agencies or groups emerge whose position should be reflected in its deliberations and recommendations.

There is no need to make any changes in the powers or functions of any existing department or agency of our State in order to accommodate an atomic energy program as I have outlined it in this message.

5. *Advisory Committee*

Such an Office of Atomic Development will face many novel and challenging problems. It will be a pioneer among the states in atomic energy development. So novel and intricate are these problems likely to be that I urge the creation of a citizen Advisory Committee, small enough to be effective, but large enough to be representative of the varied industry, labor and professional points of view which must have a voice in shaping a fruitful State atomic program. Such a committee would be a source of invaluable informed advice for the Director on the many ramifications of a State effort to promote the use and understanding of atomic energy.

6. *Conclusion*

With an atomic energy law such as I propose, New York will be in a position to exercise genuine leadership in atomic matters. Such a law will also give the State a readiness to deal with any future scientific developments which have important State significance.

I am confident that the imagination and drive of private enterprise, with active cooperation from the State Government, will point the way to atomic developments within the State which will be a source of strength to our economy and to our people.

(Signed) NELSON A. ROCKEFELLER

McKINNEY'S
1959 SESSION LAWS
OF NEW YORK

Comprising
Authentic Text of the Laws
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182nd SESSION
Laws of the Regular Session
Chapters 1–880

With
TABLES and INDEX

BROOKLYN, N. Y.
EDWARD THOMPSON COMPANY

Burlington, Town of—Auditing and Financing Certain Claims

CHAPTER 40

An Act to authorize the town of Burlington, Otsego county, to audit and pay certain claims and to provide for the financing of the payment thereof.

Became a law March 3, 1959, with the approval of the Governor. Effective March 3, 1959.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section 1. The town of Burlington, Otsego county is hereby authorized to borrow money and to issue a capital note pursuant to the local finance law in an aggregate principal amount not exceeding the sum of twenty-one hundred dollars, to provide money for the payment of certain unpaid claims against such town, incurred for material and equipment furnished to the town for highway construction during the years nineteen hundred fifty-six, nineteen hundred fifty-seven and nineteen hundred fifty-eight. The period of probable usefulness of the object or purpose for which such capital note is to be issued is hereby determined to be two years computed from the date of issuance thereof.

§ 2. Notwithstanding the provisions of any other general, special or local law, such claims against the town of Burlington for material and equipment furnished to the town for highway work during the years nineteen hundred fifty-six, nineteen hundred fifty-seven and nineteen hundred fifty-eight, are hereby legalized and confirmed subject, however, to audit thereof by the town board in the manner provided by law.

§ 3. This act shall take effect immediately.

State Atomic Energy Law

CHAPTER 41

An Act to amend the executive law, in relation to the creation of an office of atomic development within the executive department, and making an appropriation for such office and its expenses.

Became a law March 9, 1959, with the approval of the Governor.
Effective March 9, 1959.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section 1. The executive law is hereby amended by inserting therein a new article, to be article nineteen-d, to read as follows:

ARTICLE 19-D

ATOMIC ENERGY LAW

Section
450. Short title.
451. Legislative findings and declaration of policy.
452. Definitions.
453. Office of atomic development; director; employees.

deletions by ~~strikeouts~~

Section
454. General functions, powers and duties of office.
455. Assistance of other departments, agencies and political subdivisions; review of regulations.
456. Contracts for atomic energy facilities.
457. Atomic energy special fund.
458. Coordinating council.
459. Advisory committee.
460. No disqualification.

§ 450. Short title

This article shall be known, and may be cited, as the "state atomic energy law."

§ 451. Legislative findings and declaration of policy

The legislature hereby finds and declares that:

1. The development and use of atomic energy for peaceful purposes is a matter of important concern to the economic growth, and the health and safety of the people, of the state. It is, therefore, declared to be the policy of the state to encourage such development and use within the state as fully as possible, consistent with the health and safety of workers and the public as well as with the powers and responsibilities of the federal government and the governments of other states.

2. The development of atomic energy and of the industries producing or utilizing such energy is certain to create new opportunities for affirmative state action in the public interest and to result in new conditions calling for changes in state laws, regulations and procedures. Hence, it is declared to be the further policy of the state

(a) to initiate continuing studies of the ways in which atomic energy activities may more fruitfully be developed and coordinated, and private atomic energy enterprises more effectively encouraged;

(b) to adapt its laws, regulations and procedures from time to time to meet the new opportunities and conditions in ways that will encourage the development of atomic energy and of the private enterprises producing or utilizing such energy, while fully protecting the interest, health and safety of the public; and

(c) to assure the coordination of the studies and actions thus undertaken with other atomic energy development activities, public and private, throughout the United States.

§ 452. Definitions

When used in this article:

1. The term "atomic energy" means all forms of energy released in the course of nuclear fission or nuclear fusion or other nuclear transformation.

2. The term "director" means the director of the office of atomic development.

3. The term "office" means the office of atomic development.

4. The term "person" means any natural person, firm, association, public or private corporation, organization, partnership, trust, estate, or joint stock company, or any political subdivision of the state, or any officer or agent thereof.

§ 453. Office of atomic development; director; employees

There is hereby created within the executive department an office of atomic development. The head of such office shall be a director, who shall be appointed by the governor, by and with the advice and consent of the senate, and shall hold office during the pleasure of the governor. He shall receive an annual salary to be fixed by the governor within the amount available therefor by appropriation. He shall also be entitled to receive reimbursement for expenses actually and necessarily incurred by him in the performance of his duties. The director may appoint such officers, employees, agents, consultants and special committees as he may deem necessary, prescribe their duties, fix their compensation and provide for reimbursement of their expenses within the amounts available therefor by appropriation.

§ 454. General functions, powers and duties of office

The office of atomic development, by and through the director or his duly authorized officer or employee, shall, subject to the supervision and direction of the governor, have the following functions, powers and duties:

1. To advise the governor and the legislature with regard to the status of atomic energy research, development, education and regulation, and to make recommendations to the governor and the legislature designed to assure increasing progress in this field within the state.

2. To advise and assist the governor and the legislature in developing and promoting a state policy for atomic energy research, development, education and regulation.

3. To coordinate the atomic energy activities of the departments, agencies, offices, commissions and other agencies of the state and the political subdivisions of the state.

4. To cooperate with business enterprise and other persons concerned with atomic energy, the federal government and the governments of other states, and to correlate the atomic energy activities of the state and its political subdivisions with the atomic energy activities of the foregoing.

5. To sponsor or conduct studies, collect and disseminate information and issue periodic reports with regard to atomic energy research, development, education and regulation and proposals for further progress in the field of atomic energy.

6. To accept, without regard to the limitations of section eleven of the state finance law relating to unconditional gifts but with the concurrence of the director of the budget, and to administer loans, grants, or other contributions from the federal government or other sources, public or private, for carrying out the policies or purposes of this article.

7. To foster and support research and education relating to atomic energy through contracts or other appropriate means of assistance, including acquisition of land and construction of facilities, on such terms and conditions as the director may deem necessary or appropriate in the public interest and within the amounts available therefor by appropriation.

8. To keep the public informed with respect to atomic energy development within the state and the activities of the state and its political subdivisions relating thereto.

9. To do all things necessary or convenient to carry out the functions, powers and duties set forth in this article.

§ 455. Assistance of other departments, agencies and political subdivisions; review of regulations

1. All departments, divisions, offices, commissions and other agencies of the state and all political subdivisions thereof are directed to keep the director fully and currently informed as to their activities relating to atomic energy or ionizing radiation.

2. The director may request from any department, division, office, commission or other agency of the state or any political subdivision thereof, and the same are authorized to provide, such assistance, services and data as may be required by the office in carrying out the purposes of this article.

3. No rule, regulation or ordinance or amendment thereto or repeal thereof, primarily and directly relating to atomic energy or the use of atomic energy, which any department, division, office, commission or other agency of the state or of any political subdivision thereof may propose to issue or promulgate, shall become effective until ninety days after it has been submitted to the director, unless either the governor or the director by order waives all or any part of such ninety day period.

§ 456. Contracts for atomic energy facilities

In making contracts or providing other appropriate assistance to foster and support atomic energy research or education, the director shall require that any state funds provided through the office for the acquisition of land or the construction of facilities affixed thereto be matched by funds or other contributions from other sources of at least equal amount or value, and that any such land and facilities be available for research and training, for such period of time and on such terms as may be approved by the director, to the departments, divisions, offices, commissions and other agencies of the state and of the political subdivisions thereof, to educational and non-profit institutions in the state and to other persons, consistent with the purposes of this law.

§ 457. Atomic energy special fund

1. There is hereby established in the custody of the state comptroller a special fund, to be known as the "atomic energy special fund."

2. All moneys received from grants or other contributions accepted pursuant to subdivision six of section four hundred fifty-four of this article shall be deposited directly in the atomic energy special fund.

3. The moneys of the atomic energy special fund, subject to the terms and conditions of such grants or contributions and to segregation by the director of the budget, shall be available for payment of any and all costs and expenditures, including contracts and grants under section four hundred fifty-six of this article, required in carrying out the purposes of this article, and costs and expenditures incidental and appurtenant thereto. All payments from such fund shall be made on the audit

and warrant of the state comptroller on vouchers approved by the director.

§ 458. Coordinating council

The governor shall designate a coordinating council, under the chairmanship of the director, to advise, assist and make recommendations to the director with respect to coordination of the atomic energy activities of the departments, divisions, offices, commissions and other agencies of the state and the political subdivisions of the state. The coordinating council shall consist of such representatives of state departments and agencies importantly concerned with atomic energy and such other persons as the governor may from time to time designate.

§ 459. Advisory committee

1. There shall be within the office a general advisory committee consisting of not more than fifteen members appointed by the governor who shall broadly reflect the varied interests in and aspects of atomic energy within the state, one of whom shall be designated as chairman by the governor and who shall serve as chairman at the pleasure of the governor. The advisory committee shall meet from time to time at the call of the chairman or the director, shall advise the director on atomic energy matters and, if so requested by the director, may make particular atomic energy studies.

2. The members of the advisory committee shall serve without compensation but shall be allowed their actual and necessary expenses incurred in the performance of their duties hereunder.

3. All members of the advisory committee shall be appointed for terms of three years, such terms to commence on April first and expire on March thirty-first; provided, however, that of the members first appointed one-third shall be appointed for one-year terms expiring on March thirty-first, nineteen hundred sixty, and one-third shall be appointed for two-year terms expiring on March thirty-first, nineteen hundred sixty-one. Any member chosen to fill a vacancy created otherwise than by expiration of term shall be appointed for the unexpired term of the member whom he is to succeed.

§ 460. No disqualification

No member of the coordinating council or the advisory committee shall be disqualified from holding any other public office or employment, nor shall he forfeit any such office or employment by reason of his appointment hereunder, notwithstanding the provisions of any general, special or local law, ordinance or city charter.

§ 2. Sections four hundred fifty, four hundred fifty-one, four hundred fifty-two and four hundred fifty-three of such law are hereby renumbered sections five hundred fifty, five hundred fifty-one, five hundred fifty-two and five hundred fifty-three, respectively.

§ 3. The sum of ten thousand dollars ($10,000), or so much thereof as may be necessary, is hereby appropriated out of any moneys in the state treasury in the general fund to the credit of the state purposes fund, not otherwise appropriated, and made immediately available, for the expenses of the office of atomic development, including personal service, maintenance, operation and travel in and outside the state, in carrying out the provisions of article nineteen-d of the executive law as added by this act and for the other purposes of said article nineteen-d, for the balance of the fiscal year of the state ending March thirty-first, nineteen hundred fifty-nine. Such moneys shall be payable on the audit and warrant of the comptroller on vouchers certified or approved in the manner prescribed by law.

§ 4. This act shall take effect immediately.

Teachers' Retirement Systems—35 Year Service

CHAPTER 42

An Act to amend the education law, in relation to an increased pension for members of the New York state teachers' retirement system for service in excess of thirty-five years.

Became a law March 10, 1959, with the approval of the Governor.

Effective March 10, 1959.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section 1. Paragraph g of subdivision two of section five hundred ten of the education law, such paragraph having been added as paragraph f by chapter three hundred seventy-three of the laws of nineteen hundred fifty-five and relettered paragraph g by chapter seven hundred thirty of the laws of nineteen hundred fifty-six, is hereby amended to read as follows:

g. The provision of paragraph (c) of subdivision two of this section shall apply only to members retiring on and after the date on which paragraph (c) of subdivision two of this section becomes operative and prior to July first, nineteen hundred ~~sixty~~ sixty-five.

§ 2. This act shall take effect immediately.

Second Class Cities—Penalties

CHAPTER 43

An Act to amend the second class cities law, in relation to penalties.

Became a law March 10, 1959, with the approval of the Governor.

Effective March 10, 1959.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section 1. Section forty-two of the second class cities law is hereby amended to read as follows:

§ 42. Penalties for violation of ordinances

Any person violating an ordinance of the common council shall be guilty of a misdemeanor, except that an ordinance may provide that a violation thereof shall be an offense, and the common council may provide therein or by general ordinance, that any person guilty of such violation shall be liable to a fine which shall not exceed one hundred and fifty dollars in amount, or to imprisonment not exceeding one hundred and fifty days, or to both such fine and imprisonment, or such ordinance may provide for a penalty, not exceeding five hundred dollars to be recovered by the city in a civil action. The city may maintain an action or proceeding

USIR STAMPS ATTACHED $ [illegible] DEC 14 1959

The People of the State of New York, by the Grace of God, Free and Independent,

TO ALL TO WHOM THESE PRESENTS SHALL COME, GREETING:

Know ye, *That*, pursuant to resolutions of the Board of Commissioners of the Land Office adopted May 19, 1959 and October 27, 1959, and in consideration of the sum of two thousand six hundred fifty-one dollars ($2,651.00), lawful money of the United States, paid by Consolidated Edison Company of New York, Inc., a corporation organized and existing under and by virtue of the Laws of the State of New York and having its principal office and place of business at No. 4 Irving Place, in the Borough of Manhattan, in the City of New York and State of New York and upon the conditions hereinafter expressed, we have given and granted and by these presents do give and grant unto the said CONSOLIDATED EDISON COMPANY OF NEW YORK, INC., the owner of the land adjacent to the land hereinafter described, its grantees or successors in interest (hereinafter referred to as the patentee), the following described land under water, to wit:

All that certain parcel of land lying now or formerly under the waters of the Hudson River situate in the Village of Buchanan, Town of Cortlandt, County of Westchester and State of New York, bounded and described as follows:

Beginning at a point in the Hudson River on the exterior line of the herein described grant of lands under water said point being on line with the westerly prolongation of the center line of a pier and bearing North fifty-one degrees, twenty-six minutes, twenty seconds West, along the line of the center line of said pier a distance of two hundred twenty-two and fifty-four one-hundredths feet from a cross cut in the concrete floor of a pavillion; thence in the waters of the Hudson River North thirty-eight degrees, thirty-three minutes, forty seconds East eight hundred sixty-nine and fifty-four one-hundredths feet; thence still in the waters of the Hudson River South fifty-one degrees, twenty-six minutes, twenty seconds East one hundred twenty-six and ninety-six one-hundredths feet to the high water line of the Hudson River; thence along said high water line the following courses and distances: South four degrees, fifty-four minutes East, seventy and twenty-six one-hundredths feet; South ten degrees, five minutes West, ninety-one and fortyone one-hundredths feet; South seven degrees, fifty-eight minutes East, fifty and forty-eight one-hundredths feet; South twenty-seven degrees, fifty minutes, forty seconds West, fifty-nine and ninety-five one-hundredths feet; South thirty-four degrees, sixteen minutes, thirty seconds West, one hundred ninety feet; South thirty-nine degees, twenty-five minutes, fifty seconds West, one hundred sixteen and fifty-one one-hundredths feet; South fifty-two degeees, twenty-five minutes West, sixty-five and sixty-one one-hundredths feet; South thirty-nine degrees, twenty-one minutes, fifty seconds West, thirty-eight and thirty-one one-hundredths feet to the northeast corner of a grant of land under water to the Bonner Brick Company dated June 28, 1905; thence along the inshore bounds of said Bonner Brick Company grant South thirty-five degrees, forty-three minutes, twenty seconds West, seventy-nine and thirty-five one-hundredths feet and South thirty-five degrees, twenty-one minutes West, one hundred fourteen feet to the northerly boundary of a grant of land under water to William Lyell, dated March 24, 1857; thence continuing along the inshore bounds of the Bonner Brick Company grant South forty-three degrees, twenty-one minutes West, four hundred ten feet and South twenty degrees, twenty-one minutes West, one hundred nine feet to the southeast corner of the aforesaid Bonner Brick Company grant; thence along the high water line of the Hudson River the following courses and distances: South twenty-seven degrees, thirty-five minutes West, twenty-three and eighty-four one-hundredths feet; South seventy-eight degrees, thirty-four minutes, twenty seconds West, ninety-five and thirty-one one-hundredths feet; South sixty-eight degrees, forty-five minutes, forty seconds West forty and thirty-three one-hundredths feet; due South twenty feet; South forty-six degrees, twenty-six minutes West eighty-four and seventeen one-hundredths feet; South sixty-five degrees, fourteen minutes West forty-two and ninety-five one-hundredths feet and South forty-two degrees, two minutes West one hundred ninety-one and eighteen one-hundredths feet to the northwest corner of a working right of way of the Algonquin Gas and Transmission Company and the southeast corner of the herein described grant; thence into the waters of the Hudson River North fifty-one degrees, twenty-six minutes, twenty seconds West, one hundred sixty-six and three one-hundredths feet; thence still in the waters of the Hudson River North thirty-eight degrees, thirty-three minutes, forty seconds East nine hundred twenty-eight and nine one-hundredths feet to the point of beginning containing four hundred thirty-three thousand five hundred twenty-four square feet, more or less, of which forty-eight thousand seven hundred fifty-five square feet, more or less, is filled in land and three hundred eighty-four thousand seven hundred sixty-nine square feet, more or less, is unfilled land.

All bearings refer to the Buchanan True Meridian.

All co-ordinates refer to the Cortlandt Grid.

These letters-patent are issued, however, and this grant is made and accepted:

Upon the express condition that if at the end of five years from the date of these presents or at any time thereafter, any part of said land hereby granted is not improved as follows:

1. Erection of a fuel unloading wharf.
2. Deposit of backfill between the upland and the wharf.
3. Construction of ash pits, screen wells, a water condenser and intake and discharge tunnels.
4. Erection of a mooring facility, pile clusters, ice breakers and similar or related facilities.

then these letters-patent and this grant shall become null and void as to the part not so improved; and no right, title or interest in and to the land hereinabove described not so improved shall vest in the said patentee or accrue by virtue of these presents; and The People of the State of New York may thereupon re-enter into and become possessed of the land hereinabove described or any part thereof which has not been or which is not then so improved, without any liability.

There is reserved to the said People the full and free right, liberty and privilege of entering upon and using all and every part of the above described land which has not been improved as aforesaid, as the said People might have done had this grant not been made.

In Testimony Whereof, *We have caused these our Letters to be made Patent, and the Great Seal of our said State to be hereunto affixed.*

Witness, CAROLINE K. SIMON, *Secretary of State of our said State at our City of Albany, the* twenty-seventh *day of* October, *in the year of our Lord one thousand nine hundred* fifty-nine.

Passed the Secretary's Office the 27th day of October, 1959.

Approved as to form:
Louis J. Lefkowitz
Attorney General
By
Assistant

Executive Deputy Secretary of State

OK
N.B.J.

OK
C.11.J.

17

LIBER 5973 PAGE 293

STATE OF NEW YORK, } ss.:
Department of State }

I hereby certify that the foregoing patent is issued pursuant to a resolutions of the Board of Commissioners of the Land Office, adopted May 19, 1959 and October 27, 1959.

Witness my hand and the Official Seal of the Department of State, at the City of Albany this 27th day of October, 1959.

Executive Deputy Secretary of State

W64107

860 B — 39

The People of the State of New York

to

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.

NO. 49212

DEC 14 1959

1:40 P.M.

LETTERS PATENT

STATE OF NEW YORK
Department of State

Recorded in Book of Patents No. 75 at page 181

Executive Deputy Secretary of State

The land affected by the within instrument lies in the Village of Buchanan, Town of Cortlandt, County of Westchester, State of New York

R+R Consolidated Edison Company of New York
9 South First Ave
Mt Vernon NY

The foregoing instrument was endorsed for record as follows: The property affected by this instrument is situate in the TOWN OF CORTLANDT

County of Westchester, N. Y. A true copy of the original LETTERS PATENT

RECORDED DEC. 14, 1959 at 1:40 PM at request of INTER-CO. T. G. & M. CO.

FEE: $ 8.60 No. 49212 EDWARD L. WARREN, County Clerk.

An Atomic Development Plan for the State of New York

A Report to Governor Nelson A. Rockefeller

December 1, 1959

OFFICE OF ATOMIC DEVELOPMENT ALBANY

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VICE CHAIRMAN

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CHAIRMAN

Oliver Townsend, *Director, Office of Atomic Development*

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Office of Atomic Development

Oliver Townsend, *Director*
Jon D. Anderson, *Deputy Director*
David N. Bressler, *Counsel*
Robert D. Vessels, *Nuclear Health Physicist*

Letter of Transmittal

OFFICE OF ATOMIC DEVELOPMENT
ALBANY

December 1, 1959

To the Honorable Nelson A. Rockefeller
Governor of the State of New York

As you know, you asked the New York State Legislature in its 1959 session to establish within the Executive Department of the State Government an office of Atomic Development to advise you and the Legislature on atomic energy matters, to coordinate the atomic energy activities of the state and its political subdivisions, to cooperate with private industry, the federal government and the governments of other states, and to foster and support within the state the development of atomic energy for peaceful purposes.

This law was adopted by the Legislature and the Office of Atomic Development began functioning on April 3, 1959. As prescribed by the law, and to advise the office with regard to its functions, you subsequently appointed a General Advisory Committee, consisting of fifteen of the state's foremost nongovernmental experts in atomic energy, and a Coordinating Council, consisting of the heads of the governmental agencies of the state most directly concerned with atomic energy, plus the Commissioner of Health of the City of New York.

Your first instruction to the Office of Atomic Development was that it prepare and submit to you as its primary order of business a report on the current status of the State of New York in the field of atomic energy together with a recommended program for improving that status with the objective of enhancing the welfare of the people of the state subject to the paramount objective of protecting the public health and safety.

This report is attached. It is submitted to you with the concurrence of both the General Advisory Committee and the Coordinating Council, as evidenced by the attached letter and memorandum. There is also attached a memorandum from one member of the General Advisory Committee submitting an individual view regarding one aspect of the report. We would like you to know that the generous amounts of time, energy and wise counsel contributed by the members of the General Advisory Committee and the Coordinating Council have been of invaluable aid to us in the preparation of this report.

Respectfully submitted,

Oliver Townsend

Oliver Townsend
Director

Table of Contents

An Atomic Development Plan For the State of New York

In approaching the task assigned to us, it has been impossible to be unaware of the fact that very serious questions are now being raised in this country and abroad about the radiation risks inherent in atomic energy activitiy. We have noted with satisfaction, however, that these questions have been correctly raised almost entirely in regard to the testing and possible use of atomic energy as a weapon of war, and not with regard to its use for peaceful purposes. We consider that it would be most unfortunate if radiation safety questions concerning the testing and possible use of atomic weapons were to inhibit the peaceful development of atomic energy.

Actually, our researches have shown, on the basis of the record to date, that the peaceful development of atomic energy can be among the safest of human endeavors. We have been gratified to note, for example, that no person has lost his life, and fewer than 25 persons have received detectable injuries, because of overexposure to radiation incurred in the course of peaceful atomic development in the United States.* We have been equally gratified to note that, although there have been four known nuclear reactor accidents in the world (one in Canada, one in England, one in the United States, and one in Yugoslavia), only one of these has resulted in loss of life or measurable human injury. This was an accident which occurred in a Russian-supplied reactor in a Yugoslavian research institute and which involved the loss of one life and injury to five other persons.

We do not mean to imply by citing these facts that there are no risks associated with peaceful atomic development. Such risks do exist, both gross and insidious, as they do in regard to nearly every aspect of human endeavor. In order to gain access to the energy contained in conventional fuels, for example, humanity has accepted such gross risks as those illustrated by the Centralia, Illinois, and Texas City, Texas, disasters in 1947 and the fatalities from concentrated smog in Donora, Pennsylvania in 1948, and in London, England, in 1952 and 1956. The degree of the persistent, insidious risks that may be involved in the use of conventional fuels is still the subject of much difference of opinion among medical experts as it is also in the case of atomic energy.

In spite of the questions that have been raised in regard to radiation hazards, the record to date demonstrates that these hazards can be controlled, and through careful control by the experts who are responsible for protecting the public health and safety, can be held to a level that is at least as low as the level which applies in other energy industries.

A new force

When aboriginal man discovered fire, he thereby made potentially available perhaps as much as 50 quintillion BTU's‡ of energy. When modern man discovered the nuclear fission reaction he made potentially available probably as much as 600 quintillion BTU's of energy. And when modern man discovered the thermonuclear fusion reaction, he made potentially available more than 3,000,000,000 quintillion BTU's of energy.

In considering the question of radiation safety, the fact cannot be ignored that this incredible new force is now loose in the world. The problem facing humanity today is not whether or not atomic energy can be wished out of existence, because this is impossible; the problem instead is to determine how best to control it and put it to work for constructive rather than destructive purposes. In our opinion, the best way to do this, in addi-

* Three radiation fatalities have occurred in the United States atomic energy program; they all occurred in connection with that part of the program related to weapons.

‡A BTU (British Thermal Unit) is the amount of energy required to raise the temperature of one pound of water one degree according to the Fahrenheit scale. A quintillion is the figure 1 followed by 18 zeros.

tion to any arms control agreements that may be entered into, is through the vigorous development of atomic energy for peaceful purposes.

The energy releasable by nuclear fission and fusion takes on special meaning when it is considered in the light of the fact that the world is undergoing a surge in population (from about one billion in 1850 to nearly three billion today), and at the same time a surge in the will of most of these people to raise their standard of living.

This combination is resulting in very rapidly expanding demands (as great now per month as per century in the Middle Ages) on the earth's store of energy. So much so, in fact, that it is only prudent to assume—no matter how secure today's sources of energy may appear to be—that, within a period measured in decades, persistent shortages among the world's economically accessible reserves of "fire energy" fuels may be expected to be encountered. And well before this happens, the long tentacles of rising costs may be expected to probe, at first sporadically but with ever increasing authority, throughout the older national and regional economies based on relatively limited local supplies—or politically unreliable imported supplies—of coal, oil and natural gas. The touch of this chill reality has already been felt in Great Britain, where the response was the launching of the largest atomic power program in the world.

The peaceful importance of atomic energy, however, lies only in part in its potential for shoring up the world's older and better developed economies against the inevitability of rising costs and consequent declining living standards. It lies also and primarily in the possibility that it may be the most effective—and perhaps the only—means by which the productiveness of the earth can be sufficiently increased and sufficiently widely distributed to eliminate those causes of war, and therefore of atomic war, that are traceable to economic inequities or inadequacies. Certainly, no other result of peaceful atomic development could be more important or more appropriate.

Present Status of New York State

Atomic energy is a very large and enormously complex, still partially secret, subject. It is large and complex, not only in regard to its implications, but also in regard to the industry and technology which comprise it.

This year in this country approximately $3 billion will be spent for purposes that can probably correctly be called "atomic". All but less than $150 million of this sum will be federal government funds, spent primarily to produce weapons, to manufacture atomic engines for naval vessels, and to conduct research and development.

As can be seen from these figures, atomic energy today is a big industry. In its private, purely civilian aspects, however, it is a relatively small industry. Yet above and beyond this present disproportionate situation there lie these compelling facts:

1. This year there will be purchased by the United States Government, primarily for military purposes, approximately 33,000 tons of uranium.

2. If all of the new electric power plants which came on the line last year in the United States (amounting to 14 million kilowatts) had been of the atomic type, the uranium needed to provide their initial loading of nuclear fuel would have amounted to approximately 50,000 tons.

The reason the peaceful atomic industry is not a big industry today is because atomic energy, although it already has been used successfully for such potentially massive civilian purposes as the generation of electricity and the propulsion of seagoing vessels, cannot yet do these things as cheaply as can the energy derived by fire from coal and oil.

Meanwhile, because of the dual usefulness of uranium as a source of both nuclear explosives and fuel, much of what is done today for military reasons has a sufficient peaceful pertinence to make it impossible to examine the atomic industry meaningfully without looking at it from all of its principal aspects.

This we have attempted to do, and, as a result, have concluded that the current status of New York in atomic energy can best be summarized under the following headings, which in their progression follow the production and utilization chain of the atomic industry:

Uranium mining

No uranium is mined in New York State, and no economically recoverable reserves of uranium are known to exist in the state. The leading state is New Mexico.

Uranium milling

There are 23 mills in the United States where gross impurities are removed from uranium ore. None is in New York. All are located west of the Mississippi where uranium is mined. The leading state is New Mexico.

Uranium refining

There are three uranium refineries in the United States where concentrates from mills are processed to produce a virtually pure natural uranium product. None of these is in New York. The active states are Illinois, Missouri, and Ohio.

Uranium enrichment

There are three plants in the United States, all federally owned and each costing about $1 billion, where uranium is "enriched" to produce a product which is to natural uranium as high octane gasoline is to crude oil. None of the plants is in New York. The active states are Kentucky, Ohio and Tennessee.

Plutonium production

There are two plants in the United States, both federally owned, where plutonium, another high efficiency reactive material, can be produced from uranium in large quantities. Neither is in New York. The active states are South Carolina and Washington.

Weapons manufacture

Except as a component supplier of relatively modest rank, New York is not engaged in the manufacture of atomic weapons. The leading state is New Mexico.

Uranium fuel preparation

There are two federally owned and four privately owned plants in the United States where enriched uranium is processed into the chemical forms used by nuclear fuel manufacturers. None is in New York. The leading state is Missouri, with two such plants.

Uranium fuel manufacturing

There are 10 privately owned plants in the United States substantially engaged in the fabrication of enriched uranium into the shapes, sizes and metallurgical forms in which it is useful as a nuclear fuel. One such plant is located in New York. The leading states are Connecticut, Massachusetts and Pennsylvania, with two plants each. (So far as dollar volume is concerned, the principal fuel manufacturing market today is the U. S. Navy. Five plants do all of this business. None is in New York, although four of the five plants are located in states bordering New York.)

Uranium fuel reprocessing

There are four plants in the United States, all federally owned, where used uranium fuel is processed to recover reusable fuel and valuable by-products. None of these plants is in New York. The active states are Idaho, South Carolina, Tennessee and Washington.

Nuclear reactor manufacture

There are 15 companies in the United States which have contracts for the design, development and delivery of nuclear reactors, which are to atomic energy as furnaces are to fire energy. One of these companies maintains its reactor headquarters in New York. The leading state is California, where five companies maintain such headquarters.

Reactor development centers

All manufacturers of nuclear reactors maintain privately owned design and development facilities, as do some engineering firms. The largest volume of reactor development work, however, is performed in six federally owned laboratories. One of these, devoted to the development of reactors for the propulsion of naval vessels, is the Knolls Atomic Power Laboratory at Schenectady, New York. Two land-based prototypes of nuclear reactors for the propulsion of naval vessels have been constructed by the Knolls Laboratory at the Laboratory's test site at West Milton, New York, and one other is under construction there. The country's principal center for the construction of prototypes, however, is the federally owned National Reactor Testing Station in Idaho.

Component and equipment supply

In addition to uranium fuel, nuclear reactors consist of a large and complicated assembly of heavy and light components, auxiliary equipment and instrumentation. Unlike fuel, these are for the most part manufactured in existing rather than new, specially constructed facilities, and the actual site of the work performed is therefore very difficult to trace. The best current source of information in this regard is a survey conducted by the U. S. Bureau of Census for the year 1957, which attempted to ascertain the dollar volume of shipments by locale of the non-weapons atomic energy industry. This survey was able to trace about $100 million worth of such business, of which about 70% involved reactor components, equipment and instrumentation, about 15% involved radiation detection and monitoring instruments, and about 15% involved equipment for the processing and use of radioactive materials. According to our evaluation of the results of this survey, New York ranks seventh among states as a supplier of nuclear components, equipment and instrumentation, following Pennsylvania, Ohio, Illinois, Massachusetts, California and Tennessee, in that order.

Atomic power plants

The largest potential use of the energy produced by nuclear reactors, on the basis of current technology, is the generation of electricity. At present there is one full-scale atomic power plant in operation in the United States. It is in Pennsylvania. Four more are in advanced stages of construction, one each in Illinois, Massachusetts, Michigan and New York. Work is also underway or planned on six more such full-scale plants, one each in California, Florida, Michigan (its second), Nebraska, Pennsylvania (its second), and South Dakota. The New York plant, now being constructed by the Consolidated Edison Company at Indian Point on the Hudson River, will produce 151,000 kilowatts by means of atomic energy and 104,000 kilowatts by means of an oil-fired superheater. This will make it the nation's second largest power plant from the purely atomic energy standpoint. The largest is under construction in Illinois and will produce 180,000 kilowatts from atomic energy. None of these plants will generate electricity as cheaply as can plants fueled with coal, oil or natural gas.

Small power plants

In addition to the 11 full-scale plants discussed above, there are now operating, under construction or planned 18 small (less than 25,000 kw) atomic power plants or prototypes. None is in New York. The leading state is Idaho, with four.

Nuclear ship construction

At present in the United States there have been completed, are under construction or authorized, 37 nuclear powered submarines, plus a merchant ship, a destroyer, a cruiser and an aircraft carrier. None of this work has been, is being, or is planned to be done in New York. The active states are California, Connecticut, Maine, Massachusetts, Mississippi, New Jersey and Virginia.

Nuclear test reactors

These are high-powered reactors which do not generate electricity or propel ships, but which are used to develop and test the fuel elements that will be used in future power and propulsion reactors. At present there are four such test reactors in the United States and two are under construction. None is in New York. The leading state is Idaho, with two such reactors.

Research reactor utilization

These are relatively small reactors used by universities, industrial concerns, government installations and scientific institutions for research, training and medical purposes. At present in this country there are 87 such devices in operation, under construction or planned. Eight are in New York, four of which are in existence and four of which are under construction or planned. The leading state is California, with 14.

Radioactive by-product utilization

Radioisotopes, the radioactive by-products of nuclear reactor operation, are produced for commercial sale almost entirely by the federal government in a reactor located in Tennessee. About $2.5 million worth of these materials is sold annually to users in the fields of medicine, agriculture, industry and research. New York, with a total of 536 users, stands first among states in the overall utilization of these materials. In the important specific category of medical utilization, New York also stands first with 283 users. In the important category of industrial utilization, New York with 157 stands second to California with 188 users.

Non-reactor research and development

New York occupies a leading position in this important field, which involves primarily physical research, biological and medical research, and research having to do with the technology of utilizing radioisotopes. This work is done primarily in six major federally owned laboratories, two located in New York, two in California, and one each in Illinois and Tennessee. The two New York laboratories are the Brookhaven National Laboratory on Long Island, which is devoted primarily to basic research, including fundamental medical research, and the atomic energy project at the University of Rochester, which is devoted primarily to medical research. New York furthermore stands first in the volume of non-reactor research work carried on outside of government owned laboratories but under contract to the Atomic Energy Commission. Under these contracts, physical research in New York, outside of the field of thermonuclear fusion, amounts to about $3.5 million in the current fiscal year and involves 16 institutions; medical and biological research amounts to $1.6 million and involves 23 institutions, and isotope research amounts to over $540,000 and involves 7 institutions. New York also stands first among states as a recipient of grants from the Atomic Energy Commission for equipment utilized by educational institutions for atomic energy training purposes. To date grants totalling $1.1 million have been made to New York institutions.

Thermonuclear fusion research

In the special category of thermonuclear fusion research, which promises ultimately a virtually limitless new source of energy, the federal government this year will spend over $35 million. All but about $1.4 million of these funds will be spent in four major research centers located in California, New Jersey, New Mexico and Tennessee. About one-third of the remaining funds will be spent in New York, primarily at New York University and at the research laboratory of a private company. The largest privately supported research program in the thermonuclear fusion field is being carried on in California.

Education and training

New York State has just under 10% of the nation's total population and, in the 1957-58 school year, granted approximately 10% of all of the nation's undergraduate and graduate degrees in the physical sciences, engineering and mathematics, the fields of education most pertinent to the atomic industry. The number of degrees granted in these fields by New York State institutions was 6,991, a figure which placed the state—appropriately, considering the state's share of the total national population—first in the nation. At the undergraduate level, New York educational institutions granted approximately 10.5% of all degrees in the physical sciences, approximately 9% of all degrees in mathematics and approximately 9% of all degrees in engineering. At the graduate level, New York institutions granted approximately 13% of all degrees in the physical sciences, approximately 18% of all degrees in mathematics and approximately 12% of all degrees in engineering. New York state with 41 out of a total of 259, also stands first among states as a recipient of Atomic Energy Commission fellowships to outstanding graduate students in the fields of nuclear science and engineering and health physics.

State government investment

The State of Georgia has allocated $2.5 million for the construction of a high powered research and training reactor at the Georgia School of Technology. The State of Pennsylvania has allocated or expended over $2 million for nuclear research and training facilities at Pennsylvania State University. The State of California has allocated $1.5 million for use in cooperation with the federal government in the construction of a nuclear reactor to produce energy for the conversion of sea water into fresh water, and approximately $300,000 toward the construction of a nuclear training center at the University of California at Los Angeles. The State of New York is contributing $1 million toward the establishment of a nuclear research center, including a nuclear reactor, at the University of Buffalo. Many other states have contributed lesser amounts to atomic energy research and development.

State regulation

New York is one of seven states that have adopted comprehensive codes to protect the workers and general public of the state against the hazards of atomic energy. The others are Connecticut, Massachusetts, Michigan, Minnesota, Pennsylvania and Texas. One other state, California, has a comprehensive code to protect employees but it does not apply to the general public. In New York, the principal regulatory agencies are the State Departments of Health and Labor and the New York City Department of Health.* To assist in the coordination of the activities of these and other governmental agencies, all atomic energy rules, regulations and ordinances within the state must, under the new state atomic energy law, be submitted to the director of the Office of Atomic Development 90 days before they take effect, unless this waiting period is waived by either the Governor or the director. The state atomic energy law also created a Coordinating Council, chaired by the director of the Office of Atomic Development, of which the heads of the principal regulatory agencies within the state are members.

Workmen's compensation

The national Council of State Governments recently recommended ten standards for use in determining the inadequacies of the radiation injury protection afforded by state workmen's compensation laws. According to the Council of State Governments, New York's law expressly meets seven of these ten standards. The laws of only three other states (California, Hawaii and North Dakota, each meeting eight) expressly meet more. The extent to which any real inadequacies may exist in the New York law in regard to radiation injury protection and the measures that would be necessary to eliminate them are now being examined by the Office of Atomic Development and other appropriate state agencies.

State development organizations

The New York state atomic energy law adopted in 1959 goes beyond the law of any other state in its express grant of authority to an administrative agency to assist the Governor and the Legislature in developing, promoting and implementing a state policy for atomic energy research, development, education and regulation; to coordinate the regulatory and developmental activities of agencies of the state and its political subdivisions, and to foster and support research and education through contracts or other means of assistance. This New York State agency is the Office of Atomic Development, which has a full-time director responsible to the Governor and a staff of three professional people. One other state, California, has a full-time atomic energy coordinator responsible to the Governor and appointed pursuant to state statute. He was appointed in September 1959. Another state, Washington, has adopted legislation providing for a full-time coordinator, but the official has not yet been appointed. Fourteen other states have adopted legislation providing for a part-time governmental commission, committee or official responsible to the Governor, to coordinate the regulation and development of atomic energy within the state. Some of these part-time agencies employ one or more staff members on a full-time basis. In 23 additional states the Governor or some administrative agency or official has appointed, sometimes under specially granted statutory authority and sometimes by independent administrative action, a committee or commission with advisory or study functions but without coordinating responsibility. In addition to New York, California and Washington, the states which at present have laws establishing some type of agency, responsible to the Governor, to coordinate atomic energy activities within the state are: Alaska, Arkansas, Connecticut, Florida, Kansas, Kentucky, Maine, Massachusetts, Nebraska, New Hampshire, North Carolina, Ohio, Rhode Island and Tennessee.

* Each of these departments now requires the registration, and has commenced inspection, of radiation sources within its jurisdiction.

Approach to the Problem

It is gratifying to note that New York leads all states in the utilization of radioactive materials in medical research, diagnosis and treatment, a field of clear and vital interest to the people of the state and to people everywhere.

It is equally gratifying to note that New York is one of seven states to have adopted comprehensive regulatory codes to protect the people of the state against the radiation hazards of atomic energy, and one of 17 states to have adopted legislation providing for the coordination of state atomic energy activities as well as the stimulation of atomic development.

New York also ranks high among states in the important fields of basic nuclear research, applied non-reactor research, the development of nuclear engines for ship propulsion, the construction of atomic power plants, training and education, and the utilization of radioactive materials in industry.

A review of the present status of New York cannot help but reveal, however, that the state plays no direct role in the now well established multi-billion dollar per year industry, mainly federally owned, involving the production of atomic explosives and their fabrication into weapons.

The state furthermore plays no direct role either in the fabrication of fuel elements for the propulsion of ships, which is now the only production line atomic energy activity outside of the weapons field, or in the construction of nuclear propelled ships. This is in spite of New York's important position as a research and development center for nuclear propulsion units for naval vessels and its traditional pre-eminent position as a maritime state.

Probably the most disturbing single fact, however, is that the expanding non-weapons portion of the atomic industry, where the bulk of private investment in research and manufacturing facilities is being concentrated in anticipation of a large future market, has to date not been seeking New York as a principal site.

Basic premises

We have approached the problem which appears to be posed by these facts on the basis of the following premises:

1. Reasonable competition among states in attracting industry is a healthy activity and an effective stimulant to the nation's economic development. The United States of America, however, is an economic unit, and that which benefits any part of it must ultimately benefit every part of it. This is particularly true in the case of New York, which serves as the financial and business management capital of the nation. In view of these factors, it is our opinion that competition among states is most effectively carried on, not with the objective of proselyting activities which are already located elsewhere, or which with more economic logic might be located elsewhere, but with the objective of finding the best possible placement of new or expanding industries.

2. Nearly all atomic development activity in the United States to date has been carried on either by the federal government or by private industry. State governments have been almost completely inactive and therefore represent a latent "third force" whose proper role has not yet been determined. Conceivably state governments could, if they desired, join the federal government and private industry as substantial owners and operators of atomic energy facilities. We believe, however, that this would be neither practical nor wise, except in those very few instances where the public health and safety or education was importantly involved or where every other means of accomplishing a clearly desirable end had been exhausted. Our premise, instead, is that the proper role of the states in atomic energy is that of a discriminating catalytic agent which helps to bring into being within the state important new activities that reasonably should be placed there and that otherwise might not exist there. It is part of this premise that the state's participation must be of sufficient degree to be meaningful in accomplishing the desired purpose.

3. The atomic industry until now, for safety reasons having to do with the prudence that correctly accompanied a lack of experience, has primarily sought open spaces, away from centers of population. This trend has unquestionably worked to the disadvantage of the industry of the State of New York. And yet, if there is to be an atomic age that has real meaning, atomic energy must be brought back to where the people are. It is our opinion that the atomic age is inevitable, and that the first highly populated, highly industrialized area to realize and exploit this inevitability will benefit the most from it, in terms of industry, employment and overall well being.

4. Atomic development will progress most rapidly, in our view, if the regulatory control of it can be made as nearly normal as possible, so that atomic matters are not always both literally and figuratively a "federal case." This involves a gradually but steadily increasing role for states and localities vis-a-vis the federal government in the regulation of atomic activities, not only in the interest of normalization but also in the interest of

bringing additional competent judgments to bear on the important health and safety aspects of atomic development. It is important, however, that the assumption of this authority by states and localities should at no time exceed their capability to administer it fairly and effectively. It is equally important that the radiation limits specified in codes and standards be as uniform as possible as between state and local governments and the federal government, so that development is not inhibited by confusion or by overlapping or conflicting regulations.

With these premises in mind, it is our conclusion that the best approach for New York to take in regard to atomic development is to concentrate on the non-weapons part of the atomic industry, which has the largest potential for growth and which is still largely uncommitted to any particular geographical location. Specifically, we believe that the state government should attempt to identify and through appropriate catalytic action help bring into being within the state those projects which can find in New York and economically sensible home, and which, as time passes, are likely to serve as magnets for further atomic and other industrial development. In this way, both the cause of the state and the overall cause of atomic progress can be most effectively served.

Beyond this, we believe that the state should do all that it reasonably can to create a regulatory, scientific and educational environment which is conducive to atomic development.

Activities to date

In keeping with this approach, the activities to date of the Office of Atomic Development, aside from the organizational activities associated with its establishment, have been primarily channeled along five principal lines:

1. A series of investigations have been conducted with representatives of private industry, other state agencies and the Atomic Energy Commission with the objective of identifying projects which with economic sense might be considered for location in New York. The results of these investigations are reflected in the recommendations of this report.

2. A contract has been negotiated between the state and the University of Buffalo under which $1 million of state funds appropriated by the Legislature in its 1959 session will be made available on a matching basis for the establishment in Buffalo of a $2 million Western New York Nuclear Research Center. The Center will serve state and federal agencies, education and research institutions and private industry. Both private industry and the federal government, along with the state, are contributing to the cost of the Center, which will be operated by a non-profit educational corporation to be formed for this purpose. Although the state will have a voice in the management of the Center, it has agreed to withdraw at any time that its contribution, less depreciation, is repaid to it. Construction of the Center has started and completion is scheduled for 1961.

3. The Office of Atomic Development, on behalf of the New York State government, testified for and supported the adoption by the Congress during its 1959 session of an Atomic Energy Commission sponsored bill providing for the transfer, under individually negotiated agreements, of certain regulatory authority from the Commission to qualified states. This bill was enacted in September. On September 16 negotiations were opened between the state and the Commission with the objective of entering into an agreement at the earliest practicable date. As a first step, the state has proposed that state regulatory and inspection personnel be assigned for indoctrination purposes to the Commission's Washington headquarters and New York Operations Office.

4. In conformance with the requirement of the New York State atomic energy law that all atomic energy rules, regulations and ordinances within the state be submitted to the director of the Office of Atomic Development 90 days before they become effective, the New York City Department of Health in August, 1959, submitted the radiological hazards provisions of a new City Health Code to the director, together with a request that the 90 day waiting period be waived so that those provisions could take effect on October 1. In response to this request, the director waived the waiting period with regard to the radiological hazards provisions of the Code, except for certain notification and approval requirements which the federal government questioned. A meeting between city, state and federal officials to discuss the effect of these requirements was held in November, in advance of the expiration of the waiting period, and an agreement was reached that a resolution of the problem could, should and would be negotiated.

5. The Office of Atomic Development has proposed to the New York Joint Legislative Committee on Interstate Cooperation that it consider the desirability of interstate cooperation to assure that all persons harmed by a nuclear accident be compensated on the same terms. The Committee has agreed to consider this matter.

So far as the state's future atomic energy activities are concerned, the primary objectives, in both the developmental and regulatory fields, are discussed under the headings which follow. In regard to development, the program envisioned focuses primarily on the establishment of a few "keystone" facilities which are deemed to be vital to the growth of a substantial atomic industry within the state and which give excellent promise of attracting other atomic industrial enterprises as the overall production and utilization of atomic energy continues to expand.

Discussion of Atomic Power

It is generally accepted that the one transcending event that would do more than anything else to transform peaceful atomic development into a large, important new American industry is the achievement of economically competitive atomic power.

In the national effort to achieve this goal, the New York State utility industry has to date made, or committed itself to make, the largest investment of any state's utility industry. This investment, including commitments through 1965, amounts to approximately $110 million, the bulk of which is being paid by the Consolidated Edison Company for the $100 million atomic power plant the company now has under construction at Indian Point, near Peekskill.

This project, when completed in early 1961, will be the nation's second largest atomic power plant. It also has the expensive objective of substantially advancing the technology of atomic power by utilizing, along with uranium, a new hitherto largely unused and little understood material called thorium as a source of nuclear fuel.

Of the remaining $10 million invested by New York State utilities, approximately $9 million represents contributions to projects located in other states, and approximately $1 million represents the estimated cost of current and projected design and feasibility studies conducted within the state.

There is no doubt that the New York State utility industry will benefit from its forward-looking contributions to atomic power projects in other states. The fact remains, however, that at present the Indian Point plant is the only atomic power plant in existence, under construction or planned within the State of New York itself. The fact also remains that, at this important early stage of development, each atomic power project that is undertaken serves as both a beacon and a magnet to the scientific, educational and industrial worlds which make its existence possible.

Need for a plan

With these considerations in mind, it is our opinion that it would be in the best interests of the people of the state if there were to exist a definite plan for the construction within the state of at least one atomic power plant in addition to the one now under construction by the Consolidated Edison Company. Such a plan would provide continuity to atomic power development within the state beyond the 1961 completion date of the Indian Point plant, would tend to keep the state in the forefront of such development, and would, most importantly, serve as an effective stimulant to the atomic industry generally in the New York area.

In view of the still relatively early stage of atomic development, however, it is our opinion that any new atomic power project in New York State should be well and carefully conceived in regard to timing, costs and selection of plant type.

In this connection, the United States Atomic Energy Commission is currently preparing a new national atomic power development program, generally referred to as the "Ten Year Program" which will include recommendations as to specific full scale atomic power plants and prototypes deemed worthy of further development and construction. It is expected that this program will be proposed to the United States Congress in its 1960 session for the purpose of obtaining the Congressional authorizations required to place the program into effect. It may be reasonably anticipated, therefore, that by the close of the next session of Congress there will be in the United States a specific national program to achieve economically competitive atomic power within ten years.

It is our opinion that the New York State utility industry should carefully review this anticipated new national program with the objective of determining whether at least one of the projects included in it might productively be constructed in the State of New York, and, if so, proceed to develop and construct the full scale plant or prototype on the basis of the schedule provided in the program.

It is of course possible that no new national program will be agreed upon in the next session of Congress. It is also possible that, although a new national program is agreed upon, no project included in it would meet the specific requirements and conditions that prevail in New York. In either of these events, we believe that it would be appropriate and desirable for the New York State utility industry to develop an independent program, designed to meet requirements and conditions in New York, which would proceed toward the goal of economically competitive power within the state at the earliest practicable date.

We do not believe, considering the large investment already made by New York State utilities, that it would be either in the interest of the utility builders of the plant or the people of the state if the plant envisioned here were to be a full scale unit of a type that would be likely to constitute an economic liability over all or most of its useful life. We believe instead that the project, exclusive of research and development costs, should be preferably a full scale plant which will give reasonable promise of being competitive on an averaged annual basis over its useful life with conventionally fueled power plants in the same geographical area, or a prototype which would lead directly toward the construction of an economically competitive full scale atomic power plant of the same type. Such an approach not only seems to be prudent; it also seems to be possible. It furthermore has the additional overridingly important advantage of keeping the state pointed directly at the single most rewarding goal—economic competitiveness—in the atomic power field today.

If such a project as that envisioned here, whether developed independently or as a part of the national program, were undertaken within the state, it may be expected that there would be associated with it certain research and development expenses ranging into the millions of dollars. The government of the State of New York, in its role as a catalytic agent, might appropriately share these research and development expenses with the understanding that the state's contribution would be at least matched by one or more utilities, some of which might be located outside of the state; that the research and development program would be undertaken for the purpose of leading directly and specifically toward the construction within the state of either a full scale atomic power plant or prototype; and that the state's contribution would not be payable until completion of the plant. It would be further understood that the state's contribution would be payable only in connection with a project that either was a part of the anticipated new national program, or was deemed by the state and the sponsoring utility or utilities to be more suitable for New York State than any project in the national program, or was deemed by the state and the sponsoring utility or utilities to be suitable for New York State in the absence of a national program. The power plant, whether full scale or prototype, would be of a type selected by its sponsoring utility or utilities. It would be further understood that the plant when completed would be available to the higher educational institutions in the state to the maximum extent possible for training purposes, and that all information produced by research and development work carried on with state funds would be readily available to the people, including the

NUCLEAR POWER EXPENDITURES: N. Y. UTILITIES

	Expenditures to 12/31/59	*1960*	*Presently Committed Future Expenditures* *1961*	*1962*	*1963*	*1964*	*1965*	*Total Expenditures*
NIAGARA MOHAWK								
Mich. Research Project...	$ 1,145,600	$ 300,000	$ 300,000	$ —	$ —	$ —	$ —	$ 1,745,600
Pa. Plant Project........	1,500	56,000	346,500	282,500	80,500	—	—	767,000
Company Studies........	25,000	100,000	150,000	200,000	200,000	200,000	200,000	1,075,000
Total.............	$ 1,172,100	$ 456,000	$ 796,500	$ 482,500	$280,500	$200,000	$200,000	$ 3,587,600
CONSOLIDATED EDISON								
N. Y. Plant Project......	$53,350,000	$31,100,000	$15,550,000	$ —	$ —	$ —	$ —	$100,000,000
Mich. Research Project...	766,000	100,000	100,000	—	—	—	—	966,000
Total.............	$54,116,000	$31,200,000	$15,650,000	$ —	$ —	$ —	$ —	$100,966,000
ROCHESTER GAS & ELEC.								
Mich. Research Project...	$ 616,800	$ —	$ —	$ —	$ —	$ —	$ —	$ 616,800
Mich. Plant Project......	360,500	90,000	90,000	90,000	—	—	—	630,500
Mich. Plant Project......	—	—	—	—	—	40,000	40,000	270,000*
Pa. Plant Project........	1,200	25,600	159,800	130,300	37,100	—	—	354,000
Total.............	$ 978,500	$ 115,600	$ 249,800	$ 220,300	$ 37,100	$ 40,000	$ 40,000	$ 1,871,300
NEW YORK STATE ELEC. AND GAS								
Mich. Research Project...	$ 427,500	$ 110,000	$ 110,000	$ —	$ —	$ —	$ —	$ 647,500
Pa. Plant Project........	800	30,200	189,200	153,700	43,800	—	—	417,700
Total.............	$ 428,300	$ 140,200	$ 299,200	$ 153,700	$ 43,800	$ —	$ —	$ 1,065,200
CENTRAL HUDSON								
Mich. Research Project...	$ 143,000	$ —	$ —	$ —	$ —	$ —	$ —	$ 143,000
Mich. Plant Project......	160,000	40,000	40,000	40,000	—	—	—	280,000
Mich. Plant Project......	—	—	—	—	—	18,000	18,000	120,000*
Total.............	$ 303,000	$ 40,000	$ 40,000	$ 40,000	$ —	$ 18,000	$ 18,000	$ 543,000
LONG ISLAND LIGHTING								
Mich. Research Project...	$ 435,000	$ 90,000	$ —	$ —	$ —	$ —	$ —	$ 525,000
Mich. Plant Project......	496,000	124,000	124,000	124,000	—	—	—	868,000
Mich. Plant Project......	—	—	—	—	124,000	124,000	124,000	372,000*
Company Studies........	91,500	15,000	15,000	15,000	15,000	15,000	15,000	181,500
Total.............	$ 1,022,500	$ 229,000	$ 139,000	$ 139,000	$139,000	$139,000	$139,000	$ 1,946,500
Grand Total........	$58,020,400	$32,180,800	$17,174,500	$1,035,500	$500,400	$397,000	$397,000	$109,979,600

* Bank notes payable 1964 thru 1970.

industries and educational institutions, in the state.

It is not the purpose of this report to try to determine which utility or utilities, whether privately or publicly owned, might most desirably undertake the type of project described here. Our purpose is only to attempt to bring the project into being, for the benefit of the people of the state, by proposing that the state participate in the research and development phases to a meaningful degree. In this connection, the New York State Power Authority, under present law limiting its power generation activities to hydro development, would be precluded from participating in such a project. The Authority has informed the Office of Atomic Development that it would not be feasible for the Authority to finance an atomic power plant in the absence of more federal aid than is now available, but nevertheless believes state law should be changed to permit it to build such plants in the future if it so desires. We consider that the question of whether or not the Authority should be authorized to construct atomic power plants is secondary to the public policy question of whether or not the Authority should be authorized to construct non-hydro electric power generation facilities of any type, and we consequently believe that it would be inappropriate for us to make any recommendation regarding it.

Also in regard to atomic power, the Atomic Energy Commission has recently invited rural electric cooperatives and municipally owned power systems to express their interest in an atomic power plant of 16,500 electrical kilowatts whose nuclear portions would be built and owned by the Commission. The plant would not be economically competitive, but the Commission would sell the steam produced by the plant to the power system at a subsidized competitive price. Furthermore, any research and development costs would be borne by the Commission. Two New York municipalities, Jamestown and Wellsville, have expressed tentative interest in the Commission's invitation.

Although there would seem to be little that the state government might bring to such an enterprise beyond what the federal government already provides, it is our opinion that the state should stand ready to cooperate, to the extent that the state can be useful, with any municipality wishing to pursue this project. The Office of Atomic Development is in contact with the appropriate officials in Jamestown and Wellsville with this end in view.

Discussion of Nuclear Fuel

The largest industries in atomic energy today, except for the weapons field, are the design and manufacture of nuclear reactors and the fabrication of their uranium fuel elements. These are already substantial industries, and they have the promise of becoming truly large industries later on. Both are by now fairly well established, and they are, furthermore, established primarily outside of the State of New York.

There seems to be no clear economic reason why New York should not have become more active than it is in regard to fuel fabrication and nuclear reactor manufacture. This is particularly true with respect to the fabrication of fuel for use in nuclear ships, an activity which is centered primarily in the northeast, but not at all in New York.

As the nuclear fuel market grows, as it must with the conversion of the Navy to atomic propulsion and the achievement of economically competitive atomic power, there would seem to be every reason to expect that the participation of New York industries in it can, and logically should, increase. There appears to be very little that the state government can do to assist this, however, except by offering its good offices in the establishment of new plants and the acquisition of new business, by the creation of as favorable a business climate as possible, and by the accumulation and dissemination of useful information. These things, we believe, the state government should do, as vigorously and as effectively as it can. We also believe it would help to foster further growth if the state were to adopt as a definite objective the enlargement of its present role in fuel fabrication as the industry in general expands, including particularly the fabrication of fuel for ship propulsion.

Reprocessing—an opportunity

Because it is an already rather well established, highly competitive industry, the opportunities for increasing New York's participation in the nuclear fuel fabrication business are limited. This is not at all true, however, of the potentially very large companion industry involving the reprocessing of nuclear fuels after use. At present this function is carried on entirely by the federal government, primarily for its own purposes, in its own facilities. Whereas the fuel fabrication industry is now mainly privately owned, except for prototype development and manufacture, there is no private activity whatsoever in regard to fuel reprocessing. This is because, at this early stage of atomic development, not enough nuclear reactors have been operated long enough to produce a substantial volume of fuel reprocessing business. It is inevitable, however, that as activity in regard to the in-put of fuel into reactors increases, as it is doing today, activity on the out-put end will increase proportionately several years later, as the in-put of fuel comes due for reprocessing and recovery.

There lies within this inevitability an opportunity for the industry of the State of New York. Whether this is a natural or forced opportunity, however, depends upon the location of the market and the resources which the state can bring to the problem of serving the market.

So far as the market is concerned, it exists in three principal places. It exists in the servicing of fuel from atomic power and research reactors in this country; it exists in the servicing of fuel from nuclear ships, whether Naval or civilian, operating under the flag of this or some other friendly country, and it exists in the servicing of fuel from abroad.

New York's accessibility to the sea, representing as it does both the maritime market (the nuclear Navy as a minimum) plus the market potentially available abroad (an undetermined but conceivably substantial quantity), is well known and needs no elaboration.

With regard to the potentially very large market represented by domestic atomic power reactors, it is worth noting that the State of New York exists in a power supply region which at present has both the largest installed electrical generating capacity and the largest annual volume of new construction of any of the eight power regions into which the continental contiguous United States is divided by the Federal Power Commission. Furthermore, the costs of producing electricity from conventional fuels in most of New York and New England range from medium to high as compared to the rest of the country, with the result that the demand for atomic power is likely to be greater initially in this area than in most other areas.

So far as the resources which New York can bring to the problem of fuel reprocessing and recovery are concerned, the state's high rank in the fields of industry generally, transportation and skilled labor are all pertinent. Particularly in the field of chemistry, which is the industry most pertinent to fuel reprocessing, New York ranks second (after New Jersey) in the nation.

The most important resource that any state can bring to fuel reprocessing, however, is a clearly safe place to store radioactive by-products and wastes. This is true of atomic energy in general, but is particularly true of fuel reprocessing, which produces the largest concentration of waste materials of any aspect of the atomic industry.

Discussion of Waste Storage

A report issued in August, 1959, by the Joint Congressional Committee on Atomic Energy, based on hearings held by the Committee in January, February and July of this year, said the following:

"For low level wastes, the program has been to dispose of them to nature (air, ground, water) with or without treatment, as required, under careful control and management. The problem may be expected to increase as the nuclear power industry increases in size or if acceptable limits of radioactivity in the environment are further reduced."

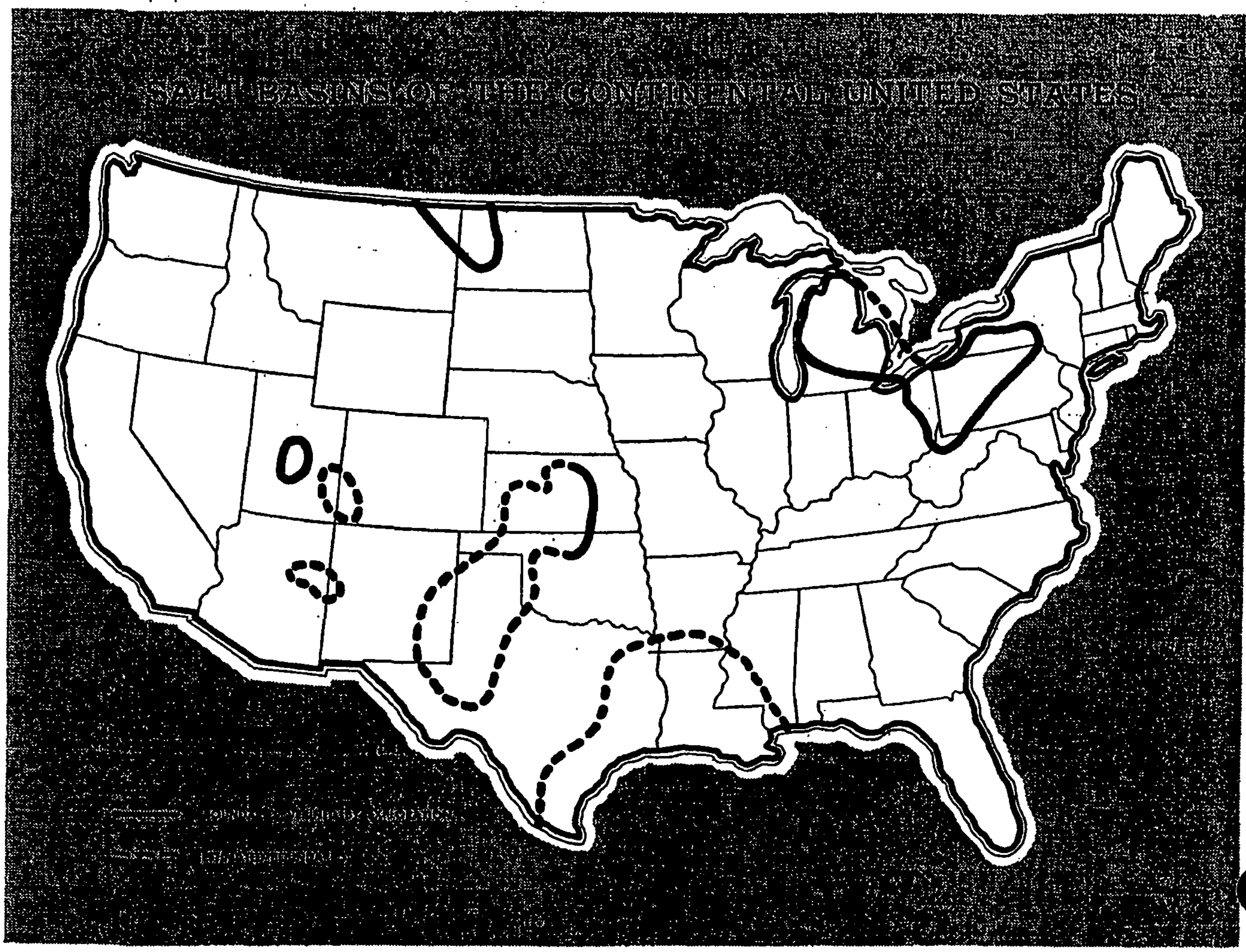
"High level wastes . . . are stored in underground tanks. . . . While the cost of tank storage probably could be borne by a nuclear power economy, there is considerable doubt that tank storage represents disposal in the ultimate sense. This is particularly true since our experience is limited to 15 years and it is difficult to extrapolate this experience to give a realistic tank lifetime. Consequently there is considerable interest in developing other methods of ultimate disposal."

On the very important question of what approach might be better than current practices, the Joint Congressional Committee's report said:

"Although a number of possibilities were described during the hearings, the conversion to solids and the storage of these in salt formations seemed to be the most favored at this time. The least favored was the disposal of high-level wastes in the sea."

As to why salt was favored, the report pointed out that salt occurs at great depths below the fresh water table, that "salt has considerable compressive strength," that "excavations in salt are practically always dry," and that, "because of its plasticity, any fractures in salt close rapidly."

Salt, in the form of beds or domes, underlies more than 400,000 square miles of the continental United States. It exists primarily in three enormous deposits, one in the Great Lakes area, one in the Gulf Coast area, and one in the area of Kansas and the Texas Panhandle. The most easterly extension of salt in the United States, pointing meaningfully at both the sea and the relatively high cost electric power area of the northeast, occurs in New York State. This salt underlies over 10,000 square miles of the southern half of the western part of the state at depths ranging from about 800 to 6,000 feet, below the surface of the ground, and extends east beyond the Finger Lakes.



This huge, deep but accessible bed of salt represents a potentially very valuable resource of the state so far as the development of an atomic industry is concerned.

Considering this potential, it is our opinion that the state government should, by contract with an engineering firm, survey the state with the objective of determining one or more places at which a by-product and waste storage site might safely be established. This would serve at least two desirable purposes. It would serve to attract the fuel reprocessing industry (which is as yet uncommitted to any geographical location outside of federal reservations) to New York State, and it would also work toward the establishment of a single site where wastes from many sources within the state might be concentrated and disposed of safely under easily controllable conditions.

We believe it to be appropriate that the state government conduct this survey, not only because of its effect on attracting an important new private industry to the state, and not only because of the public health and safety benefits that would accrue to the people of the state through the establishment of a closely controlled site for radioactive waste storage, but also because the storage site itself would probably always have to be owned by either the federal or state government in the interest of the long-term health and safety of the public. The site envisioned here, therefore, is more of a governmental than it is a private concern. And, if the state wishes to use the site for such of its own purposes as the attraction of industry and the concentration of wastes generated within its own borders, it is more of a concern of the state than it is of the federal government.

In our opinion, a survey looking toward the establishment of such a site in New York by either the federal or state government should be undertaken as soon as possible. The urgency exists because the Atomic Energy Commission is presently undertaking to augment its own fuel reprocessing and waste disposal facilities in Idaho, South Carolina, Tennessee and Washington State to handle the increased business expected to be forthcoming soon from the Navy and privately owned atomic power plants. Once this expansion of AEC capacity takes place, private entry into the fuel reprocessing business may be postponed for some time, conceivably even permanently. Without private activity, and without a site for the safe storage of waste products, New York has very little hope of being the home of a fuel reprocessing industry.

At present the by-products of fuel reprocessing plants are thought of as "wastes" because it is not yet known how to utilize them economically for such foreseeable purposes as the sterilization of foods, the production of battery-type power and the catalyzation of chemical reactions. They do, nevertheless, represent a considerable reservoir of energy, and it is conceivable that this energy can be put to sufficiently productive use to add a value to "waste" products beyond the cost of separating them. In this connection, the U. S. Atomic Energy Commission plans in the near future to establish at the Brookhaven National Laboratory in New York a $1.6 million laboratory to attempt to find economically rewarding ways of using highly radioactive materials. The establishment of this laboratory at Brookhaven creates yet another reason why New York would make an excellent site for the introduction of a fuel recovery and reprocessing industry. It is also pertinent to note, in connection with so-called "waste" disposal, that the Brookhaven Laboratory is one of the Atomic Energy Commission's principal centers for the development of means by which the residue from fuel reprocessing can be solidified for safe storage and possible future reclamation.

Discussion of Test Reactors

High powered nuclear test reactors are vital to the development of the fuel elements that will feed the atomic power plants and ship propulsion units of the future. So important are they that three leading private manufacturers of fuel and reactor components have built or are building such reactors of their own, one in California, one in western Pennsylvania, and one in Virginia.

In addition to these, two even higher powered test reactors are owned by the federal government. Both are located at the Atomic Energy Commission's National Reactor Testing Station in Idaho, where they serve primarily the government's ship, aircraft and power reactor programs and to a lesser extent private industry. A third government owned test reactor is under construction in Ohio by the National Aeronautical and Space Administration. No such reactor is located in the northeast.

The Atomic Energy Commission recently announced that it believes its own requirements will increase sufficiently within the next few years to justify the construction of yet another test reactor, which would be of the highest known power level in the world. The Commission is currently conducting a survey to determine how much use would be made of such a reactor by private industry. Upon completion of this survey, the Commission plans to invite private industrial interest in building and owning the reactor under certain specified conditions having to do with the volume of business the reactor might expect to receive from the Commission, and the charges that the Commission would be expected to pay.

If no private company or group of companies expresses interest in the project under the conditions prescribed by the Commission, then the Commission may be expected to construct and own the reactor itself. If this is done, it may be expected that the Commission will proceed to construct the reactor at its reservation in Idaho, where both a site and supporting facilities are readily available.

A valid project

It is our opinion that this reactor should be built in the northeast and not in Idaho, and that it therefore constitutes a valid project for New York State, for the following reasons:

1. The Idaho test reservation of the Atomic Energy Commission was established in 1949 when nuclear reactors were not as fully understood as they are now, and when, because of this lack of knowledge, there appeared to be good reasons for placing test reactor facilities as far away from concentrations of population, and therefore of industry, as possible. This has, however, worked to the detriment of industry in other places, particularly in the northeast, where no such test facilities now exist. It is a major premise of this report that, if atomic development is to continue on the most efficient possible basis, a fair share of such key facilities as test reactors must be located where they will be of maximum benefit to existing industrial centers.

2. Two of the largest users of the new reactor will be the federal government's naval ship propulsion laboratories, one of which is in New York and the other in Pennsylvania. Two other large users will almost undoubtedly be the federal government's nuclear aircraft propulsion laboratories, one of which is in Connecticut and the other in Ohio. The largest private users will be the fuel fabrication companies, of which there is a substantial concentration—and a substantial potential for expansion—in the northeast.

We believe that it should be an objective of the State of New York to bring this proposed new high powered test reactor to the state, not only because of the value of the facility itself, which is expected to be between $20 and $25 million, but also because of the stimulating effect that the presence of this project would have on the atomic industry generally in this area.

There are three ways that the project can be constructed in the State of New York: by private industry, by the federal government, or by the state itself. In conformance with our premise that the state's proper role is that of a catalytic agent, we do not believe that the third alternative should be considered until the other two alternatives have been fully explored. Because of the importance of this project, we do not believe, however, that the possibility of state ownership, perhaps through the State University system, should be permanently rejected.

Our first preference is that the project be brought into being by private industry. Our second preference is that it be constructed by the federal government with the state government or private industry bringing enough to the enterprise to make it necessary for the Atomic Energy Commission to give serious consideration to New York as the location.

Whichever route is followed, it will be necessary for the project to have a suitable site. In its role as a catalytic agent, and in the interest of having the project placed in the best possible location from the point of view of both the public health and safety and the project's relationship to other projects in the state's atomic development plan, it would be reasonable, in our view, for the state government to undertake a site survey for this project as soon as possible.

We also believe, if this project is not undertaken by private industry, that the state should proceed to acquire the most suitable site within the state and make it available to the Atomic Energy Commission. This site acquisition would be done, however, only if the Commission had previously agreed to utilize the site for the purpose intended. The possession of such a site by the state conceivably could also serve to attract other important future test projects, which might more productively be constructed in the east than in Idaho, including those of the nuclear ship propulsion laboratories at Schenectady and in Pennsylvania, and the nuclear aircraft propulsion laboratory in Connecticut.

We are not proposing that a site be acquired at this time or at any time in the future in advance of reasonable commitments to use it. We are, however, proposing that a thorough site survey be accomplished as soon as possible so that, if necessary, the site could be acquired without delay if suitable commitments are forthcoming.

Discussion of Atomic Port Facilities

New York shipyards have not to date been engaged in the construction and servicing of nuclear powered ships, in spite of the fact that 41 such ships have been built, are under construction or authorized.

This type of activity, which has until now been financed and directed exclusively by the federal government, at present involves a total capital investment, including commitments, of over $3 billion. Most of this work is being done at privately owned shipyards in Connecticut, Massachusetts, Mississippi, New Jersey and Virginia, and the rest of it in federally owned yards in California and Maine.

As is well known, there exist in New York both private shipyards and a major federally owned facility—the New York Naval Shipyard, owned and operated by the U. S. Navy in Brooklyn.

There seems to be very little that the state government can do to initiate private activity within the state in regard to the building and servicing of nuclear ships, except to establish a state policy favoring such activity and to offer the state's good offices to the Navy, the Maritime Administration and private industry. This latter action could be particularly meaningful, we believe, if it were to take the form of establishing, on the basis of thorough study, the acceptability of such activity in this area from the point of view of the public health and safety. The fact that seven other states are now active in the nuclear shipbuilding field makes it possible for this type of assurance to be based on a substantial body of actual accumulated experience.

So far as the New York Naval Shipyard is concerned, the suggestion has been put forward unanimously by all members of Congress from New York that the yard be the site of construction of the nation's second nuclear aircraft carrier, tentatively authorized in the 1959 session of Congress. Whether or not this project should be finally authorized in the next session of Congress is a national policy question that clearly is beyond the purposes of this report. We do believe, however, that, if such authorization is forthcoming, there are a number of good reasons why the Naval Shipyard in Brooklyn should be seriously considered as the construction site. The Brooklyn yard, for example, is one of the few places in the country capable of handling a project of such magnitude. It also is the only large Navy-owned yard still inactive in the nuclear field.

From the standpoint of the state, if such a project could be undertaken in New York, it would tend to attract additional projects by serving to demonstrate to the shipbuilding industry generally the acceptability of nuclear ship projects in this area. It therefore would seem to be appropriate and desirable for the state government, regardless of whether or not another nuclear aircraft carrier is approved, to request the Navy to consider utilizing the Brooklyn shipyard for the construction of nuclear naval vessels of all types. We consider this suggestion to be particularly appropriate in the light of the Navy's declared objective to convert the fleet entirely to nuclear propulsion at the earliest practicable date.

Beyond and in addition to the matter of building and servicing nuclear ships, there is a need to provide in the United States a number of ports through which used uranium fuel from both ships and land-based foreign and domestic reactors can be shipped enroute to fuel recovery and reprocessing plants. At present there are only two ports where this has been done—Groton, Connecticut and Kittery, Maine (the Portsmouth, New Hampshire Naval Shipyard). In both, only fuel from nuclear submarines has been involved. In each instance the fuel has been shipped overland, across the country, including across the State of New York, to the Atomic Energy Commission's reprocessing plant in Idaho. This is a practice which almost undoubtedly cannot be continued permanently, for both economic and safety reasons.

It seems to us that, if New York wishes to become a substantial center of the growing non-weapons atomic industry, it should attempt to capitalize on its leading position as a maritime state by identifying within the state one or more port locations where atomic materials can be handled safely and economically.

It is our opinion that any special port facility established within the state to handle atomic materials should be owned and operated by either private industry or by one of the existing governmental agencies or authorities already engaged in this type of activity. We are not proposing, therefore, that the state government itself contemplate undertaking such a project. It does seem to us, however, that the state government has a sufficient interest in the health and safety aspects of the problem, as well as in the need for relating it to a possible state-owned waste storage and disposal site, to warrant the state's identifying at least one acceptable port location for the handling of used uranium fuels.

Discussion of Educational Facilities

One of the primary purposes of the Office of Atomic Development, as described in the New York State atomic energy law, is "to foster and support research and education relating to atomic energy through contracts or other appropriate means of assistance, including acquisition of land and construction of facilities," subject to the conditions that "any state funds provided through the office for the acquisition of land or the construction of facilities affixed thereto be matched by funds or other contributions from other sources of at least equal amount or value, and that any such land and facilities be available for research and training, for such period of time and on such terms as may be approved by the director [of the Office of Atomic Development], to the departments, divisions, offices, commissions and other agencies of the state and of the political subdivisions thereof, to educational and non-profit institutions in the state and to other persons. . . ."

In approaching our responsibilities under these provisions of the law, we requested the State Department of Education to conduct a survey of the state's 179 institutions of higher learning to ascertain the nuclear training and research equipment which they presently have available plus what they consider to be their requirements for such equipment in the immediate future.

This survey, which was conducted in August and September of this year, showed that 6 institutions presently have relatively high energy nuclear particle accelerators or generators, 9 have sub-critical reactor-type training devices, 19 have equipment for the utilization radioisotopes, and 38 have at least some type of equipment useful in physical or biological research and training in the field of atomic energy. In addition to these facilities and equipment whose total value amounts to approximately $13 million, there are now under construction within the state a $2 million nuclear research center, including a nuclear research reactor, at the University of Buffalo, and a $1.6 million similar center, including a nuclear research reactor of a different type, at Cornell University.

The Department of Education survey also showed that 7 institutions require a high energy particle accelerator or generator either on campus or readily accessible, 8 require a sub-critical reactor-type training device, 10 require either on campus or readily accessible a nuclear research and training reactor, and 10 require equipment making possible the utilization of radioisotopes for research and training purposes. In addition, 9 institutions reported that they require physical or biological equipment not presently available.

In considering the results of this survey, we have been mindful of the following facts:

1. New York State will in this academic year produce approximately 10% of all of the nation's graduates in the scientific and technological disciplines most pertinent to atomic development, a percentage that is roughly proportional to the state's share of the national population. At the graduate level, the state's rank as a producer of trained people is somewhat higher than strict proportional levels.

2. The state government through the Office of Atomic Development is contributing $1 million toward the establishment of the nuclear research center, to be known as the Western New York Nuclear Research Center, now under construction on the campus of the University of Buffalo.

3. The Office of Atomic Development presently has before it one specific proposal that the state participate financially in the construction of a nuclear training and research facility.

4. The largest concentration of institutions desiring access to specialized atomic energy research and training facilities not now in existence is in the New York City area.

5. The Brookhaven National Laboratory on Long Island is one of the nation's leading nuclear research centers. Although it is enormously valuable as a research center to educational in itutions working in the most advanced fields of nuclear research, its facilities are not suitable, nor could they be used, as an aid to undergraduate and ordinary graduate training in the field of nuclear education.

In our view, the fact that New York is producing approximately its proportionate share of scientific and technical people does not constitute grounds for complacency, considering the concentration of industry and financial resources within the state. We do believe, however, that it suggests that any state support of education and training facilities in the atomic energy field beyond that already being made available in Buffalo be undertaken on a most careful and discriminating basis.

In light of the information available to us, we have concluded that the state should, particularly in the next few crucial years, when the shape of the atomic industry is still being formed, provide assistance not otherwise available to the extent of approximately $1 million for the establishment of atomic energy research and training facilities at educational institutions outside of the area served by the Western New York Nuclear Research Center in Buffalo. In approaching this undertaking, we believe that the state should be guided both by the relative technical capability of the state's educational

TECHNICAL DEGREES GRANTED, 1958*

LEADING STATES

	Eng.	*Math.*	*Chem.*	*Physics*	*Met.*	*Other Phy. Sci.*	*Total all Tech.*
New York	3,986	887	1,016	591	2	509	6,991
Pennsylvania	3,115	609	693	350	30	283	5,080
California	3,192	445	424	453	1	347	4,862
Massachusetts	2,625	341	451	341	0	191	3,949
Texas	2,027	522	473	207	0	654	3,883
Illinois	1,887	414	547	256	0	166	3,270

STATE-NATIONAL COMPARISON

Type of Physical Science	*Number Granted by New York State Institutions of Higher Education*				*Numbers Granted by All Higher Educational Institutions in U. S. A.*			
	Bachelor's	*Master's*	*Doctor's*	Totals	*Bachelor's*	*Master's*	*Doctor's*	Totals
Mathematics	623	226	38	887	6,924	1,234	247	8,405
Engineering	3,216	698	72	3,986	35,332	5,788	647	41,767
Chemistry	774	136	106	1,016	7,010	1,125	939	9,074
Physics	422	95	74	591	4,116	1,081	242	5,439
Metallurgy	—	2	—	2	40	33	10	83
All Others	324	154	31	509	3,186	795	464	4,445
Totals	4,865	1,154	303	6,991	56,608	10,056	2,549	69,213

* State data from N. Y. State Dept. of Education; National data from U. S. Dept. of Health, Education and Welfare.

institutions and by the number of institutions that would be benefited by the establishment of any proposed facility at any given location.

The above conclusion applies only to the establishment of facilities, and not to grants from the state for the operation of facilities. A marked difference of views exists in regard to the desirability of making grants for operating purposes. Although we do not wish to foreclose the possibility permanently, it is our present view that no state funds should be expended in atomic education except for the achievement of measurable "closed end" objectives, and that operating grants, therefore, should be made available only for overriding reasons not now recognizable.

This is not to say, however, that the state, for reasons having to do with the public interest, might not wish to enter into contracts with educational institutions for the performance of specific atomic energy research work leading toward clearly defined goals. We are not proposing any such contracts at this time, but we can foresee the desirability of this type of activity in the future, particularly, for example, in regard to the training of state personnel in atomic energy inspection and regulatory techniques, the development of information useful in the preparation of codes and standards, and the study of methods by which radioactive wastes and by-products can be packaged for storage within the state in a manner consistent with the public health and safety.

Discussion of Other Objectives

In addition to the areas described under the headings above, there are several other fields that warrant consideration for inclusion in any atomic development program for the State of New York. These, which have to do both with development and with the regulation of atomic energy in the interest of the public health and safety, are as follows:

Federal relationships

The state's relationships with the federal government in regard to the peaceful aspects of atomic energy are at present focused on the negotiations which have been initiated by the state Office of Atomic Development with the Atomic Energy Commission to enter into an agreement between the Governor of the state, on behalf of the state, and the Commission providing for the transfer of certain regulatory authority, primarily over radioisotopes, from the Commission to the state. These negotiations are being carried on under a federal law which was adopted in September 1959 and which was supported by the New York State government in public testimony.

It is our opinion, in the interests of both the normalization of the regulatory aspects of the atomic industry, and the public health and safety, that such an agreement between the state and the Atomic Energy Commission should be entered into at the earliest practicable date. We consequently believe that the state should begin immediately to prepare itself for such an agreement by assuring that express statutory authority exists for the state to assume and execute the functions covered by the agreement. We therefore suggest that, at the next session of the Legislature, the Governor be given express authority to enter into such an agreement, and that the state Department of Health be given express appropriate licensing authority*.

We further suggest that the state should proceed to prepare itself for assuming the regulatory functions that would be covered by such an agreement by a series of interim steps under which state personnel, in cooperation with the Atomic Energy Commission, be indoctrinated regarding present Commission regulatory procedures.

Also in regard to federal-state relationships, we note that New York leads all states in the value of atomic energy contracts and grants awarded to institutions within the state. These are roughly in the same proportion as New York's population is to that of the nation and we therefore consider that the state's present share of contracts and grants is appropriate and requires no specific state action.

Perhaps the most conspicuous present inadequacy in regard to the state's relationships with the federal government is that no member of Congress from New York serves on the Joint Congressional Committee on Atomic Energy. In this regard, New York is the only state in which there are substantial Atomic Energy Commission facilities within its borders that is not represented on the Committee. We realize that this problem lies outside of the purview of this report, but wish to note it nevertheless.

Process heat reactor

Although a large amount of money and considerable effort has been expended on the national program to develop atomic energy for the generation of electric power and the propulsion of ships, relatively little has

* The State Department of Labor appears already to possess adequate licensing authority (Sec. 28.2 of the "Labor Law"), as does the Board of Health of the City of New York (Sec. 561, New York City Charter).

yet been done to foster development in the very promising field of heat production for industrial process use. The principal project to be undertaken to date in the process heat field is the project, recently approved, to utilize atomic heat in the purification of sea water in a plant to be constructed in California. This project, costing an estimated $6 million to $10 million, is a cooperative undertaking of the Atomic Energy Commission, the Department of the Interior and the State of California. The state will contribute $1.5 million.

In our opinion, the California plant, although desirable for the purpose intended, will not necessarily adequately demonstrate in itself the value of atomic heat in such industrial processes as those involved in the chemical and paper industries, both of which are important to New York State. We therefore believe that it would be in the interest of New York State as well as other industrialized areas if there were to be built in the near future a denmonstration nuclear process heat reactor specifically designed for use in an established industry, such as the chemical or paper industry.

If such a project were to be undertaken, we would of course hope that it could be undertaken in the State of New York, because of the stimulating effect it would have on atomic development generally in this area. One way to accomplish this objective would be for one or more industrial concerns within the state to undertake the project without governmental assistance. Another way would be for the federal government to undertake the project with New York State industry bringing enough to it to assure a New York location. A third way would be for the state government to participate to the extent required to assure a New York site for the project.

We are not at this time proposing any state participation in an enterprise of this sort, beyond the exercise of the state's good offices with respect to any industrial effort that might be made to launch such a project within the state. We do believe, however, that a process heat project merits very serious consideration by New York State industrial concerns, and we believe further that the state government may find good and sufficient reason later on to participate in such a project if progress is not forthcoming in any other way. Certainly we believe that the construction of a process heat reactor within the state is worthy of being included as an objective of the state's atomic energy program.

Radioisotopes

Although New York, by virtue of its population and highly developed industry, might be expected to lead the nation in the utilization of radioisotopes for industrial purposes, the state actually ranks second. This may be due to a lack of appreciation among the state's industry of the value of radioactive materials in industrial processes. We therefore believe that it would serve a most useful purpose for the Office of Atomic Development to undertake an industrial education program to make sure that the usefulness of radioactive materials is fully understood throughout the industry of New York State. We further believe that the state government, by means of an educational and information program, should attempt to stimulate research within the state directed toward the discovery of new productive uses for radioactive materials.

Actually, the availability of radioactivity in massive quantities is an impressive new phenomenon on earth which has not yet been exploited to more than a fraction of the extent possible. The volume of radioactive materials now used in medicine, agriculture, industry and research is at present very small and production occurs almost entirely in one nuclear reactor located in Tennessee. The value of these materials produced each year is approximately $2.5 million. It is possible, however, that if sufficient new productive uses for the massive quantities of radiation now becoming available in the atomic industry could be found, the value of the annual production of such materials could range into the scores of millions of dollars. Such a development would not only create an important new industry; it would also help substantially the economics of atomic power, inasmuch as radioactive materials are always produced as a by-product of atomic power generation.

Radiation protection

There are over 500 locations in the State of New York where radioactive materials are in use. In addition, there is considerable shipment in and through the state by air, sea and land of such materials. The possibility exists, therefore, however remote, of accidents occurring which involve, or may mistakenly be believed to involve, radioactive materials.

We consider it to be only prudent that the state take steps to insure that any such accidents be evaluated and handled as effectively and as rapidly as possible. It is therefore our opinion that the state should establish training programs and prepare, maintain currently and distribute within the state a roster of qualified radiation experts and a list of the type and location of useful instruments and other specialized equipment within the state so that competence in the radiation field may be readily available in the event of any accident, fire or disaster believed to involve radioactivity.* It is important not only that such accidents be evaluated correctly, but also that complete and accurate information concerning them be made available to local officials, as well as to the press and public, without delay.

* The New York City Department of Health now has in effect a working arrangement under which its own staff of radiation experts are available to the City Fire and Police Departments in the event of a radiation accident.

A 12-Point Program

Based on the foregoing discussions, we propose the following as objectives to be achieved within the state at the earliest practicable date:

1. Expansion of the state's atomic power capacity, including particularly the construction at the earliest practicable date of either an economically competitive full-scale atomic power plant or a prototype leading directly toward the construction of an economically competitive full-scale plant.

We propose this because we believe that there is no single event that would do more to establish the peaceful atomic industry on a permanent, flourishing basis in the State of New York than the achievement of economically competitive atomic power in this area.

2. Construction of a uranium fuel recovery and reprocessing plant.

We propose this because the fuel reprocessing industry is not yet committed to a geographical area and because we believe New York is uniquely well situated from the standpoint of both the potential market and the state's resources to become the site of such an industry.

3. Establishment of a site where radioactive byproduct and waste materials may be stored without hazard to the public health and safety.

We propose this because we believe such a site to be necessary from the standpoint of the health and safety of the people of the state, and also because the existence of such a site would serve to encourage the growth of the atomic industry within the state.

4. Construction of a high powered nuclear test reactor.

We propose this because no such reactor exists in the northeast, because most of the potential users of such a reactor are located in the northeast, and because such a reactor would tend to stimulate atomic industrial development in the state.

5. Establishment of at least one shipyard as a center for the construction of nuclear ships.

We propose this because nuclear shipbuilding is a large, growing industry, and because New York, although a leading maritime state, is at present not engaged in this type of activity.

6. Establishment of a port facility capable of handling used fuel from nuclear ships and foreign and domestic reactors entering the state by sea.

We propose this both in the interest of the public health and safety and because such a facility would be a necessary adjunct to any fuel reprocessing industry that might be established within the state.

7. Expansion of the state's volume of fuel fabrication work, including particularly the entry of the state's industry into the business of fabricating nuclear fuel for ship propulsion.

We propose this because New York is well situated with regard to the nuclear fuel market, and because the state is at present not engaged, outside of federally owned laboratories, in the fabrication of nuclear fuel for ship propulsion.

8. Construction of a process heat reactor for industrial utilization.

We propose this because demonstration of the feasibility of producing usable industrial heat from atomic energy would stimulate atomic development within the state and at the same time benefit such other of the state's major activities as the chemical and paper industries.

9. Execution of an agreement with the Atomic Energy Commission providing for the assumption by the state of regulatory authority over radioisotopes and such other nuclear materials as may be possible under federal law.

We propose this because a law authorizing such an agreement was enacted in the last session of Congress, and because we believe that both the public health and safety and the atomic industry will benefit if states play an increasingly larger role in the regulation of atomic activities.

10. Strengthening, on a state-wide basis, of the atomic research and training facilities of the state's higher educational system.

We propose this because maintenance of a scientific educational environment of high quality is necessary to the growth of an atomic industry within the state.

11. Expansion of the industrial use of radioactive materials and of research directed toward discovering new productive uses for such materials.

We propose this because we believe that more industries within the state could productively employ radioactive materials than are currently doing so, and because such materials have an enormous potential for industrial utilization that has not as yet been realized, to the detriment of the economics of the entire atomic industry.

12. Establishment of training programs and identification of personnel and equipment useful in handling accidents believed to involve radioactive materials.

We propose this in the interest of the public health and safety and also because we believe that the hazards of radioactivity may not be so great in themselves as the possibility that they may be misinterpreted and consequently not handled in the most effective possible way.

Specific Recommendations

Meaningful progress toward some of the above objectives can be made by the Office of Atomic Development and other state agencies as part of their regular program of activities. The other goals, however, are of such magnitude or nature that they can be achieved only by means of special action. With this fact in mind, the following recommendations for specific implementing action in 1960 are respectfully submitted:

1. That the state government contribute to the costs of research and development leading directly and specifically toward the construction within the state of (a) preferably a full-scale atomic power plant which will give reasonable promise of being economically competitive, except for research and development costs, on an averaged annual basis over its useful life with conventionally fueled power plants in the same geographical area, or (b) a prototype atomic power plant which would lead directly toward the construction of an economically competitive full-scale atomic power plant of the same type. The power plant, whether full-scale or prototype, would be of a type selected by its sponsoring utility or utilities. It would be either part of an anticipated new national program, or deemed by the state and sponsoring utility or utilities to be more suitable for New York State than any project in the national program, or deemed by the state and sponsoring utilities to be suitable for New York State in the absence of a national program. The costs contributed by the state would be at least matched by the sponsoring utility or utilities, some of which might be located outside of the state, and not paid until completion of the plant. When completed, the plant would be available to the higher educational institutions in the state to the maximum extent possible for training purposes, and all information produced by research and development work carried on with state funds would be readily available to the people, including the industries and educational institutions, in the state.

2. That the state government locate within the state one or more sites at which radioactive by-products and wastes produced by industrial, medical, agricultural and scientific organizations could be concentrated and stored in a manner consistent with the public health and safety. It would be understood that such a site, if found, would be acquired by either the federal or state government and that it would be located in as close proximity as possible to a suitable site for a uranium fuel recovery and reprocessing plant.

3. That the state government locate within the state one or more sites at which a high powered nuclear materials test reactor could be constructed and operated in a manner consistent with the public health and safety. It would be understood that, if the construction of such a project were not undertaken by private industry, the state would acquire such a site and make it available to the federal government provided that the cost of the site is not excessive, that the federal government agrees to utilize the site for the purpose intended, and that the federal government fails to acquire the site itself.

4. That the state government locate within the state one or more port facilities capable of handling the fueling and servicing of atomic propelled vessels and the shipping of used uranium fuel in a manner consistent with the public health and safety.

5. That the state in the next few years enter into one one or more arrangements with educational institutions under which the state would provide a total of up to $1 million of assistance not otherwise available on no more than a matching basis in the establishment of one or more nuclear facilities, designed primarily for training purposes, in an area outside of the area served for training purposes by the Western New York Nuclear Research Center in Buffalo or the Brookhaven National Laboratory at Upton, Long Island.

6. That the Governor be expressly authorized by statute to enter into an agreement or agreements on behalf of the state with the Atomic Energy Commission whereby the federal government will discontinue, and the state would assume, regulatory authority with respect to atomic energy activities relating to by-product materials, source materials, and special nuclear materials in quantities not sufficient to form a critical mass within the state now or hereafter regulated by the federal government.

7. That the State Department of Health be expressly authorized by statute to license the use of atomic energy materials covered by any agreement entered into between the Governor of the state and the Atomic Energy Commission.

8. That the Office of Atomic Development be expressly authorized by statute to prepare, maintain currently and distribute within the state for use in the event of an accident, fire or disaster believed to involve radioactive materials, a roster of qualified radiation experts and a list of the type and location of useful instruments and other specialized equipment within the state, and to cooperate with the federal government and state civil defense commission in establishing training programs relating to handling such accidents, fires or disasters.

Appendix I

LETTERS OF CONCURRENCE AND COMMENT

(The foregoing report was submitted to Governor Rockefeller by the Director of the Office of Atomic Development with the concurrence of both the State's General Advisory Committee on Atomic Energy and its Atomic Energy Coordinating Council. The membership of these groups is listed on page ii of this document. Their written concurrence is reproduced herewith in the form of a letter from the Chairman of the General Advisory Committee, Mr. Francis K. McCune, Vice President of General Electric Company, and a memorandum from the Secretary of the Coordinating Council, Mr. J. D. Anderson, together with the individual comment on one part of the report by a member of the General Advisory Committee, Mr. Thomas F. Farrell, consultant to the New York State Power Authority.)

Concurrence of the Advisory Committee

December 1, 1959

The Honorable Nelson A. Rockefeller
The Governor of New York
Albany, New York

Dear Governor Rockefeller:

At Mr. Townsend's request the New York State General Advisory Committee on Atomic Energy has reviewed and considered the report entitled "Atomic Development Plan for New York State" which the Office of Atomic Development has prepared for submission to you. The whole Committee generally approved of the report. In one instance Mr. Townsend worked with a subcommittee to revise a portion so as to be more in conformance with the thinking of those on the Committee particularly concerned. As a result it is with pleasure that I inform you that the Committee concurs in the report and its conclusions and recommendations.

It is my understanding that one member of the Committee, General Farrell, has submitted directly a separate individual view concerning one aspect of the report. The full Committee considered General Farrell's comments but did not recommend any change in the position proposed by Mr. Townsend.

Sincerely,
/s/ Francis K. McCune
Chairman

Concurrence of the Coordinating Council

December 1, 1959

MEMORANDUM TO: Mr. Oliver Townsend, Chairman, Coordinating Council

FROM: Mr. J. O. Anderson, Secretary to the Council.

The report to the Governor of the Office of Atomic Development entitled "An Atomic Development Plan for the State of New York" has been reviewed by the officials on the Atomic Energy Coordinating Council and they have all notified me that they are in agreement with the conclusions and recommendations of the report.

/s/ J. D. Anderson
Secretary to the Council

Memorandum From Thomas F. Farrell

October 14, 1959

MEMORANDUM TO: Mr. Oliver Townsend, Director of Atomic Development

FROM: Mr. Thomas F. Farrell

It is recommended that the Section of the report on Atomic Power include a recommendation for permissive State legislation authorizing the Power Authority to build and operate nuclear power plants.

It is entirely possible as a result of additional assistance not now available that the Authority may find it feasible during the early years ahead to finance and build an atomic power plant logically and economically related to other facilities of the Authority which would not otherwise be built in New York State. Permissive legislation passed now would enable New York State to have one more full scale atomic power plant in operation and thus take another step toward economically competitive atomic power. The State should be at all times in a position to accept and use assistance which would help to reach this desired goal. It is not proposed that the Authority be the exclusive State agency in the atomic field, but that it be in a position to contribute its share. Certainly the Authority should not be excluded.

/s/ Thomas F. Farrell

Appendix II

MEMORANDUM BY THE GOVERNOR

(In immediate implementation of certain of the recommendations of the foregoing report, Governor Rockefeller on December 3, 1959, submitted several specific legislative proposals to the New York State Legislature. The Governor's memorandum describing these proposals is reproduced below.)

December 3, 1959

TO: The Leaders of the Legislature

The year 1959 has marked for New York State the beginning of a coordinated program of State action in the development and use of atomic energy for peaceful purposes. Legislation enacted at the 1959 Session recognized that atomic energy is a matter of important concern to the economic growth and the health and safety of the people of the State.

New York has been the leader in the medical uses of atomic energy. It has, however, lagged with respect to the development of atomic industry. The specific steps taken in 1959 point toward placing New York in a position of genuine leadership in atomic matters. These steps include:

1. Enactment of a State Atomic Energy Law creating the Office of Atomic Development;
2. Initiation of the Western New York Nuclear Research Center and negotiation of a contract between the State and the University of Buffalo for the construction of the Center;
3. Completion of a definitive study by the Office of Atomic Development identifying economically sound atomic projects for location in New York;
4. Initiation of discussions between the State and the United States Atomic Energy Commission looking to the development of an agreement under which the State would assume regulatory authority of certain atomic energy activities;
5. Initiation of a systematic review of all rules, regulations and ordinances pertaining to atomic energy within the State.

It is noteworthy that the act creating the Office of Atomic Development anticipated the action taken by the Federal Government in September of this year when it authorized the transfer of regulatory control of certain atomic energy activities from the Atomic Energy Commission to qualified states. Through its forward-looking atomic energy program New York now stands prepared to assume such regulatory control.

When the State Atomic Energy Law was enacted early in 1959, it was recognized that all the specific steps to encourage atomic development could not be taken in that initial legislation. The time is now at hand to strengthen the State's activity with respect to atomic energy. A well conceived program for 1960 has been developed based upon the comprehensive report of the Office of Atomic Development. I am submitting for your consideration a copy of this report with this memorandum. I have found the report of great value in understanding the difficult and technical problems associated with atomic development.

The report can and should be implemented by legislation at the 1960 Session. Such legislation would focus on three major areas: public health and safety with respect to nuclear materials, development of atomic industry in New York and cooperation with the Federal Government in the regulation of atomic energy.

1. *Public health and safety with respect to nuclear materials*

Atomic industry can be and must be safe industry. As the report of the Office of Atomic Development points out the peaceful development of atomic energy can be among the safest of human endeavors. Risks associated with the peaceful development of atomic energy cannot, however, be ignored. These risks can be effectively controlled by careful planning. Such planning should take into account that the hazards of radioactivity may not be so great in themselves as in the possibility that they be misunderstood and thus not handled in the proper manner.

I am proposing legislation to direct the Office of Atomic Development to cooperate with the Federal Government, the State Civil Defense Commission and appropriate agencies of State and local Government, including our fire and police organizations in establishing training programs relating to the handling of accidents, fires or disasters believed to involve radioactive materials.

In order to be further prepared to cope promptly and effectively with any accident which might involve radioactive materials, I am also recommending legislation which would direct the Office of Atomic Development to prepare and maintain a roster of persons within the State qualified in the detection and handling of radiation hazards and a list of the type and location of technical equipment which could be of use in connection with any such accident. The roster and list would be distributed throughout the State, available to all agencies of government concerned with the public health and safety.

These two measures would provide important steps in discharging the State's continuing responsibility for the public health and safety as we move into the atomic era.

2. *Development of Atomic industry in New York*

The creation of jobs through economic expansion requires forward looking policies to seize opportunities springing from nuclear developments. New York, as a highly industrialized, highly populated State, can, through careful planning, benefit to the maximum extent for the exploitation of atomic energy.

Such planning is being carried forward by the Office of Atomic Development, which in its immediate recommendations recognizes that the proper role of the State is to act as a catalytic agent to provide incentives for atomic development within the State.

To implement these recommendations, I am submitting proposed legislation which would direct the Office of Atomic Development to locate within the State, with due regard for the public health and safety:

(a) sites at which radioactive byproducts could be concentrated and stored;

(b) sites at which an atomic test reactor could be constructed and operated; and

(c) port facilities capable of handling the fueling and servicing of atomic propelled vessels and the shipping of used uranium fuel.

(a) *Storage sites for radioactive byproducts.* The use of atomic fuels results in the creation of radioactive waste materials which must be safely disposed of. Atomic industry will be attracted to those areas which provide safe and convenient sites for the disposal of such waste materials. The early identification of such sites is necessary, not only as a health and safety measure, but because their existence would serve to encourage the growth of atomic industry within the State. It is contemplated that such sites, when located, would be acquired either by the State or Federal Government.

(b) *Sites for an atomic test reactor.* Nuclear test reactors are high-powered reactors which do not generate electricity or propel ships, but which are used to develop and test the fuel elements that will be used in future power and propulsion reactors. Such test reactors are vital to the development of the fuel elements that will feed the atomic power plants and ship propulsion units of the future. No nuclear test reactor exists in the Northeast, despite the fact that most of the potential users of such a reactor are located in this area of the country. The existence of such a reactor should substantially stimulate atomic industrial development within the State. The identification of a suitable site in New York for such a reactor is, however, a prerequisite to its construction by private industry or the Federal Government.

(c) *Port facilities for the atomic era.* In order to preserve New York's pre-eminence in the maritime commerce, it is vital to plan for the atomic fleets of the future. Now is the time to determine the feasibility of locating within the State safe port facilities capable of handling the fueling and servicing of nuclear ships as well as the shipment of used uranium fuel entering or leaving the State by sea.

These three measures would constitute significant steps toward improving the climate for atomic development within the State. I recommend them for your favorable action.

3. *Cooperation with the Federal Government with respect to regulation of atomic energy.*

The Federal Government recognizes the soundness of State control over some of the peaceful uses of atomic energy. In September 1959, the Congress established procedures for the discontinuance of the Atomic Energy Commission's regulatory authority with respect to radioisotopes, natural uranium and thorium, and small quantities of fissionable materials and for the assumption of this authority by the states. The Atomic Energy Commission was authorized to enter into agreements with any state for the transfer of such regulatory authority from the Commission to the State, and to provide for the performance of inspections or other functions on a cooperative basis.

The State should assure that the dynamic forces of private industry are put to work to bring the benefits of the atomic age to its people. Hand in hand with this new role of the State in atomic matters must go the development of State regulations designed to protect fully the health and safety of the individual citizen.

In order to provide for such State regulation, I recommend legislation:

(a) authorizing the Governor, on behalf of the State, to enter into an agreement or agreements with the Federal Government whereby the State would assume regulatory authority over atomic byproduct materials, source materials and special nuclear materials in quantities not sufficient to form a critical mass;

(b) authorizing the Office of Atomic Development, with the approval of the Governor, to enter into agreements with the Federal Government under which the State will perform on a cooperative basis with the Federal Government inspections or other functions with respect to atomic energy activities within the State, and

(c) authorizing the State Department of Health to license the use of atomic energy materials.

Such express authority will permit the State to assume appropriate regulatory control over matters relating to atomic energy and effectively to protect the health and safety of the people.

* * *

The Legislative proposals which I have outlined, do not embody two of the recommendations made by the Office of Atomic Development in its report. These matters are under continuing consideration. One relates to the development of an additional atomic power plant within the State. The other relates to the establishment of additional nuclear facilities for training purposes at educational institutions. The question of atomic power generation should appropriately await the imminent report of the Governor's Committee on Power Resources. The establishment of additional nuclear faciilties at educational institutions should be considered in the light of the work presently going forward for the Western New York Nuclear Research Center.

Conclusion

The measures which I have outlined are embodied in two proposed bills which I am submitting to you with this memorandum with the request that they be prefiled. The enactment of this legislation would advance the position of New York toward leadership in the field of atomic energy by furthering the public health and safety with respect to nuclear materials, by stimulating atomic industry within the State, and by authorizing the State to assume regulatory control over various aspects of atomic development that touch upon the wellbeing of the citizens of the State.

(signed) NELSON A. ROCKEFELLER

Appendix III

BACKGROUND INFORMATION

The Nature of Atomic Energy

Atomic reactions resemble fire in that the energy they produce appears primarily in the form of heat. This heat can be utilized in many of the same ways in which heat from fire is utilized. Whatever other uses it may have will in the long run probably be determined only by the dimensions of man's imagination.

Although the nature of atomic heat and fire heat is the same, the quantities and concentrations are strikingly different. Thus the heat from one pound of atomic fuel is equivalent to the heat from 1,500 tons of coal. And, whereas the maximum temperatures achievable by means of fire range upward to only about 10,000 degrees Centigrade, the temperatures that can be reached by atomic means range into the millions of degrees

Atomic heat also differs from fire heat in that it is always accompanied by the release of energy in the form of nuclear radiation. Before the discovery of atomic energy, nuclear radiation was known chiefly as an emanation from radium and X-ray machines. However, as in the case of heat, there is a striking difference in quantity and concentration of radiation. Thus, the nuclear radiation from one small atomic bomb explosion exceeds that of all of the radium that has ever been mined.

The Status of Atomic Development

Atomic energy can be released by two principal types of reactions—nuclear fission, which is the process used in the atomic bomb, and thermonuclear fusion, which is the process used in the hydrogen bomb.

At present, however, only fission can be used to release useful quantities of energy slowly and in a controlled manner. This means that, whereas the world today is beginning to gain access for peaceful purposes to the 600 quintillion BTU's of energy represented by nuclear fission, it does not yet know how to utilize the 3,000,000,000 quintillion BTU's of energy represented by thermonuclear fusion except explosively.

As might be expected, therefore, the world's major atomic nations have substantial research programs underway with the objective of harnessing the fusion reaction for peaceful purposes. If and when success will be achieved is now not known. The stakes, however, are clearly enormous.

So far as the better understood fission reaction is concerned, the controlled release of atomic energy is accomplished in a machine called a nuclear reactor, which is to atomic energy as a furnace is to fire.

To date, nuclear reactors have been developed to the point where they have been used successfully for the propulsion of seagoing vessels and the generation of electric power. Development has not yet progressed sufficiently, however, for these things to be done through atomic energy at a cost that is as cheap as the cost of utilizing for the same purposes the energy derived by fire from coal and oil. Consequently, much of today's atomic research is directed toward reducing the costs of building and operating nuclear reactors. Much additional research is also being conducted with the objective of finding new productive uses for reactors.

Meanwhile, the radiation produced by reactors is beginning to find many useful applications in industry, agriculture, medicine and research. The impact of these activities on the world's economy has not yet been very great, but their potential meaningfulness—in terms of health, food, and the manufacture of industrial products—can ultimately be very large. Certainly the availability of nuclear radiation in massive quantities is a new phenomenon on earth, and the implications of this fact may in the long run be just as important as the discovery that atomic energy can be released at all.

Government Control of Atomic Energy

In apparent recognition of the enormity of the forces with which they are dealing, every nation that has ever had anything substantial to do with atomic energy has set up a special agency to develop and control it.

In the United States this agency is the Atomic Energy Commission, which was established in 1946, soon after Hiroshima. Comparable agencies now also exist in the Soviet Union, Great Britain, France and every other country with a noteworthy atomic energy program. All of these agencies are empowered by their governments to develop, produce and use atomic energy, and to control through a system of orders, licenses and regulations all important functions which they do not perform themselves.

Even on the international level, where effective cooperation has often been hard to achieve, a special agency—called the International Atomic Energy Agency—has been created with all of the world's major atomic powers, including the United States and the Soviet Union, as members. The authority of this agency to develop and control atomic energy is limited to those activities placed voluntarily under its jurisdiction by member nations. This authority, however, is no more limited than is the authority of most other international political bodies, including the United Nations itself, at this point in the world's history.

Regionally, too, insofar as nations have undertaken cooperative endeavors, they have tended to treat atomic energy as a special problem. For example, the six most integrated nations of Western Europe—France, Italy, West Germany and the Benelux countries—have entered into agreements establishing not only a common market and a common coal and steel economy, but also a European Atomic Energy Community (Euratom).

United States Atomic Energy Commission

The basic atomic energy law of the United States, the law that established the Atomic Energy Commission, was adopted in 1946. This law vested in the Commission exclusive ownership of all atomic energy fissionable materials and all major facilities, including nuclear reactors, for the production of fissionable material. Thus control of atomic energy was concentrated within the Commission in a most effective way—exclusive and direct ownership. As a result, no person other than the Commission had the right under the law to engage in the substantial production of fissionable material except as a contractor to the Commission.

The 1946 law also granted authority to the Commission to control for safety reasons all users of the radioactive by-products of atomic energy (the radium-like elements called radioisotopes), not through ownership, but through the less stringent method of licensing and regulation.

This situation prevailed until 1954, when a new law was adopted to permit the Commission to exercise its control over nuclear reactors and other major atomic energy facilities primarily through a licensing and regulatory system rather than through exclusive and direct ownership. Thus the nature of the Commission's control over major facilities became more nearly analogous to the nature of the control it had previously exercised over the users of radioisotopes. Thus, also, it became possible for the first time for persons and organizations other than the Commission to own and operate major nuclear facilities, but only with the approval of the Commission. The effect of this change in federal law was to diminish the stringency of Commission control over major atomic activities, but in no way to diminish the comprehensiveness of its control.

This situation prevailed until September 1959, when a new amendment to the nation's basic atomic energy law was adopted which authorizes the Atomic Energy Commission to transfer to qualified states the regulatory authority it now possesses over radioisotopes, natural uranium and thorium, and small quantities of fissionable material. Such transfers, under the law, must take place on the basis of agreements to be entered into between individual states and the Commission. As these agreements are negotiated and signed, they will result in the first reduction in the comprehensiveness of federal control over atomic energy in the United States since the establishment of the Commission in 1946.

In spite of modifications in the law, the Atomic Energy Commission has remained the nation's largest owner and operator of atomic energy facilities. The Commission's facilities, for example, represent an investment of over $7 billion, and its annual operating budget exceeds $2.5 billion. The Commission employs over 6,000 people directly and over 115,000 more indirectly through contractors. It conducts and supports research, development, training and promotional activities; produces all of the nation's refined atomic fuels and explosives, and controls the dissemination of information. All of these activities tend to enhance the force and effect of the control the Commission exercises over the atomic energy field by means of its licensing and regulatory system.

Role of the States Prior to 1954

Prior to 1954, state governments were almost completely inactive in atomic energy, except for some state universities which performed work under contract to the AEC or used radioisotopes in their own laboratories under AEC license.

It is not surprising that state governments were so inactive, considering that their activity, except for taxation, falls generally into one of the following three categories: regulation; ownership-operation; promotion. They could not regulate, own fissionable material or own or operate major facilities producing fissionable material, all of which were owned exclusively by the AEC and not subject to state regulation. Nor could they engage in promotional activities, because no person could engage in major atomic activities except as an AEC contractor.

In the less federally dominated field of utilizing radioactive byproduct materials, ownership of which was not vested exclusively in the AEC, state governments could have been more active than they were. They could, for example, have engaged as AEC licensees in the promotion of the use of radioisotopes in research or development, medical therapy and industry. Conceivably, they also could have challenged the exclusive right of the federal government to regulate byproduct materials, because the intrastate aspects of public health and safety have been traditionally a state, rather than a federal, responsibility.

The states, however, did not do these things, probably partly because they did not possess the necessary knowledge and skilled personnel, and probably partly also because, no matter what they may have attempted to do, they would in any event have been dominated by the overriding authority concentrated in the AEC by virtue of its exclusive right to own and operate all fissionable material and major facilities producing fissionable material.

Role of the States After 1954

With the 1954 change in federal law and its consequent opening of the field of atomic energy to non-federal ownership-operation under AEC license, the potential role of the state governments was greatly increased. For example, it became possible for them for the first time to engage in promotional activities—a traditionally highly valued and universally practiced state function—in regard to major atomic facilities. It also became possible for state governments and their political subdivisions themselves to own and operate such facilities, either directly or through universities, utility systems, authorities or some type of public body.

The 1954 change in federal law also had an important impact on the regulatory activities of state governments and their political subdivisions, particularly in regard to public and industrial health and safety codes, building codes, zoning, public utility operations, conservation, insurance, labor relations and transportation. Whereas the AEC, the previous exclusive owner of major atomic facilities, was essentially immune from this type of state and local control, the private persons who in 1954 became eligible to own and operate such facilities were traditionally subject to it.

This extremely important regulatory impact of the 1954 change in federal law was in at least one respect somewhat uncertain. This uncertainty, which stemmed from the continuation of the AEC as a regulatory authority over atomic energy activities, was particularly troublesome in the field of public health and safety. Although this field was historically a vital concern of states and localities, it remained under the Atomic Energy Act of 1954, a principal declared continuing interest of the federal government in the control of atomic energy.

In recognition of this uncertainty, one of the first stated purposes of the new 1959 amendment to the Act is "to clarify the respective responsibilities under this Act of the States and the Commission with respect to the regulation of byproduct, source, and special nuclear materials" in quantities not sufficient to form a critical mass. The amendment accomplishes this by providing a mechanism (agreement between individual states and the AEC) through which exclusive regulatory authority over these materials within a state may be transferred by the federal government to the state government. With regard to major atomic energy facilities, however, federal law specifically precludes the AEC from relinquishing to the states its regulatory authority over public health and safety.

The new amendment also recognizes that states have a valid interest in the health and safety aspects of major atomic facilities, and provides that state representatives may participate in federal licensing proceedings to the extent that they may "offer evidence, interrogate witnesses, and advise the Commission as to the application without requiring such representatives to take a position for or against the granting of the application." Notwithstanding the amendment, however, there still remains unresolved the Constitutional question of whether state or federal authority would be supreme in this area in the event of a jurisdictional conflict.

State Government Activity to Date

Following the 1954 revision in federal law, the interest and activity of state governments in atomic energy markedly increased. And, as national and international governmental entities that had dealt with the question had done before them, they tended to consider atomic energy as not readily assimilable into an existing governmental structure.

The legislatures of 17 states since 1954 have adopted legislation providing specifically for the creation of some kind of special governmental commission, committee or official with the functions of advising the governor about, and coordinating activities with respect to, the regulation and development of atomic energy within the state. Two of these states, California and New York, have full-time officials responsible to the Governor; several other states have full-time staff members responsible to part-time commissions.

The legislatures of 13 other states have specifically authorized by legislation or resolution the creation of a committee or commission, with advisory or study functions, but without coordinating functions.

In 10 additional states, the governor or some administrative agency or official has appointed a committee or commission with advisory or study functions, but without coordinating functions.

In the regulatory field, 7 states have adopted by administrative actions of their departments of health or labor, comprehensive radiation protection codes or regulations. (The applicability of such state regulation to AEC licensed activities, which include all major atomic energy activities, has not been the subject of adjudication. It is clear, however, that state regulation may extend over certain radiation sources which are not covered by the Atomic Energy Act of 1954 and which neither the AEC nor any other federal agency has regulated. Included in such radiation sources are natural radiation emitting elements such as radium; x-ray and gamma ray machines; and radioisotopes produced in high energy machines such as particle accelerators.)

One state (Minnesota), acting through its State Board of Health, has promulgated regulations prohibiting the commencement of construction of a nuclear reactor or facility without the approval of the Board of Health, and prohibiting the operation of a reactor without such approval. (The applicability or these regulations to AEC licensed activities, about which there is some controversy between the AEC and the State of Minnesota, has not been the subject of adjudication.)

Twenty-four states have provided for registration of radiation sources within the state.

Although there has been considerable interstate cooperation particularly in New England and the South, in atomic energy studies, conferences and seminars, no interstate compact has been entered into expressly referring to atomic energy. However, the Southern Regional Advisory Council on Nuclear Energy has drafted and forwarded a draft Southern Interstate Nuclear Compact to its 16 member states (Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia and West Virginia). This compact provides for interstate cooperation for promotion and development, but not the regulation, of atomic energy.

The current status of significant state administration in the field of atomic energy and radiation control is summarized below. Except where otherwise indicated, the bodies referred to are appointed by and responsible directly to the governor.

Alabama. Non-statutory advisory committee under State Planning and Industrial Board to examine the State's needs in the nuclear field.

Alaska. Statutory part-time coordinator. Registration of radiation sources.

Arizona. No significant action reported to date.

Arkansas. Statutory part-time coordinator, and non-statutory nuclear energy advisory committee. Registration of radiation sources.

California. Statutory full-time coordinator, plus statutory atomic energy advisory council and departmental coordinating committee. Radiation protection code applicable to workers. Registration of radiation sources.

Colorado. Non-statutory radiation protection advisory committee under State Department of Health. Registration of radiation sources.

Connecticut. Statutory part-time coordinator, plus non-statutory atomic energy advisory committee. Comprehensive radiation code. Registration of radiation sources.

Delaware. Non-statutory atomic-energy-in-industry advisory committee. Registration of radiation sources.

Florida. Statutory part-time coordinating commission employing full-time executive director.

Georgia. Nuclear energy advisory commission established by legislative resolution.

Hawaii. No significant action reported to date.

Idaho. No significant action reported to date.

Illinois. Statutory atomic energy study commission, plus statutory radiation protection advisory council under State Department of Public Health. Registration of radiation sources.

Indiana. Statutory radiation protection advisory commission under State Board of Health. Registration of radiation sources.

Iowa. Non-statutory advisory committee on general problem of power, including possible uses of atomic power.

Kansas. Statutory part-time coordinator, plus statutory atomic energy advisory council and radiation protection advisory council. Registration of radiation sources.

Kentucky. Statutory part-time coordinating committee, plus statutory full-time director of nuclear information within State Department of Economic Development.

Louisiana. Non-statutory atomic energy advisory committee.

Maine. Statutory part-time coordinator. Registration of radiation sources.

Maryland. Non-statutory atomic energy advisory committee.

Massachusetts. Statutory part-time coordinator, plus statutory atomic energy advisory commission. Comprehensive radiation protection code. Registration of radiation sources.

Minnesota. Non-statutory atomic energy advisory committee. Comprehensive radiation protection code, requiring approval of Board of Health before commencement of construction of nuclear reactor or facility or operation of nuclear reactor. Registration of radiation sources.

Mississippi. Non-statutory atomic energy advisory committee.

Missouri. Statutory atomic energy advisory commission.

Montana. No significant action reported to date.

Nebraska. Statutory part-time coordinator.

Nevada. No significant action reported to date.

New Hampshire. Statutory part-time coordinator.

New Jersey. Atomic energy advisory commission established by legislative resolution, plus statutory part-time radiation protection commission within State Department of Health. Registration of radiation sources.

New Mexico. Statutory radiation protection advisory council within State Department of Health, Registration of radiation sources.

New York. Statutory full-time coordinator, plus statutory atomic energy advisory committee and departmental coordinating council. Registration of radiation sources.

North Carolina. Statutory part-time coordinating committee. Registration of radiation sources.

North Dakota. Registration of radiation sources.

Ohio. Statutory full-time coordinator within State Department of Industrial and Economic Development, plus statutory radiation protection advisory council under State Department of Health and statutory atomic energy advisory board. Registration of radiation sources.

Oklahoma. Statutory radiation protection advisory committee under State Board of Health.

Oregon. Statutory radiation protection advisory committee under State Board of Health.

Pennsylvania. Comprehensive radiation protection code. Registration of radiation sources.

Rhode Island. Statutory part-time coordinating commission.

South Carolina. Statutory atomic energy advisory committee.

South Dakota. Registration of radiation sources.

Tennessee. Statutory part-time coordinator. Registration of radiation sources.

Texas. Atomic energy study committee established by legislative resolution. Comprehensive radiation protection code. Registration of radiation sources.

Utah. No significant action reported to date.

Vermont. No significant action reported to date.

Virginia. Atomic energy advisory council established by legislative resolution.

Washington. Statutory full-time coordinator, plus statutory atomic energy advisory council.

West Virginia. No significant action reported to date.

Wisconsin. Non-statutory atomic energy advisory committee.

Wyoming. Registration of radiation sources.

Activities of New York State to Date

The government of the State of New York first became specifically interested in atomic energy in 1955 when both the State Departments of Health (which regulates public and medical health matters outside of the City of New York) and of Labor (which regulates industrial health and safety matters throughout the state) adopted radiation safety codes.

Also in 1955 the Governor established by executive action a Council on the Use of Nuclear Materials, consisting of the State Commissioners of Commerce and Health, the State Industrial Commissioner (who heads the State Labor Department), and a State Public Service Commissioner, and an executive secretary, with the Commerce Commissioner as chairman. The functions of the Council, as described in the statement of its establishment, were "to coordinate safety activities related to atomic energy in New York State, to promote the use of atomic energy in New York State by advising industry on the use of new technological tools for the control of atomic radiation, [and] to coordinate liaison relationships with the Atomic Energy Commission."

On August 7, 1956, the Governor, also by executive action, created an Atomic Energy Advisory Committee, consisting of 21 members from science, industry, labor, education and the federal government. The functions of the Committee, as described in the announcement of its establishment, were to "assist the Governor and his Council on the Uses of Nuclear Materials in expanding industrial applications of atomic energy and maintaining the health and safety of workers in plants using nuclear materials," and also to produce "specific recommendations for . . . necessary legislation."

This Advisory Committee recommended legislation which was proposed to the Legislature by the Governor in 1958 but which failed to pass. The Legislature instead, in 1958, passed a bill granting less authority to the executive dapartment, which was vetoed.

Also in 1958, when the Health Department of the City of New York adopted a radiation safety code, each principal state regulatory agency within the state was provided such a code.

The first atomic energy law to be adopted by New York State was proposed to the Legislature by the Governor in early 1959, was passed in February, and was signed into law on March 9, 1959. This law in its grant of authority to a state atomic energy agency goes well beyond anything previously proposed in New York State by either the Governor or the Legislature, and beyond any law adopted to date by any other state.

In essence, the New York State atomic energy law of 1959 provides for the following:

1. That there be established within the executive department of the state government an Office of Atomic Development to be headed by a director responsible to the Governor and appointed by him with the advice and consent of the state senate.

2. That the Office of Atomic Development have the authority to advise and assist the Governor and the Legislature on atomic energy research, development, educational and regulatory matters; to coordinate the developmental and regulatory activities of the agencies of the state and its political subdivisions, and to cooperate with private industry, the federal government and the governments of other states, including the correlation of state atomic energy activities with the similar activities of the foregoing.

3. That the Office of Atomic Development have the authority to sponsor and conduct studies and disseminate information on atomic energy matters, and otherwise to foster and support research and education through contracts and other means of assistance, including the acquisition of land and the construction of facilities, provided that in these latter two instances all state funds be matched by funds from other sources.

4. That no rule or regulation or amendment thereto, primarily and directly related to atomic energy, that any agency of the state or its political subdivisions might propose to issue can take effect until 90 days after it has been submitted to the director of the Office of Atomic Development, unless this waiting period is waived by either the Governor or the director.

5. That there be established an Atomic Energy Coordinating Council to consist of the director of the Office of Atomic Development as chairman and such other persons, including primarily representatives of state departments and agencies, as the Governor might appoint.

6. That there be established a primarily non-governmental General Advisory Committee on Atomic Energy, to be appointed by the Governor, which would "broadly reflect the varied interests in and aspects of atomic energy within the state," and which would advise the director of the Office of Atomic Development on all of the atomic energy matters with which he is concerned.

To provide for its operation during its first year, the Office of Atomic Development had appropriated to it the sum of $100,000. It also had appropriated to it the sum of $1 million for use on a matching basis in establishing, under contract with the University of Buffalo, a Western New York Nuclear Research Center in Buffalo.

In implementation of the New York State Atomic Energy Law, the Office of Atomic Development, the Coordinating Council and the General Advisory Committee have all been established and are now functioning. The contract with the University of Buffalo has also been negotiated and signed and work on the Nuclear Research Center provided by it is well under way.

Appendix IV

SUPPLEMENT ON CERTAIN LEGAL ASPECTS*

In the course of preparing the report, many areas of possible State action were examined. Some of these areas, and particularly those about which the report contains a specific implementing recommendation, are discussed in the report. The purpose of this portion of the Appendices is to discuss areas not covered, and to discuss in greater detail some areas covered, in the report.

*Prepared by David N. Bressler, Counsel to the Office of Atomic Development.

Amendment X to the United States Constitution reads: "The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people." The State possesses several powers which it may exercise, or refrain from exercising, to promote the development and use of atomic energy within the State for peaceful purposes. Neither the existence nor applicability of these powers is unique with regard to atomic energy; the powers exist and are applicable generally with regard to activities within the State. The question becomes: should the powers be exercised, and if so in what specific manner, with regard to atomic energy activities?

State and Local Taxation

One such power, not discussed in the report, is that of taxation.

It appears improbable that the economic impact of State and local taxation, in and of itself, is sufficiently great to be determinative of whether private enterprise will undertake a particular atomic energy activity. However, favorable State and local tax consideration could be at least psychologically significant in the evaluation of the overall State business climate, and would constitute demonstrable evidence of the State's favorable disposition toward the development and use of atomic energy.

Two of the existing diverse incidences of State taxation might be modified in a manner that may be meaningful in promoting the development and use of atomic energy within the State.

The taxation of real property is such an incidence.[1] One possibility would be to exempt in whole from this tax real property on which is situated a major atomic facility. However, this exemption could have the serious and obvious adverse effect of depriving localities of a source of tax revenue. It would appear not unlikely, therefore, that such an exemption could cause localities to discourage the establishment of atomic facilities in their areas, thereby retarding rather than promoting the development and use of atomic energy within the State.

A compromise possible with regard to atomic power plants, the capital costs of which are presently greater than those of non-atomic power plants, is to grant a partial exemption; i.e., limit the amount of real property taxes on an atomic power plant to what would have been the amount of the taxes on a comparable non-atomic power plant. Thus, neither the locality nor the atomic industry would be unduly penalized or rewarded because an atomic, rather than a non-atomic, power plant was established.

This compromise applicable to atomic power plants would, however, appear inapplicable to non-power atomic facilities, such as recovery and reprocessing plants, test reactors, fuel fabrication plants and waste disposal sites, since these facilities are essentially unique for which comparable non-atomic counterparts do not exist. Therefore, any real property tax exemption granted with regard to these non-power atomic facilities would necessarily be somewhat arbitrary, and involved the risk of incurring local antagonism toward establishing the facilities. Nevertheless, it should be recognized that localities might consider the presence of an atomic facility to afford advantages, economic or otherwise, outweighing the disadvantage of losing revenue resulting from a real property tax exemption. Accordingly, legislation might be enacted granting not only the partial exemption with regard to atomic power plants described in the preceding paragraph, but also granting to localities within the State the right to exempt by local law, in whole or in part, any atomic energy facility from real property taxes.

Relatedly, it seems clear that the core of a nuclear reactor, like coal or oil fired in a furnace, is not and should not be deemed to be, real property subject to the real property tax. Rather, it is personal property not liable to ad valorem taxation in the State.[2]

Taxation on the *gross* earnings or income, regardless of profit, of certain organizations is the other existing incidence of State taxation which might warrant modification. Particular reference is made to the gross earnings franchise tax on organizations formed for or principally engaged in the business of supplying water, steam, gas or electricity;[3] the gross income tax on utilities;[4] and the gross direct premium tax on insurance corporations.[5] Legislation might be enacted exempting from these taxes gross earnings, income or premiums derived from major atomic energy activities if the activity did not yield a net profit.

Taxes such as the regular business corporation franchise tax,[6] personal income tax[7] and tax upon the income of unincorporated business associations,[8] are essentially upon *net* income. They tax net profits, the existence of which could indicate an absence of circumstances justifying special tax relief.

The ramifications of modifying taxation incidences are complex and not always predictable, and a thorough and detailed study would be in order before undertaking such modification. Granting an ill conceived and unwarranted tax benefit could result in proselyting to a state activities which with more economic logic might be located elsewhere.

1. N. Y. Real Property Tax Law, §300.
2. *Ibid.*
3. N. Y. Tax Law, §186
4. *Id.* §186-a.
5. *Id.* §187.
6. *Id.* §§208-219-pp.
7. *Id.* §§350-385.
8. *Id.* §§386-386k.

Interstate Compacts

The report mentions the possibility of interstate cooperation in the field of atomic energy. Article I, section 10 to the United States Constitution reads: "No State shall, without the Consent of Congress, . . . enter into any Agreement or Compact with another State, or with a foreign Power . . . ." Thus, although negatively phrased, the "compact clause" quoted above affords a mechanism by which states may handle regional but sub-national problems.

It appears that the New York State Legislature has authorized the State's participation in not less than 32 interstate compacts.[9] Several of these compacts deal with interstate boundaries. Generally speaking, the others represent interstate attempts to conserve, develop or regulate the use of a common resource or solve a common problem; and they demonstrate the utility of the interstate compact in handling regional matters better handled by collective, rather than individual, state action. For example, New York State is party to the Interstate Compact to Conserve Oil and Gas; the Ohio River Valley Water Sanitation Compact; the New England Interstate Water Pollution Control Compact; the Delaware River Basin Water Commission Compact; the Atlantic States Marine Fisheries; the Military Aid Compact; and the Interstate Compact on Mental Health.

The nature of the activities contemplated under interstate compacts may vary considerably. The Interstate Compact to Conserve Oil and Gas illustrates a compact envisaging essentially advisory, study and reporting activities; and the Ohio River Valley Water Sanitation Compact illustrates a compact envisaging continuing regulation through an interstate agency or commission.

The Southwestern Legal Foundation has published a study of the feasibility of interstate compacts in the field of atomic energy.[10] A final draft Southern Interstate Nuclear Compact for the states administratively and geographically grouped under the Southern Governors Conference has been prepared by the Southern Regional Advisory Council on Nuclear Energy, and covers developmental purposes.[11] The study does not emphasize, and the draft compact does not cover, the regulatory aspects of atomic energy. In this regard, the following recent comment is noted:

> "There is nothing unique about the regulatory control of radiation, as a public health or industrial safety matter, which justifies a regional or multistate regulatory group. The only aspect of radiation control which does have well-defined geographic limits in more than one State is waste disposal into interstate streams or rivers. Existing compacts and the Water Pollution Control Board provide adequate means for adjusting state interests in this area."[12]

Relatedly, the Commission of the New England Interstate Water Pollution Control Compact (to which the states of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island and Vermont are party) adopted at its Fall, 1959, meeting, a recommendation of its Technical Advisory Board to add "radioactivity" to the standards of water quality in the Commission's Classification and Standards of Quality for Interstate Waters.

There may be, however, aside from waste disposal into interstate streams or waters, at least one other aspect of atomic energy that transcends state borders and is not entirely covered by federal legislation. This aspect concerns compensating the public for harm sustained from nuclear incidents. It seems clear that if a nuclear incident occurs, the publics of all states sustaining harm should be compensated on essentially the same terms, and that none should receive or be denied compensation on different terms merely because of fortuitous differences among substantive state laws concerning liability.

The Price-Anderson amendments to the Atomic Energy Act of 1954, as amended, were approved on September 2, 1957.[13] They provide, in part, for the federal government to agree to indemnify and hold harmless persons from public liability arising from nuclear incidents up to $500 million in excess of the level of any financial protection required, and limit aggregate liability for a single nuclear incident at that amount.[14] However, the amendments do not purport to set forth substantive laws prescribing the circumstances under which public liability is to be imposed. In other words, these provisions of the Price-Anderson amendments apply *if* liability is imposed, but they do not answer the substantive question of *when* liability is imposed.

Under traditional conflict of laws principles, the ap-

9. In addition to the 27 compacts listed in "Interstate Compacts 1783-1956", (Council of State Governments, July, 1956), the New York State Legislature has authorized the State's participation in the following 5 interstate compacts: New York-New Jersey Metropolitan Transit District Compact; Interstate Compact on Detainers; New York-New Jersey Transportation Agency; New York- New Jersey Interstate Compact on Smoke and Air Pollution; and New York-Vermont Interstate Compact on the Lake Champlain Basin.

10. Reproduced in part in pages 346-359 "Selected Materials on Federal-State Cooperation in the Atomic Energy Field" published by the United States Joint Congressional Committee on Atomic Energy (86th Cong., 1st Sess., 1959).

11. BNA, Atomic Industry Reporter §55.141.

12. Berman and Hydeman, "A Study—Federal and State Responsibilities for Radiation Protection: The Need for Federal Legislation" (Univ. of Mich., Jan., 1959), reproduced at pages 373-453 of "Selected Materials . . ." etc. referred to in note 10, *supra* at page 411.

13. P.L. 85-256 (71 Stat. 576) added §170 to the Atomic Energy Act of 1954, as amended (P.L. 83-703).

14. *Ibid.*

plicable substantive law governing tort liability is that of the jurisdiction in which the wrong occurs;[15] and, that jurisdiction is generally deemed to be that in which the *harm is sustained.*[16] Thus, if a nuclear incident causes members of the publics in more than one state (jurisdiction) to sustain harm, each such state could apply its own different substantive law of public liability. For example, one crucial issue of substance would be whether liability is to be predicated upon the presence of fault, or rather is to be imposed "absolutely" (even in the absence of fault). The unilateral resolution of such issues by one state would not be binding upon other states. Unless uniformity of state law is achieved, such substantive issues could be resolved in the states on a claimant-by-claimant basis, thereby possibly resulting in an unfortunate and unnecessarily inconsistent variety of holdings.

The desirability of uniform state substantive laws covering public liability for nuclear incidents appears evident, and might be achieved through either federal legislation nation-wide in application, or uniform state legislation, or an interstate compact. The interstate compact appears to be the most immediately promising method of the three. Federal legislation, although requiring enactment by only one (the federal) government, simply does not appear to be forthcoming; and uniform state legislation, unlike the interstate compact, is subject to unilateral state repeal or amendment.

An interstate compact might be of two types. The broader type could set forth the substantive law of public liability for nuclear incidents. The more limited type could supply merely the mechanics for resolving conflicts of substantive laws, by providing that the jurisdiction in which the tort occurs—and, therefore, the jurisdiction whose substantive law will be applicable—shall be deemed to be that in which is situate the nuclear installation giving rise to the nuclear incident (instead of the possibly multiple jurisdictions in which harm is sustained).

The broader type of compact, since presumably its provisions would be more controversial than those of the more limited type, would probably be more difficult and take longer to consummate. However, once consummated it would be more useful in resolving uncertainty and achieving maximum uniformity. The relatively non-controversial and more limited type would assure only that all persons harmed by any particular nuclear incident would be compensated without discrimination due to diverse state substantive laws; but it would not prevent persons sustaining identical harm caused by successive identical nuclear incidents (arising from installations in different states, or even in the same state) from being compensated on the basis of different and unpredictable substantive state laws. The broader type of compact would therefore appear to be preferable.

15. Restatement, Conflict of Laws, §378.

16. *Id.* §377.

Federal-State Relationships

Protection of public health and safety, discussed throughout the report, has been traditionally a state responsibility. However, states have been reluctant to assume such responsibility over byproduct,[17] source [18] and special nuclear[19] materials, which are the radiation sources covered by the Atomic Energy Act of 1954. One cause of such reluctance was that although the Act provided "a comprehensive framework for development and regulation of atomic energy uses by the Federal Government . . . [it was] silent as to the corresponding responsibilities and regulatory powers of State and local governments. . . . Because of doubt as to whether Congress had 'preempted the field' in certain areas of Federal regulation, or whether the States were free to legislate, many persons . . . urged Congress to amend the . . . Act to delineate more clearly the respective areas of responsibility of the Federal Government on the one hand, and State and local governments on the other."[20]

On September 23, 1959, the President approved PL 86-373 which amends the Act and adds thereto Sec. 274. Subsection b. of this new section authorizes the Atomic Energy Commission, subject to the findings and certifications required by Subsection d., to enter into agreements with the governor of any state to provide for the transfer from the AEC to the state of regulatory authority with respect to byproduct materials, source materials, and special nuclear materials in quantities not sufficient to form a critical mass.[21]

It does not appear that the Laws of New York expressly authorize the Governor to enter into such an agreement. The existence of such express authority would be desirable, and should be conferred upon the Governor by the Legislature when next it meets.

The licensing function is included in the regulatory authority to be transferred to the state under a Sec. 274.b. agreement.[22] Although New York may decide against utilizing licensing as a regulatory device, the appropriate governmental regulatory bodies within the State should nevertheless possess express licensing authority. Presumably, these governmental bodies will be

17. Atomic Energy Act of 1954, as amended, P.L. 83-703 at §11.e.

18. *Id.* §11.x.

19. *Id.* §11.y.

20. "Selected Materials . . ." etc., referred to in note 10, *supra* at page 1.

21. §274.b. and d.

22. "The words 'and license' were not considered necessary because, as used elsewhere in the bill, the word 'regulate' includes the licensing function." S. Rep. No. 870, 86th Cong. 1st Sess. 2. (1959).

those three which now require registration of radiation sources and conduct field inspections thereof within their separate jurisdictions in the State: the State Departments of Health and Labor, and the New York City Department of Health.

The State Department of Labor,[23] and the New York City Department of Health,[24] appear already to possess express licensing authority. However, the State Department of Health appears not already to possess such express authority,[25] which should be conferred upon it by the Legislature when next it meets.

Before entering into an agreement pursuant to Sec. 274.b., the AEC will probably require that the state's proposed regulatory program fulfill certain conditions or meet certain standards prescribed by the AEC. These conditions or standards have not yet been publicly disclosed; indeed, they may not even as yet have been entirely identified or formulated by the AEC. When they are disclosed, a re-examination of the state's proposed program and the powers of its regulatory agencies will be in order, to ascertain whether they fulfill the AEC's conditions and meet its standards. Of course, one cannot now predict with assurance whether such re-examination will show at that time the need for additional State legislation.

It should also be noted that Sec 274.i. of the Act reads:

> "The Commission in carrying out its licensing and regulatory responsibilities under this Act is authorized to enter into agreements with any State, or group of States, to perform inspections or other functions on a cooperative basis as the Commission deems appropriate. The Commission is also authorized to provide training, with or without charge, to employees of, and such other assistance to, any State or political subdivision thereot or group of States as the Commission deems appropriate. Any such provision or [sic][26] assistance by the Commission shall take into account the additional expenses that may be incurred by a State as a consequence of the State's entering into an agreement with the Commission pursuant to subsection b."

Interim agreements entered into, and assistance provided, under the subsection quoted above could be particularly useful until, and to hasten the time that, an agreement with the State is entered into under Sec. 274.b.

Non-Military Nuclear Incidents

The report discusses the remote possibility of a non-military nuclear incident causing harm to the public, and recommends that a plan exist to protect the public in the unlikely event such an incident occurs. It might be desirable to vest ultimate responsibility over the radiological aspects of rescue, decontamination and similar activities in an appropriate, preferably local, official.

It is difficult to assert with certainty in whom such responsibility is now vested—whether in the fire, police, health or other department or official. This uncertainty arises at least in part because some relevant State statutes covering disasters do not expressly mention, and may be interpreted to exclude, non-military nuclear incidents. On the one hand, statutes covering civil defense assistance in non-military emergencies refer to "natural" disaster or disaster emergencies,[27] which, it may be contended, exclude all nuclear incidents, both military or non-military. On the other hand, the New York State Defense Emergency Act appears to cover only enemy attacks, and to exclude natural or peacetime disasters including non-military nuclear incidents.[28] (It should be noted, however, that the Interstate Civil Defense and Disaster Compact which refers to "any emergency or disaster from enemy attack or other cause (natural or otherwise)" may cover non-military nuclear incidents.[29] It should also be noted that the General Municipal Law may be applicable to non-military nu-

23. "Whenever the board finds that any industry, trade, occupation or process involves such elements of danger to the lives, health or safety of persons employed therein as to require special regulation for the protection of such persons, the board may make special rules to guard against such elements of danger by . . . requiring licenses to be applied for and issued by the department as a condition of carrying on such industry, trade, occupation or process, ..." N. Y. Labor Law, §28.2.

24. "The board of health may in its discretion grant, suspend or revoke permits for businesses or other matters in respect to any subject regulated by the department." New York City Charter, §561.

25. §201.1 of the N. Y. Public Health Law reads: "The department shall, as provided by law:
    (a)-(r) . . .
    (s) supervise and regulate the public health aspects of the use of ionizing radiation and the handling and and disposal of radio-active wastes."
However, in other subsections ((i); (j); (r)) of §201.1, the department is given authority to "*license*, supervise and regulate" (underscoring supplied). The omission of the word "license" from subsection (s) may have been intentional.

26. Probably should read "of".

27. N. Y. General Municipal Law, §209-n.(a); §209.o.2.

28. §3.3. The Report of the Joint Legislative Committee to Study the Military Law states: "The definition of civil defense in Article I, section 3, subdivision 3, differs from that contained in the 1950 act in that it is now limited to measures dealing with enemy attack. It no longer relates to natural or peacetime disasters and, therefore, civil defense officials are no longer authorized to mobilize or utilize civil defense forces for such disasters."

29. §1, Article I (Laws of New York, 1951, c. 674, §§1-3).

clear incidents: it provides that emergency relief squads may be organized within fire departments and fire companies and "may render services in case of accidents, calamities or other emergencies in connection with which their services may be required, as well as in case of alarms of fire".[30])

Clarifying legislation might be enacted to include expressly non-military nuclear incidents within the coverage of the statutes providing for assistance in non-military disasters and emergencies.

Insurance

The basic problems of nuclear liability and indemnity, not discussed in the report, have been handled by federal legislation, and it does not appear that major problems exist calling for State action or adversely affecting the State. The Price-Anderson amendments,[31] enacted in 1957 and amending the Atomic Energy Act of 1954, established the overall federal indemnity program. When subsequent developments disclosed that agencies of some states applying for, or possessing, AEC licenses were unable to comply with the financial responsibility requirement, amending legislation was enacted exempting from that requirement "any license . . . for the conduct of educational activities to a person found by the Commission to be a nonprofit educational institution, ..."[32]

State assistance has been sought by the insurance industry with regard to one phase of nuclear insurance in which the State prescribes the contents of the insurance policy. Affixed to most regular liability insurance policies is a clarifying "Nuclear Peril Exclusion Clause" declaring that the coverage of the policy does not extend to loss or damage caused by nuclear reaction or nuclear radiation or radioactive contamination. The insurance industry contends that such exclusions are proper because the nuclear peril was not contemplated when the policies and rates were conceived; and, furthermore, because the public receives substantial protection under the federal indemnity program and nuclear insurance policies issued to the owner or operator of a nuclear facility. However, to neither the statutory "standard fire insurance policy of the state of New York"[33] nor the automobile liability policies issued or delivered in the State[34] is such a clause affixed.

In many states including New York,[35] the form of the standard fire insurance policy is prescribed by statute, and in these states it would seem desirable (if not mandatory) that authority to affix to the policy the nuclear peril exclusion clause be granted by amendment to the statute. A uniform bill for this purpose was prepared by the insurance industry and approved by the National Association of Insurance Commissioners at its meeting in December, 1958. At least 18 states have to date enacted into law the substance of the bill.[36] Although the bill was introduced into the New York Legislature during its 1959 session,[37] it was not enacted. We have been advised that the bill will probably be reintroduced into the next session of the Legislature.

It appears that all states except New York and Massachusetts have approved affixing nuclear peril exclusion clauses to automobile liability policies. We have been advised that on August 19, 1959, proposed exclusions were filed with the State Insurance Department, and that the Department's action thereon is awaited.

Workmen's Compensation

Workmen's compensation, discussed in the report, has been traditionally a state responsibility. The protection of workers exposed to radiation hazards may present serious problems under state workmen's compensation laws. These problems stem, in part, from the inordinately long period of time that may elapse between radiation exposure and manifestation of injury; from the difficulties in proving that the injury was in fact caused by radiation exposure; and from the possibility of injury caused by the cumulative effect of successive radiation exposures, none of which individually would cause injury.

With regard to the general status of New York's Workmen's Compensation Law in relation to radiation hazards, it has been recently stated:

> "The two states which lead in nuclear industry are also the two which have been most active and most adequate in providing for workmen's compensation. Indeed, New York and California codes are regarded as models by most informed commentators in the field; and labor, in pressing for federal action to insure adequate protection, is likely to be satisfied should national legislation raise the standards of other states to the level of standards found in those two states. The legislative director of the AFL-CIO, quoted earlier, told the Joint Committee on Atomic Energy, at its hearing in February and March, 1958, that the last time he had checked into it, only two states—New York and California

30. §209-b.1.
31. See note 13, *supra.*
32. §170.k. of the Atomic Energy Act of 1954, as amended, was added by P.L. 85-744 (72 Stat. 837).
33. N. Y. Insurance Law, §168.
34. *Id.* at §167.
35. See note 33, *supra.*
36. Alaska; California; Connecticut; Hawaii; Idaho; Maine; Michigan; Minnesota; Nebraska; Nevada; New Hampshire; New Jersey; North Dakota; Oregon; Pennsylvania; South Dakota; West Virginia; Wisconsin.
37. Assembly No. 4665; Senate No. 1462.

—were fully and realistically facing up to the problem."[38]

The Committee of State Officials on Suggested State Legislation of the Council of State Governments published in February, 1959, a Supplement to "Suggested State Legislation Program for 1959". This Supplement discusses "Workmen's Compensation Coverage in Light of Radiation Hazards", and declares that meeting the following 10 standards is essential to adequate workmen's compensation coverage:

1. Compulsory laws requiring every employer subject to the act to accept and comply with its provisions.

2. No numerical exemption, so that the law applies to all employers subject to it regardless of the number of employees.

3. Reciprocal arrangements for extraterritorial coverage assuring coverage for an employee sustaining injury in a state other than that in which was made his employment contract.

4. Specific prohibition against employees waiving their rights to workmen's compensation.

5. Full coverage of occupational diseases, so that any disease caused by exposure to ionizing radiation is covered as an occupational disease under the law.

6. Flexible time limit for filing claim in occupational disease cases based on the date of the worker's knowledge and the date of disablement.

7. Unlimited medical benefits for both accidental injuries and occupational diseases.

8. Authority for workmen's compensation agency to supervise and order changes in medical care, so that specialized treatment may be given in all cases deemed necessary.

9. Second or subsequent injury funds covering broadly all types of permanent physical impairments likely to hinder or impede employment.

10. Special maintenance benefits during rehabilitation.

Of the ten standards identified above, the Supplement asserts that the New York law expressly meets seven, and that the three standards not so met relate to no numerical exemption, reciprocal arrangements for extraterritorial coverage, and authority for workmen's compensation agency to supervise medical care. According to the Supplement, the laws of only three other states (California, Hawaii and North Dakota) expressly meet more of these standards than does the New York law, and of only two other states (Minnesota and Washington) as many.

Under present examination is the extent, if any, to which the asserted failure of the New York State Workmen's Compensation Law to meet expressly those three standards may actually constitute an inadequacy. The Supplement notes with regard to the New York Law that the "Numerical exemption applies only in cases of nonhazardous employments. However, the fourteen groups of hazardous industries are so comprehensive that the numerical exemption seldom applies."[39] Moreover, as the Supplement notes, the New York courts have afforded some extraterritorial effect to the New York Workmen's Compensation Law.[40]

In this regard and in response to his inquiry, the Director of the Office of Atomic Development received from Solomon E. Senior, Chairman of the New York Workmen's Compensation Board, the following letter dated December 11, 1959:

"Dear Mr. Townsend:

"Commissioner Catherwood has asked me to reply to your inquiry dated November 30th concerning possible inadequate protection under the Workmen's Compensation Law for workers exposed to radiation hazards.

"We do not believe that the report of the Committee of State Officials on Suggested State Legislation, of the Council of State Governments, on 'Workmen's Compensation Coverage in Light of Radiation Hazards' reveals any deficiency of the New York Workmen's Compensation Law in the field of radiation coverage. The only relevant comment in the report, concerning authority of the Workmen's Compensation Board to supervise medical care, was expressly withdrawn by letter dated April 17, 1959 after the error of the conclusion was called to the Committee's attention. The Workmen's Compensation Board does have ample statutory power to supervise medical care furnished to workmen's compensation claimants.

"The reach of our statute with respect to employees engaged in hazardous employment in this State, and to New York employees working on transitory assignment in other states, represents additional protection to workers rather than a deficiency of coverage. The employee, or his dependents, may not be required to accept lower benefits under that statutes of another state if he has acquired vested rights in New York.

"The exemption of charitable, religious and educational institutions and other non-profit organizations having less than four workmen or operatives in regular employment probably has no relevance to radiation risks. Even if we may assume that some nonprofit atomic research is carried on in this State, it is not likely that such research project could be staffed with less than four employees who

38. "Development and Control of Nuclear Industry in California," a report prepared for the Subcommittee on Air Pollution and Radiation Protection of the Assembly Interim Committee on Public Health, by the Bureau of Public Administration, University of California, at page 168 (February, 1959).

39. At page 19.

40. At page 5.

would fall within the workmen or operatives category.

"On the affirmative side the New York statute not only covers radiation illness under §3, subd. 2, pars. 20 and 29 thereof but it makes provision in §§28 and 40 for delayed responses to exposure. Claim for disability may be made after the normal two years statute of limitations, within ninety days after disablement and knowledge that the radiation disease is or was due to the nature of the employment. In a death case that does not follow a disability case claim may be made after two years but benefits are not payable unless the disease was contracted within five years previous to date of death.

"Finally, we believe that this matter should be brought into perspective by reference to the minimal number of claims for radiation injury. Our ionizing radiation code was set up in 1955 for statistical purposes. In that year two radiation cases were closed. The following year there were five cases. Statistics for subsequent years have not been published but it is believed that they do not reflect a major departure from the pattern. Only one New York workmen's compensation case arising out of atomic energy development or research has reached the Courts. It is reported as *Matthews (Poirier)* v. *General Electric Company,* 2 AD 2d 623.

"I trust that this discussion will prove helpful to you. Should any further question arise we shall, of course, be pleased to advise."

Very truly yours,
/s/ S. E. Senior

Appendix V

UNDERGROUND STORAGE OF RADIOACTIVE WASTE*

It has been apparent for some years that New York State is ideally situated for the long term underground storage of high level radioactive wastes which may result from the expanded use of radioactive materials in industry. Within the State there is an area of approximately 10,000 square miles in the western and west-central sections of New York which is underlain by deposits of rock salt. This occurs as individual beds up to 40 to 50 feet thick in a salt zone which increases in thickness from 0 at the northern edge to approximately 1300 feet in the vicinity of Watkins Glen. The salt zone dips gently to the south so that along the New York-Pennsylvania border it may be as much as 3500 to 4000 feet below sea level. This fact combined with an increase in topographic elevation southward causes the salt to lie at such depths that it is not considered economical to mine it south of the latitude of the middle Finger Lakes. Salt has been tapped in New York at depths under 2500 feet both in wells and in mines and more recently in wells driven for the purpose of developing artificial cavities by solution of the salt for storage of liquefied petroleum gas.

A report of the Committee on Waste Disposal of the Division of Earth Sciences of the National Research Council published in September 1957 formalized the knowledge which we had merely assumed earlier, that is, that rock salt is an almost ideal container for radioactive waste. To summarize the conclusions in this report:

a) Salt has sufficient strength in underground cavities.
b) Salt is impervious to water so that the mined out space is very dry.
c) Salt deposits are essentially horizontal.
d) Salt deposits are usually found in areas where there are few earthquakes.
e) Salt has a rather high thermoconductivity so that the heat generated could be rather easily dissipated.

On the basis of pilot studies now under way it is apparent that three types of storage in salt are possible; these are: (1) storage in abandoned parts of existing mines; (2) storage in cavities dissolved from the salt by washing through walls, and (3) mining of cavities specifically for the purpose in unworked beds of salt. In New York it would be possible to develop storage areas in salt beds which could be completely separate

*Prepared by John G. Broughton, State Geologist.

from those beds which are being worked for commercial salt. In other words, there is sufficient salt both for continuation of the New York salt industry and for storage purposes for many hundreds of years to come. Furthermore, the salt is accessible in those areas in which there is ready transportation and access to major industrial centers.

In reaching a decision as to whether abandoned portions of operating mines or a mine particularly developed for storage purposes would be most satisfactory, consideration must be given to cost of sinking a shaft and developing the storage area. There is no question but that storage of high level waste in an already existing salt mine or in an especially excavated cavity sunk in this mine would be the most economical method of storing in rock salt.

Appendix VI

NEW YORK STATE ATOMIC ENERGY LAW

NEW YORK STATE ATOMIC ENERGY LAW
CHAPTER 41 LAWS OF NEW YORK

AN ACT to amend the executive law, in relation to the creation of an office of atomic development within the executive department, and making an appropriation for such office and its expenses.

Became a law March 9, 1959, with the approval of the Governor. Passed on message of necessity pursuant to article VII, section 5 of the constitution by a majority vote, three-fifths being present.

THE PEOPLE OF THE STATE OF NEW YORK, represented in Senate and Assembly, do enact as follows:

Section 1. The executive law is hereby amended by inserting herein a new article, to be article nineteen-d, to read as follows:

ARTICLE 19-D
ATOMIC ENERGY LAW

§ 450. Short title. This article shall be known, and may be cited, as the "state atomic energy law."

§ 451. Legislative findings and declaration of policy. The legislature hereby finds and declares that:

1. The development and use of atomic energy for peaceful purposes is a matter of important concern to the economic growth, and the health and safety of the people, of the state. It is, therefore, declared to be the policy of the state to encourage such development and use within the state as fully as possible, consistent with the health and safety of workers and the public as well as with the powers and responsibilities of the federal government and the governments of other states.

2. The development of atomic energy and of the industries producing or utilizing such energy is certain to create new opportunities for affirmative state action in the public interest and to result in new conditions calling for changes in state laws, regulations and procedures. Hence, it is declared to be the further policy of the state

(a) to initiate continuing studies of the ways in which atomic energy activities may more fruitfully be developed and coordinated, and private atomic energy enterprises more effectively encouraged;

(b) to adapt its laws, regulations and procedures from time to time to meet the new opportunities and conditions in ways that will encourage the development of atomic energy and of the private enterprises producing or utilizing such energy, while fully protecting the interest, health and safety of the public; and

(c) to assure the coordination of the studies and actions thus undertaken with other atomic energy development activities, public and private, throughout the United States.

§ 452. Definitions. When used in this article:

1. The term "atomic energy" means all forms of energy released in the course of nuclear fission or nuclear fusion or other nuclear transformation.

2. The term "director" means the director of the office of atomic development.

3. The term "office" means the office of atomic development.

4. The term "person" means any natural person, firm, association, public or private corporation, organization, partnership, trust, estate, or joint stock company, or any political subdivision of the state, or any officer or agent thereof.

§ 453. Office of atomic development; director; employees. There is hereby created within the executive department an office of atomic development. The head of such office shall be a director, who shall be appointed by the governor, by and with the advice and consent of the senate, and shall hold office during the pleasure of the governor. He shall receive an annual salary to be fixed by the governor within the amount available therefore by appropriation. He shall also be entitled to receive reimbursement for expenses actually and necessarily incurred by him in the performance of his duties. The director may appoint such officers, employees, agents, consultants and special committees as he may deem necessary, prescribe their duties, fix their compensation and provide for reimbursement of their expenses within the amounts available therefor by appropriation.

§ 454. General functions, powers and duties of office. The office of atomic development, by and through the director of his duly authorized officer or employee, shall, subject to the supervision and direction of the governor, have the following functions, powers and duties:

1. To advise the governor and the legislature with regard to the status of atomic energy research, development, education and regulation, and to make recommendations to the governor and the legislature designed to assure increasing progress in this field within the state.

2. To advise and assist the governor and the legislature in developing and promoting a state policy for atomic energy research, development, education and regulation.

3. To coordinate the atomic energy activities of the departments, agencies, offices, commissions and other agencies of the state and the political subdivisions of the state.

4. To cooperate with business enterprise and other persons concerned with atomic energy, the federal government and the governments of other states, and to correlate the atomic energy activities of the state and its political subdivisions with the atomic energy activities of the foregoing.

5. To sponsor or conduct studies, collect and disseminate information and issue periodic reports with regard to atomic energy research, development, education and regulation and proposals for further progress in the field of atomic energy.

6. To accept, without regard to the limitations of section eleven of the state finance law relating to unconditional gifts but with the concurrence of the director of the budget, and to administer loans, grants, or other contributions from the federal government or other sources, public or private, for carrying out the policies or purposes of this article.

7. To foster and support research and education relating to atomic energy through contracts or other appropriate means of assistance, including acquisition of land and construction of facilities, on such terms and conditions as the director may deem necessary or appropriate in the public interest and within the amounts available therefor by appropriation.

8. To keep the public informed with respect to atomic energy development within the state and the activities of the state and its political subdivisions relating thereto.

9. To do all things necessary or convenient to carry out the functions, powers and duties set forth in this article.

§ 455. Assistance of other departments, agencies and political subdivisions; review of regulations.

1. All departments, divisions, offices, commissions and other agencies of the state and all political subdivisions thereof are directed to keep the director fully and currently informed as to their activities relating to atomic energy or ionizing radiation.

2. The director may request from any department, division, office, commission or other agency of the state or any political subdivision thereof, and the same are authorized to provide, such assistance, services and data as may be required by the office in carrying out the purposes of this article.

3. No rule, regulation or ordinance or amendment thereto or repeal thereof, primarily and directly relating to atomic energy or the use of atomic energy, which any department, division, office, commission or other agency of the state or of any political subdivision thereof may propose to issue or promulgate, shall become effective until ninety days after it has been submitted to the director, unless either the governor or the director by order waives all or any part of such ninety day period.

§ 456. Contracts for atomic energy facilities. In making contracts or providing other appropriate assistance to foster and support atomic energy research or education, the director shall require that any state funds provided through the office for the acquisition of land or the construction of facilities affixed thereto be matched by funds or other contributions from other sources of at least equal amount or value, and that any such land and facilities be available for research and training, for such period of time and on such terms as may be approved by the director, to the departments, divisions, offices, commissions and other agencies of the state and of the political subdivisions thereof, to educational and non-profit institutions in the state and to other persons, consistent with the purposes of this law.

§ 457. Atomic energy special fund.

1. There is hereby established in the custody of the state comptroller a special fund, to be known as the "atomic energy special fund."

2. All moneys received from grants or other contributions accepted pursuant to subdivision six of section four hundred fifty-four of this article shall be deposited directly in the atomic energy special fund.

3. The moneys of the atomic energy special fund, subject to the terms and conditions of such grants or contributions and to segregation by the director of the budget, shall be available for payment of any and all costs and expenditures, including contracts and grants under section four hundred fifty-six of this article, required in carrying out the purposes of this article, and costs and expenditures incidental and appurtenant thereto. All payments from such fund shall be made on the audit and warrant of the state comptroller on vouchers approved by the director.

§ 458. Coordinating council. The governor shall designate a coordinating council, under the chairmanship of the director, to advise, assist and make recommendations to the director with respect to coordination of the atomic energy activities of the departments, divisions, offices, commissions and other agencies of the state and the political subdivisions of the state. The coordinating council shall consist of such representatives of state departments and agencies importantly concerned with atomic energy and such other persons as the governor may from time to time designate.

§ 459. Advisory committee.

1. There shall be within the office a general advisory committee consisting of not more than fifteen members appointed by the governor who shall broadly reflect the varied interests in and aspects of atomic energy within the state, one of whom shall be designated as chairman by the governor and who shall serve as chairman at the pleasure of the governor. The advisory committee shall meet from time to time at the call of the chairman or the director, shall advise the director on atomic energy matters and, if so requested by the director may make particular atomic energy studies.

2. The members of the advisory committee shall serve without compensation but shall be allowed their actual and necessary expenses incurred in the performance of their duties hereunder.

3. All members of the advisory committee shall be appointed for terms of three years, such terms to commence on April first and expire on March thirty-first; provided, however, that of the members first appointed one-third shall be appointed for one-year terms expiring on March thirty-first, nineteen hundred sixty, and one-third shall be appointed for two-year terms expiring on March thirty-first, nineteen hundred sixty-one. Any member chosen to fill a vacancy created otherwise than by expiration of term shall be appointed for the unexpired term of the member whom he is to succeed.

§ 460. No disqualification. No member of the coordinating council or the advisory committee shall be disqualified from holding any other public office or employment, nor shall he forfeit any such office or employment by reason of his appointment hereunder, notwithstanding the provisions of any general, special or local law, ordinance or city charter.

§ 2. Sections four hundred fifty, four hundred fifty-one, four hundred fifty-two and four hundred fifty-three of such law are hereby renumbered sections five hundred fifty, five hundred fifty-one, five hundred fifty-two and five hundred fifty-three, respectively.

§ 3. The sum of ten thousand dollars ($10,000), or so much thereof as may be necessary, is hereby appropriated out of any moneys in the state treasury in the general fund to the credit of the state purposes fund, not otherwise appropriated, and made immediately available, for the expenses of the office of atomic development, including personal service, maintenance, operation and travel in and outside the state, in carrying out the provisions of article nineteen-d of the executive law as added by this act and for the other purposes of said article nineteen-d, for the balance of the fiscal year of the state ending March thirty-first, nineteen hundred fifty-nine. Such moneys shall be payable on the audit and warrant of the comptroller on vouchers certified or approved in the manner prescribed by law.

§ 4. This act shall take effect immediately.

State of New York }
Department of State } ss:

I have compared the preceding with the original law on file in this office, and do hereby certify that the same is a correct transcript therefrom and of the whole of said original law.

CAROLINE K. SIMON
Secretary of State

Appendix VII

FACTS AND FIGURES

ACTIVE AEC LICENSES FOR RADIOACTIVE ISOTOPES
Leading Five States and National Total*

State	*Industrial*	*Medical*	*Other*	*Total*
	AUGUST 1959			
New York	157	283	96	536
California	188	213	74	475
Pennsylvania	148	112	118	378
Illinois	109	109	63	281
Texas	97	138	41	276
National Total	2,098	1,511	1,419	5,028
	DECEMBER 1958			
New York	160	280	94	534
California	173	197	52	422
Pennsylvania	137	95	62	294
Illinois	100	106	54	260
Texas	90	128	40	258
National Total	1,463	1,954	1,009	4,426
	JUNE 1958			
New York	150	255	60	465
California	149	180	43	372
Pennsylvania	130	85	45	260
Texas	87	113	29	229
Illinois	89	96	42	227
National Total	1,334	1,734	682	3,750

*Data from U. S. Atomic Energy Commission.

UNITED STATES ATOMIC POWER PLANTS*

Name	Power (Net electrical Kw)	First Criticality
ALASKA		
**U. S. Army at Fort Greely	1,700	1960
CALIFORNIA		
**General Electric Co. at Vallecitos	5,000	1957
Pacific Gas and Electric Co. at Humboldt Bay	50,000	1962
**U. S. Atomic Energy Commission at Santa Susana	6,000	1957
FLORIDA		
Florida West Coast Nuclear Group in Western Florida	50,000	1963
IDAHO		
**U. S. Atomic Energy Commission at National Reactor Testing Station	150	1951
**U. S. Atomic Energy Commission at National Reactor Testing Station	16,500	1961
**U. S. Atomic Energy Commission at National Reactor Testing Station	400	1961
**U. S. Atomic Energy Commission at National Reactor Testing Station	200	1958
ILLINOIS		
Commonwealth Edison Co. at Dresden	180,000	1959
**U. S. Atomic Energy Commission at Lemont	4,500	1956
MASSACHUSETTS		
Yankee Atomic Electric Co. at Rowe	110,000	1960
MICHIGAN		
Consumers Power Co. at Big Rock Point	50,000	1962
Power Reactor Development Co. at Lagoona Beach	90,000	1960
MINNESOTA		
**U. S. Atomic Energy Commission at Elk River	22,000	1961
NEBRASKA		
U. S. Atomic Energy Commission at Hallam	75,000	1962
NEW YORK		
Consolidated Edison Co. at Indian Point	151,000	1961
OHIO		
**U. S. Atomic Energy Commission at Piqua	11,400	1961
PENNSYLVANIA		
**General Public Utilities Corp. at Saxton	5,000	1961
Philadelphia Electric Co. at Peach Bottom	30–40,000	1963
U. S. Atomic Energy Commission at Shippingport	60,000	1957
SOUTH CAROLINA		
**Carolinas–Virginia Nuclear Power Associates, Inc. at Parr	17,000	1962
SOUTH DAKOTA		
Northern States Power Co. at Sioux Falls	62,000	1962
TENNESSEE		
**U. S. Atomic Energy Commission at Oak Ridge	24,000	1962
**U. S. Atomic Energy Commission at Oak Ridge	300	1957
VIRGINIA		
**U. S. Atomic Energy Commission at Ft. Belvoir	1,855	1957
WYOMING		
**U. S. Air Force at Sundance	1,000	1961
SITE TO BE SELECTED		
**U. S. Army	1,500	1961
**U. S. Atomic Energy Commission	16,500	1962

* Proper names which appear in the above list are those of the organizations in which ownership of the nuclear reactor portions of the plants is vested.

**Small power plants (less than 25,000 kilowatts).

UNITED STATES COMPANIES WITH NUCLEAR REACTOR CONTRACTS

CALIFORNIA
- Aerojet-General Corp., San Ramon
- American Radiator Corp., Mountain View
- General Dynamics Corp., San Diego
- General Electric Co., San Jose
- North American Aviation, Inc., Canoga Park

CONNECTICUT
- American Machine and Foundry Co., Greenwich
- Combustion Engineering, Inc., Windsor

ILLINOIS
- Cook Electric Co., Franklin Park

MARYLAND
- The Martin Co., Baltimore

MICHIGAN
- Power Reactor Development Corp., Lagoona Beach

NEW YORK
- Alco Products, Inc., Schenectady

PENNSYLVANIA
- Curtiss-Wright Corp., Quehanna
- Westinghouse Electric Corp., Pittsburgh

VIRGINIA
- Babcock and Wilcox Co., Lynchburg

WISCONSIN
- Allis-Chalmers Manufacturing Co., Milwaukee

PROTOTYPES OF POWER AND MILITARY PROPULSION REACTORS
Operating, Under Construction or Planned

CALIFORNIA
- SNAP Experimental Reactor Test No. 2

CONNECTICUT
- Small Submarine Reactor Prototype

IDAHO
- Experimental Prototype Gas Cooled Reactor
- Gas Cooled Reactor Experiment
- Heat Transfer Reactor Experiment No. 2
- Heat Transfer Reactor Experiment No. 3
- Large Ship Reactor Prototype
- Organic Moderated Reactor Experiment
- SIW Reactor Facility

NEVADA
- Small Scale Nuclear Test Rocket Experiment

NEW MEXICO
- High Temperature Gas Cooled Reactor Experiment
- Molten Plutonium Reactor Experiment No. 1
- Power Reactor Experiment No. 2

NEW YORK
- Destroyer Reactor Prototype
- Submarine Advanced Reactor Prototype

WYOMING
- Portable Medium Power Plant No. 1

SITE NOT DESIGNATED
- One Classified Reactor Plant

NUCLEAR MATERIALS TEST REACTORS

Name	*Thermo-Power (Kilowatts)*	*Start Up*
CALIFORNIA		
General Electric Co. Materials Testing Reactor	20,000	1958
IDAHO		
AEC Engineering Test Reactor	175,000	1957
AEC Materials Testing Reactor	40,000	1952
OHIO		
National Aeronautics and Space Administration Reactor	60,000	1960
PENNSYLVANIA		
Westinghouse Testing Reactor	20,000	1959
VIRGINIA		
Babcock & Wilcox Co. Testing Reactor*	60,000	

*Contract being negotiated with Atomic Energy Commission.

RESEARCH REACTORS IN OPERATION OR UNDER CONSTRUCTION

ARIZONA
University of Arizona (1)

CALIFORNIA
Aerojet General Corp. (1)
American Radiator and Standard Sanitary Corp. (1)
University of California (1)
University of California at Los Angeles (1)
E. O. Lawrence Radiation Laboratory-Livermore (3)
General Dynamics Corp. (1)
General Electric Co. (1)
North American Aviation, Inc. (3)
Stanford University (1)
U. S. Naval Post Graduate School (1)

COLORADO
Colorado State University (1)

DELAWARE
University of Delaware (1)

FLORIDA
University of Florida (1)

GEORGIA
Georgia Institute of Technology (1)

IDAHO
National Reactor Testing Station (6)

ILLINOIS
Argonne National Laboratory (5)
Armour Research Foundation (1)

IOWA
Iowa State College (1)

KANSAS
University of Kansas (1)

MAINE
University of Maine (1)

MARYLAND
National Naval Medical Center (1)

MASSACHUSETTS
Massachusetts Institute of Technology (1)
Worcester Polytechnic Institute (1)

MICHIGAN
University of Michigan (1)

MISSOURI
University of Missouri (1)

NEBRASKA
Omaha Veterans Administration Hospital (1)

NEW JERSEY
Industrial Reactor Laboratories, Inc. (1)

NEW MEXICO
Los Alamos Scientific Laboratory (2)

NEW YORK
Brookhaven National Laboratory (4)
University of Buffalo (1)
Cornell University (1)
Nuclear Development Corporation of America (1)
Union Carbide Nuclear Co. (1)

NORTH CAROLINA
North Carolina State College (2)

OHIO
University of Akron (1)
Battelle Memorial Institute (1)
Ohio State University (1)

OKLAHOMA
University of Oklahoma (1)
Oklahoma State University of Agriculture and Applied Sciences (1)

OREGON
Oregon State College (1)

PENNSYLVANIA
Curtiss-Wright Corp. (1)
Pennsylvania State University (1)

PUERTO RICO
Puerto Rico Nuclear Center (2)

SOUTH CAROLINA
Savannah River Plant (3)

TENNESSEE
Oak Ridge National Laboratory (5)
University of Tennessee (1)
Vanderbilt University (1)

TEXAS
Rice Institute (1)
Texas A&M College (2)

UTAH
University of Utah (1)

VIRGINIA
The Babcock and Wilcox Co. (1)
University of Virginia (1)
Virginia Polytechnic Institute (1)

WASHINGTON
Hanford Atomic Products Operations (1)
University of Washington (1)
Washington State College (1)

WASHINGTON, D. C.
Catholic University of America (1)
Walter Reed Rospital (1)

WEST VIRGINIA
West Virginia University (1)

WYOMING
University of Wyoming (1)

VALUE OF SHIPMENTS OF SELECTED ATOMIC ENERGY PRODUCTS
For 1957 by Selected Regions and States*

	Value of Shipments ($1000)
CONTINENTAL U. S., TOTAL**	100,016
New England	18,453
Massachusetts	11,741
Other (N. H., R. I., Conn.)	6,712
Middle Atlantic	32,501
Pennsylvania	22,597
New York***	5,871
New Jersey	4,033
East North Central	25,943
Ohio	12,635
Illinois	12,054
Other (Indiana, Mich., Wisc.)	1,254
West North Central (Minn., Iowa, Mo.)	2,194
Pacific	9,016
California	9,016
All other****	11,099

*This information was supplied by the Bureau of the Census of the U. S. Department of Commerce. Atomic Energy Products referred to in this tabulation include: Nuclear reactors (only those reactors which are produced and assembled at the place of manufacture); reactor vessels and tanks; reactor control rod drive mechanisms; accessory instrumentation for reactor control; heat exchangers, pumps, and valves uniquely designed for nuclear applications; pressurizers and other specialized reactor components; complete reactor fuel elements shipped directly for installation or use in a reactor; partially fabricated fuel materials not shipped directly for installation or use in a reactor; core structures (barrels, cans, boxes, plates, etc. not included in the above listed items); hot laboratory equipment; radiation detection and monitoring devices; radioactive isotopes shipped from plants producing isotopes; radiation sources and other radioactive materials produced from purchased isotopes; and control and measuring devices containing radioactive isotopes.

**The following states did not report shipping atomic energy products for 1957: Maine, Vermont, North Dakota, South Dakota, Nebraska, Kansas, West Virginia, South Carolina, Georgia, Kentucky, Mississippi, Arkansas, Louisiana, Montana, Idaho, Wyoming, Colorado, Utah, Nevada, Washington, Oregon, and the District of Columbia.

***Of the New York total, each of the following items accounted for more than $750 thousand value of shipments: accessory instrumentation for reactor control; pressurizers and their specialized reactor components; partially fabricated fuel materials not shipped directly for installation or use in a reactor; and radiation detection and monitoring devices.

****More than half of this value is represented by Tennessee.

COMPANIES SUBSTANTIALLY ENGAGED IN THE MANUFACTURE AND SALE OF ENRICHED URANIUM FUEL

CALIFORNIA
General Electric Co., San Jose

CONNECTICUT
*Combustion Engineering, Inc., Windsor
*Olin Mathieson Chemical Co., New Haven

MARYLAND
The Martin Co., Baltimore

MASSACHUSETTS
*M & C Nuclear, Inc., Attleboro
Englehard Industries, Inc., Plainville

NEW YORK
Sylvania-Corning Nuclear Corp., Bayside**

PENNSYLVANIA
Nuclear Materials & Equipment Corp., Apollo
*Westinghouse Electric Corp., Pittsburgh

VIRGINIA
*The Babcock and Wilcox Co., Lynchburg

*Fabricators of fuel for the Naval Reactor Program.
**In addition the National Lead Company has recently completed a fuel fabrication plant at Albany, New York.

U. S. ATOMIC ENERGY COMMISSION BUDGET DISTRIBUTION OF ESTIMATED COSTS BY STATE

Fiscal Year 1960*

State	*Total Costs (in thousands)*	*State*	*Total Costs (in thousands)*
Alabama	$79	Nebraska	6,809
Arizona	5,701	Nevada	19,535
Arkansas	220	New Hampshire	38
California	161,828	New Jersey	25,207
Colorado	91,981	New Mexico	404,863
Connecticut	28,727	New York	119,450
Delaware	22	North Carolina	4,659
District of Columbia	12,446	North Dakota	8
Florida	19,583	Ohio	201,974
Georgia	309	Oklahoma	122
Hawaii	86	Oregon	4,951
Idaho	68,781	Pennsylvania	79,651
Illinois	89,358	Rhode Island	281
Indiana	1,684	South Carolina	125,759
Iowa	18,491	South Dakota	7,284
Kansas	396	Tennessee	254,431
Kentucky	100,719	Texas	19,388
Louisiana	76	Utah	61,095
Maine	86	Virginia	4,857
Maryland	29,332	Washington	186,492
Massachusetts	14,997	West Virginia	168
Michigan	1,461	Wisconsin	2,680
Minnesota	10,124	Wyoming	39,937
Missouri	136,591		
Montana	39	Total	$2,362,756

*Includes only those costs which are currently identifiable by state. Fiscal Year 1960 began July 1959. The amounts shown represent costs incurred for operations in each state and, for any particular state, may include cost incurred for equipment, materials and supplies procured from outside that state.

AEC CONTROLLED THERMONUCLEAR PROGRAM COSTS BY LABORATORY

Amounts for Fiscal Year Beginning July 1, 1959

CALIFORNIA	
University of California Radiation Laboratory	$6,800,000
NEW JERSEY	
Princeton University	19,364,000
NEW MEXICO	
Los Alamos Scientific Laboratory	3,350,000
TENNESSEE	
Oak Ridge National Laboratory	5,570,000
***OTHER SITES**	1,467,000
TOTAL	$36,551,000

*Includes $325,000 at New York University. In addition $135,000 was expended in calendar year 1959 for work performed by the General Electric Company at Schenectady under a contract entered into prior to Fiscal Year 1960.

CONTRACTORS WITH OVER 1,000 EMPLOYEES ENGAGED IN AEC WORK IN 1959

CALIFORNIA	
North American Aviation, Inc., Canoga Park	2,372
University of California, Berkeley	2,148
University of California, Livermore	3,754
COLORADO	
Dow Chemical Co., Rocky Flats	1,767
CONNECTICUT	
United Aircraft Corp., Middletown	1,796
FLORIDA	
General Electric Co., Pannellus	1,213
IDAHO	
Phillips Petroleum Co., Idaho Falls	1,878
ILLINOIS	
University of Chicago, Lemont	3,444
IOWA	
Mason & Hanger—Silas Mason, Inc. Burlington	1,112
KANSAS	
Bendix Aviation Corp., Kansas City	7,707
KENTUCKY	
Union Carbide Nuclear Co., Paducah	1,713
NEW MEXICO	
ACF Industries, Inc., Albuquerque	2,117
Sandia Corp., Albuquerque	7,135
University of California, Los Alamos	3,481
Zia Co., Los Alamos	1,144
NEW YORK	
Associated Universities, Inc., Upton, L. I.	1,878
General Electric Co., Schenectady	2,009
OHIO	
General Electric Co., Evendale	2,403
Goodyear Atomics, Inc., Portsmouth	2,283
National Lead Co., Fernald	2,470
PENNSYLVANIA	
Westinghouse Electric Corp., Pittsburgh	2,769
SOUTH CAROLINA	
E. I. duPont de Nemours & Co., Inc. Savannah River	7,088
TENNESSEE	
Union Carbide Nuclear Co., Oak Ridge	13,516
WASHINGTON	
General Electric Co., Richland	7,887

MAJOR FEDERALLY OWNED REACTOR DEVELOPMENT CENTERS*

CONNECTICUT
Connecticut Aircraft Nuclear Engine Laboratory
United Aircraft Corp.—Contractor
Middletown

ILLINOIS
Argonne National Laboratory
University of Chicago—Contractor
Lemont

NEW YORK
Knolls Atomic Power Laboratory
General Electric Co.—Contractor
Schenectady

OHIO
Aircraft Nuclear Propulsion Department
General Electric Co.—Contractor
Evendale

PENNSYLVANIA
Bettis Plant
Westinghouse Electric Corp.—Contractor
Pittsburgh

TENNESSEE
Oak Ridge National Laboratory
Union Carbide Nuclear Co.—Contractor
Oak Ridge

*A number of other federal laboratories are engaged to lesser extents in reactor development work, including Brookhaven National Laboratory, Upton, Long Island; Hanford Atomic Products Operations, Richland, Washington; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; and Savannah River Laboratory, Aiken, South Carolina.

INDUSTRIAL CONCERNS SUBSTANTIALLY ENGAGED IN NON-WEAPON ATOMIC ACTIVITIES IN NEW YORK STATE*

EQUIPMENT

Alco Products, Inc.
Dunkirk, Schenectady

American Machine & Foundry Co.
Brooklyn

Anton Electronics Labs., Inc.
Brooklyn

Fairchild Camera and Instrument Co.
Syosset, L. I.

Ford Instrument Co.
Long Island City

General Electric Co.
Schnectady

I. B. M.
Poughkeepsie, Endicott

Picker X-Ray Corp.
White Plains

Stromberg-Carlson
Rochester

Universal Transistor Products, Corp.
Westbury, L. I.

MATERIALS

Allegheny Ludlum Steel Corporation
Dunkirk, Watervliet

Bar Ray Products, Inc.
Brooklyn

Carborundum Metals Co.
Akron, Niagara Falls

Knapp Mills, Inc.
Long Island City

National Carbon Co.
Niagara Falls

National Lead Co.
Albany

Nuclear Shielding Sup. & Ser., Inc.
White Plains

Sylvania-Corning Nuclear Corp.
Bayside, L. I.

Speer Carbon Co.
Niagara Falls

TRG, Inc.
Syosset, L. I.

SERVICES & RESEARCH

American Electric Power Service Corp.
New York

Associated Nucleonics, Inc.
Garden City, L. I.

Atomic Accessories, Inc.
Bellerose

Byrne Associates
New York

Burns and Roe, Inc.
New York

Consolidated Edison Co.
New York

Ebasco Services Incorporated
New York

Ford, Bacon & Davis, Inc.
New York

Gibbs & Cox, Inc.
New York

Gibbs & Hill, Inc.
New York

Lockwood Greene Engineers, Inc.
New York

Lummus Co.
New York

Nucleonics Corp. of America
Brooklyn

Nuclear Development Corp. of America
White Plains

Radiation Applications, Inc.
New York

Radiation Dynamics, Inc.
Westbury

Radiation Research Corp.
New York

Sanderson & Porter
New York

Texaco, Inc.
Beacon

Vitro Corp. of America
New York

Union Carbide Nuclear Co.
Sterling Forest

*Compiled from *Nucleonics* "Buyers' Guide," AEC contractor and licensee lists and Atomic Industrial Forum "Directory." Does not include companies with only corporate headquarters in New York.

AEC RESEARCH CONTRACTS WITH NEW YORK STATE ORGANIZATIONS

Obligations for the Fiscal Year Ending June 30, 1959

Institution	No.	Total $ Value	Physical Research No.	Physical Research $ Value	Biology and Medicine No.	Biology and Medicine $ Value	Radioisotope Development No.	Radioisotope Development $ Value
Airborne Industrial Laboratory	1	18,524	—	—	1	18,524	—	—
Albany Medical College	1	11,835	—	—	1	11,835	—	—
Albert Einstein College	1	10,000	—	—	1	10,000	—	—
American Institute of Physics	1	w/o funds	1	w/o funds*	—	—	—	—
Anton Electronics Laboratory, Inc.	1	24,934	—	—	1	24,934	—	—
Army Pictorial Service	1	88,000	—	—	—	—	1	88,000
Associated Nucleonics, Inc.	2	135,000	—	—	—	—	2	135,000
Associated Universities	1	95,000	1	95,000	—	—	—	—
Bausch and Lomb Optical Company	1	10,000	1	10,000	—	—	—	—
Boyce Thompson Institute	1	8,000	—	—	1	8,000	—	—
Brooklyn, Polytechnic Institute of	4	52,597	2	37,597	2	15,000	—	—
Buffalo, University of	4	41,720	3	41,720	1	w/o funds	—	—
Canisius College	1	3,500	1	3,500	—	—	—	—
Clarkson College of Technology	2	29,100	2	29,100	—	—	—	—
Columbia University	32	2,293,976	13	1,612,291	19	681,685	—	—
Cornell University	9	238,202	5	139,693	4	98,509	—	—
Del Electronics Corporation	1	50,000	—	—	1	50,000	—	—
Evans Research and Development Corporation	1	25,500	—	—	—	—	1	25,500
Fordham University	4	72,516	1	20,000	3	52,516	—	—
Health Research, Inc.	1	10,778	—	—	1	10,778	—	—
General Electric Company	2	149,882	2	149,882*	—	—	—	—
Long Island Biological Association	1	36,333	—	—	1	36,333	—	—
Materials Research Corporation	1	26,250	1	26,250	—	—	—	—
Mary Imogene Bassett Hospital	1	33,013	—	—	1	33,013	—	—
Montefiore Hospital	3	73,632	—	—	3	73,632	—	—
National Industrial Conference Board, Inc.	1	34,000	—	—	—	—	1	34,000
New York Medical College	1	15,000	—	—	1	15,000	—	—
New York Society for the Relief of the Ruptured and Crippled	1	18,831	—	—	1	18,831	—	—
New York, State University of	3	16,548	—	—	3	16,548	—	—
New York University	9	498,211	6	446,626*	3	51,585	—	—
Radiation Applications, Inc.	3	123,500	—	—	—	—	3	123,000
Rensselaer Polytechnic Institute	9	236,215	8	136,215	—	—	1	100,000
Research Foundation for Mental Hygiene	1	14,650	—	—	1	14,650	—	—
Rochester, University of	8	1,229,398	3	1,117,896	5	111,502	—	—
Sloan Kettering Institute	3	272,657	—	—	3	272,657	—	—
Syracuse University	6	78,002	2	44,458	4	33,544	—	—
Technical Research Group	1	35,000	—	—	—	—	1	35,000
Union Carbide Metals Co.	2	48,725	2	48,725	—	—	—	—
New York State Total	126	6,159,029	54	3,958,953	62	1,659,076	10	541,000
Total of all States, Wash., D. C. and Puerto Rico	616	46,675,692	485	29,893,714	540	13,181,979	77	3,600,000

*Includes one G. E. contract ($135,000) and two N. Y. U. contracts ($348,632) for thermonuclear research. The no-cost contract with the American Institute of Physics is also for thermonuclear research.

AEC GRANTS AWARDED TO NEW YORK STATE EDUCATIONAL INSTITUTIONS TO DATE

Institution	Total $ Value	Sci. and Eng. Total $ Value	Life Sciences No.	Life Sciences $ Value	Radioisotopes No.	Radioisotopes $ Value
Adelphi College	7,500	—	1	7,500	—	—
Albany Medical College of Union University	10,000	—	1	10,000	—	—
Buffalo, University of	66,142	48,642	1	17,500	—	—
City College of New York	18,787	18,787	—	—	—	—
Clarkson College of Technology	21,448	21,448	—	—	—	—
Columbia University	94,691	71,841	2	22,850	—	—
Cooper Union	13,413	13,413	—	—	—	—
Cornell University	258,825	209,525	4	49,300	—	—
Hunter College	1,628	—	1	1,628	—	—
Long Island University	8,000	—	1	8,000	—	—
Manhattan College	5,687	5,687	—	—	—	—
Maritime College	6,240	6,240	—	—	—	—
New York University	67,667	48,642	2	19,025	—	—
Rensselaer Polytechnic Institute	340,650	330,610	1	10,040	—	—
Rochester, University of	47,941	47,941	—	—	—	—
Rosary Hill College	5,220	—	1	5,220	—	—
State University of New York	48,642	48,642	—	—	—	—
Syracuse University	107,576	80,396	2	27,180	—	—
Yeshiva University	15,000	—	1	15,000	—	—
New York State Total	1,145,057	951,814	18	193,243	—	—
Total of all States, Wash., D. C. and Puerto Rico	13,356,220	10,941,097	152	1,810,707	32	604,416

NEW YORK STATE EDUCATIONAL INSTITUTIONS REPORTING SPECIAL ATOMIC FACILITIES OR EQUIPMENT

NUCLEAR PARTICLE ACCELERATORS OR GENERATORS

Columbia University, New York
Cornell University, Ithaca
New York University, New York
Rensselaer Polytechnic Institute, Troy
University of Rochester, Rochester
Syracuse University, Syracuse

SUB-CRITICAL ASSEMBLIES

University of Buffalo, Buffalo
The City College, New York
Columbia University, New York
**Maritime College at Fort Schuyler, New York
Manhattan College, New York
New York University, New York
Rensselaer Polytechnic Institute, Troy
University of Rochester, Rochester
Syracuse University, Syracuse

NUCLEAR REACTORS

*University of Buffalo, Buffalo
*Cornell University, Ithaca

ISOTOPE FACILITIES

**Albany, College of Education at, Albany
Brooklyn College, New York
Canisius College, Buffalo
Clarkson College, Potsdam
Columbia University, New York
Cornell University, Ithaca
**Downstate Medical Center, Brooklyn
Fordham University, New York
**College of Forestry, Syracuse
New York University, New York
Rensselaer Polytechnic Institute, Troy
University of Rochester, Rochester
Rockefeller Institute, New York
St. John's University, New York
Skidmore College, Saratoga
Syracuse University, Syracuse
Union College, Schenectady
**Upstate Medical Center, Syracuse
Yeshiva University, New York

*Not available but under construction.
**State University of New York.

NEW YORK STATE INDUSTRIAL USERS OF RADIOISOTOPES*

December, 1959

Adhesive Tape Corp.
Brooklyn

Adirondack Steel Casting Co.
Watervliet

Airborne Instruments Laboratory, Inc.
Mineola

Alco Products, Inc.
Schenectady

Allegheny Ludlum Steel Corp.
Buffalo

Allegheny Ludlum Steel Corp.
Watervliet

Allied Chemical Corp.
New York

Allied Chemical Corp.
Solvay

Alpha Portland Cement
Cementon

American Can Co.
Oswego

American Cyanamid Co.
Pearl River

American Machine & Foundry Co.
Brooklyn

American Tradair Corp.
Long Island City

American White Cross Laboratory, Inc.
New Rochelle

Amkor Corp.
New York

Ansco
Binghamton

Anton Electronic Laboratories, Inc.
Brooklyn

Armstrong Cork Co.
Fulton

Asiatic Petroleum Corp.
New York

Associated Nucleonics, Inc.
Garden City

Atlantic Pipe & Line Co.
Caledonia

Atlas Steel Casting Co.
Buffalo

Atomic Accessories, Inc.
Bellerose

Barclay Manufacturing Co., Inc.
Bronx

Bausch & Lomb Optical Co.
Rochester

Behr-Manning Co.
Troy

Bell Aircraft Corp.
Buffalo

Bendix Aviation Corp.
Sidney

Bethlehem Steel Co.
Staten Island

Blaw-Knox Co.
Buffalo

Boyce Thompson Institute for Plant Research Inc.
Yonkers

Bristol Laboratories, Inc.
Syracuse

Bulova Research & Development Laboratories, Inc.
Woodside

Burroughs Wellcome & Co.
Tuckahoe

Cambridge Instrument Co., Inc.
Ossining

The Carborundum Co.
Akron

The Carborundum Co.
Niagara Falls

The Carborundum Co.
Wheatfield

Carrier Corporation
Syracuse

Chase Manhattan Bank
New York

Chrysler Corp.
Syracuse

Columbia Box Board Mills, Inc.
Chatham

*Data obtained from New York State Health and Labor Departments.

The Columbia Mills, Inc.
Minetto

Combustion Engineering Co.
New York

Commissariat A L'Energie Atomique
New York

Consolidated Edison Co. of New York, Inc.
New York

Cornell Aeronautical Laboratory, Inc.
Buffalo

Corning Glass Works
Corning

Coty Products Corp.
New York

Crucible Steel Company of America
Syracuse

Curtiss-Wright Corp.
Buffalo

Curtiss-Wright Corp.
New York

Distillation Products Industries
Rochester

Dunlop Tire and Rubber Corp.
Buffalo

E. I. duPont de Nemours & Co., Inc.
Buffalo

E. I. duPont de Nemours and Co.
Newburgh

Eastern Testing Laboratories, Inc.
Corona

Eastman Kodak Co.
Rochester

Electrical Testing Laboratories, Inc.
New York

Electronic Products Co.
Mount Vernon

Elm Coated Fabrics Co., Inc.
Brooklyn

Evans Research & Development Corp.
New York

Excelco Developments, Inc.
Silvercreek

Fairchild Camera & Instrument Corp.
Syosset

Finch, Pruyn & Co., Inc.
Glens Falls

Fisher Scientific Co.
New York

The Flintkote Co.
Lockport

Food & Drug Research Laboratories, Inc.
Maspeth

Foster Wheeler Corp.
Dansville

Geigy Chemical Corp.
Ardsley

General Dynamics Corp.
Rochester

General Electric Co.
DeWitt

General Electric Co.
Elmira

General Electric Co.
Schenectady

General Electric Co.
Syracuse

General Electric Co.
Waterford

General Foods Corp.
Tarrytown

General Measurement, Inc.
New City

General Motors Corp.
Lockport

General Time Corp.
New York

Gordon-Lacey Chemical Products Co., Inc.
Maspeth

Gould Paper Co.
Lyons Falls

Grumman Aircraft Engineering Corp.
Bethpage

Guggenheim Institute
New York

Hampton Manufacturing Co.
New Rochelle

Haskins Laboratories, Inc.
New York

Harte & Co., Inc.
Brooklyn

Hooker Electrochemical Co.
Niagara Falls

F. C. Huyck & Sons
Rensselaer

F. C. Huyck & Sons
Huntington Station

Industrial X-Ray, Inc.
New Hyde Park

Interchemical Corp.
New York

International Business Machine Corp.
Endicott

International Business Machine Corp.
Kingston

International Business Machine Corp.
Poughkeepsie

International Business Machine Corp.
New York

International Paper Co.
Corinth

International Paper Co.
Niagara Falls

International General Electric Co.
New York

Jamestown Malleable Iron Corp.
Jamestown

The M. W. Kellogg Co.
New York

Kollsman Instrument Corp.
Elmhurst

Kieley & Mueller Inc.
Middletown

Knowlton Brothers, Inc.
Watertown

Lansen-Neeve Corp.
New York

Lederle Laboratories Division
Pearl River

Linde Air Products Co.
Tonawanda

Linde Company
Tonawanda

Lockheed Aircraft Service
Jamaica

P. Lorillard Co., Inc.
New York

Louvic Watch, Inc.
New York

Markite Co.
New York

John A. Manning Paper Co., Inc.
Green Island

Marinette Paper Co.
Fort Edward

Marubeni-Iida (America) Inc.
New York

Materials Research Corp.
Yonkers

The M. L. Mason Corp.
New York

National Carbon Co.
Niagara Falls

National Dairy Products Corp.
Oakdale

National Manufacturing Co.
Penn Yan

Newton Falls Paper Mill, Inc.
Newton Falls

New York Sugar Trade Laboratory, Inc.
New York

New York Telephone Co.
New York

New York Testing Laboratories, Inc.
New York

Nuclear Advisors, Inc.
Long Island City

Nuclear Development Corp. of America
White Plains

The Nuclear Research and Radiography Corp.
Depew

Nucleonic Corp. of America
Brooklyn

Olin Mathieson Chemical Corp.
Niagara Falls

Charles Pfizer & Co., Inc.
Brooklyn

Philips Electronics, Inc.
Mt. Vernon

Philips Laboratories
Irvington

Picker X-Ray Corp.
White Plains

Presto Plastics Products Co., Inc.
Brooklyn

R & N Corp.
New York

Radiation Applications, Inc.
New York

Radiation Research Corp.
New York

Radium Chemical Co., Inc.
New York

Radiological Service Co., Inc.
Bellerose

Radiological Service Co., Inc.
Long Island City

Republic Aviation Corp.
Farmingdale

Revere Copper & Brass, Inc.
Rome

Rome Strip Steel Co., Inc.
Rome

Rubber Corp. of America
Hicksville

Rubins Industries Corp.
Flushing

St. Regis Paper Co.
Deferiet

St. Regis Paper Co.
Yonkers

Samea Clock Co., Inc.
New York

Sam Tour & Co., Inc.
New York

Schwarz Laboratories, Inc.
Mount Vernon

Foster D. Snell, Inc.
New York

Socony Mobil Oil Co., Inc.
Brooklyn

Socony Mobil Oil Co., Inc.
Buffalo

Sperry Rand Corp.
Great Neck

Sperry Rand Corp.
Syosset

Standard Coated Products, Inc.
Buchanan

Stauffer Chemical Co.
Chauncey

Sterling Winthrop Research Institute
Rensselaer

Sylvania Electric Products, Inc.
Bayside, L. I.

Sylvania Electric Products, Inc.
Seneca Falls

The Symington-Gould Co.
Depew

Taylor Instrument Companies
Rochester

Technical Research Group
New York

Technical Tape Corp.
Morris Heights

TRG, Inc.
Syosset
Terminal Radio International, Ltd.
New York

Texaco, Inc.
Beacon

Unex Products Corp.
New York

Union Carbide Nuclear Co.
Tuxedo

United Aircraft Corp.
White Plains

United Kingdom Treasury and Supply Delegation
New York

U. S. Gypsum Co.
Oakfield

United States Steel Corp.
New York

Universal Transistor Products Corp.
Westbury, L. I.

The Upson Co.
Lockport

Julius Weinberger
East Northport

Westinghouse Electric Corp.
Elmira

West Virginia Pulp & Paper Co.
Mechanicville

Wheeler Laboratories, Inc.
Great Neck

Wilson's American Co.
New York

Yuta Consolidated Industries, Inc.
Buffalo

S-10

New York State Atomic Research and Development Authority Act

For text of memorandum relating to this chapter, see p. 3614.

CHAPTER 210

An Act to amend the public authorities law, in relation to creating the New York state atomic research and development authority for the purpose of encouraging the maximum development and use of atomic energy for peaceful and productive purposes within the state and providing for the powers of such authority.

Became a law March 27, 1962, with the approval of the Governor.

Effective April 1, 1962.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section 1. Legislative findings and declaration of policy. The legislature hereby finds, determines and declares:

1. That the maximum development and use within the state of atomic energy for peaceful and productive purposes, consistent with the health and safety of the public, will promote the state's economic growth and will be in the best interests of the health and welfare of the state's population.

2. That the encouragement of such development and use requires action by the state in the provision of services required by industrial, commercial, medical, scientific, educational and governmental organizations.

3. That such encouragement further requires action by the state in conducting, sponsoring, assisting and fostering programs of research and development in the methods of production and use of atomic energy as well as in accumulating and disseminating pertinent information.

4. That such state action can most effectively and appropriately be accomplished by a public benefit corporation.

It is hereby declared to be the policy of the state to encourage, through the public benefit corporation hereinafter created, the maximum development and use within the state of atomic energy for peaceful and productive purposes.

§ 2. The public authorities law is hereby amended by adding to article eight thereof a new title, to be title nine, to read as follows:

TITLE 9

NEW YORK STATE ATOMIC RESEARCH AND DEVELOPMENT AUTHORITY

Section

§ 1850. Short title

This title may be cited as the "New York state atomic research and development authority act."

§ 1851. Definitions

As used or referred to in this title, unless a different meaning clearly appears from the context:

1. "Atomic energy" shall mean all forms of energy released in the course of nuclear fission, nuclear fusion or other nuclear transformation.

2. "Authority" shall mean the New York state atomic research and development authority created by section one thousand eight hundred fifty-two of this title.

3. "Bonds" and "notes" shall mean such bonds and notes as are issued by the authority pursuant to this title.

4. "Comptroller" shall mean the comptroller of the state.

5. "Person" shall mean any natural person, firm, association, public or private corporation, organization, partnership, trust, estate, or joint stock company, or any political subdivision of the state, or any officer or agent thereof.

6. "Real property" shall mean lands, waters, rights in lands or waters, structures, franchises, improvements and interests in land, including lands under water and riparian rights, and any and all other things and rights usually included within said term and includes also any and all interests in such property less than full title, such as easements permanent or temporary, rights-of-way, uses, leases, licenses and all other incorporeal hereditaments in every estate, interest or right, legal or equitable.

7. "State" shall mean the state of New York.

8. "State agency" shall mean any officer, department, board, commission, bureau, division, corporation, agency or instrumentality of the state.

9. "Superintendent" shall mean the superintendent of public works of the state of New York.

§ 1852. New York state atomic research and development authority

1. There is hereby created the "New York state atomic research and development authority". The authority shall be a body corporate and politic, constituting a public benefit corporation. Its membership shall consist of the director of the state office of atomic development and two

members to be appointed by the governor, by and with the advice and consent of the senate.

2. The members first appointed by the governor shall serve for terms ending April first, nineteen hundred sixty-five and nineteen hundred sixty-eight, respectively. Persons appointed by the governor for full terms as their successors shall serve for terms of six years each commencing as of April first. In the event of a vacancy occurring in the office of a member appointed by the governor, by death, resignation or otherwise, the governor shall appoint a successor, by and with the advice and consent of the senate, to serve for the balance of the unexpired term.

3. The director of the state office of atomic development shall serve as chairman and shall be the chief executive officer of the authority. He shall be primarily responsible for the discharge of the executive and administrative functions of the authority. He shall not engage in any business, vocation or employment other than that of serving as chairman, except as director of the state office of atomic development or as an advisor or consultant to other agencies of the state, the federal government, or interstate organizations of which the government of the state is a member.

4. The members shall serve without compensation, but each member, including the chairman, shall be entitled to reimbursement for his actual and necessary expenses incurred in the performance of his official duties.

5. Any member (except the chairman) may engage in private employment, or in a profession or business, subject to the limitations contained in sections seventy-three and seventy-four of the public officers law. The authority shall, for the purposes of such sections, be a "state agency" and such members shall be "officers" of the agency for the purposes of said sections.

6. Notwithstanding any inconsistent provisions of law, general, special or local, no officer or employee of the state, or of any civil division thereof, shall be deemed to have forfeited or shall forfeit his office or employment by reason of his acceptance of membership on the authority; provided, however, a member who holds such other public office or employment shall receive no additional compensation or allowance for services rendered pursuant to this article, but shall be entitled to reimbursement for his actual and necessary expenses incurred in the performance of such services.

7. The governor may remove any member appointed by the governor for inefficiency, neglect of duty or misconduct in office after giving him a copy of the charges against him, and an opportunity to be heard, in person or by counsel, in his defense, upon not less than ten days' notice. If any member shall be so removed, the governor shall file in the office of the department of state a complete statement of charges made against such member, and his findings thereon, together with a complete record of the proceedings. The holding of office by the director of the state office of atomic development shall continue to be governed by the provisions of section four hundred fifty-three of the executive law.

8. The powers of the authority shall be vested in and exercised by a majority of the members.

9. The authority may appoint such persons to serve as officers, agents or employees of the authority as it may deem advisable and may prescribe their duties and fix their compensation, subject to the civil service law and the rules and regulations of the civil service commission of the state.

10. The authority may appoint one or more advisory committees consisting of not more than seven members each to consider and advise the authority upon all matters submitted to them by the authority and to recommend to the authority such changes in the administration of this title and the operations of the authority as the advisory committee may deem desirable. Members of advisory committees shall serve without salary for such terms, not to exceed four years, as the authority may determine, and shall be entitled to reimbursement for their actual and necessary travel expenses incurred in the performance of their official duties.

§ 1853. Approval power of the governor

1. No action taken at any meeting of the authority shall have force or effect until the governor shall have an opportunity to approve or veto the same.

2. For the purpose of procuring such approval or veto, the authority shall by rule designate an officer of the authority to transmit to the governor at the executive chamber in Albany a certified copy of the minutes of every meeting of the authority as soon after the holding of such meeting as such minutes can be written out. The governor shall, within fifteen days after such minutes shall have been delivered to the executive chamber as aforesaid, cause the same to be returned to the authority either with his approval or with his veto of any action therein recited as having been taken, provided, however, that if the governor shall not return the said minutes within the said period then at the expiration thereof any action therein recited shall have full force and effect according to the wording thereof.

3. If the governor within the said period returns the said minutes with a veto against any action recited therein, then such action shall be null and void.

4. The governor may by order filed with the authority relieve the authority from the duty of procuring his approval of its action upon any particular matter or class of matters, and thereupon the authority shall be relieved from reporting the same to him.

§ 1854. Purposes and specific powers of the authority

The purposes of the authority shall be to encourage and cooperate in the maximum development and use of atomic energy for peaceful and productive purposes within the state. In carrying out such purposes, the authority shall, with respect to the activities specified, have the following powers:

1. Research and development. To conduct, sponsor, assist and foster programs of research and development in the methods of production and use of atomic energy, including the power to establish, acquire, operate, develop and manage facilities therefor.

2. The provision of services. To provide services required for the development and use of atomic energy by the industrial, commercial, medical, scientific, educational and governmental organizations within the state, including the power to establish, acquire and develop facilities therefor not otherwise available within the state, and to operate and manage such facilities.

3. The dissemination of information. To accumulate and disseminate information relating to the development and use of atomic energy, including the power to conduct, sponsor, assist and foster studies and surveys, and publish the results thereof.

In exercising the powers granted by this title, the authority shall, insofar as practicable, cooperate and act in conjunction with industrial, commercial, medical, scientific and educational organizations within the state, and with agencies of the federal government, of the state and its political subdivisions, of other states, and joint agencies thereof.

In carrying out its corporate purposes and in exercising the powers granted by this title, the authority shall be regarded as performing a governmental function.

§ 1855. General powers of the authority

Subject to the other provisions of this title and the provisions of any contract with bondholders or noteholders, the authority shall have the following powers in addition to any powers specifically conferred upon the authority elsewhere in this title:

1. To sue and be sued.

2. To have a seal and alter the same at pleasure.

3. To make and alter by-laws for its organization and internal management.

4. To make rules and regulations governing the exercise of its corporate powers and the fulfillment of its corporate purposes under this title, which shall be filed with the department of state in the manner provided by section one hundred two of the executive law.

5. To purchase, receive, lease, or otherwise acquire and hold in the name of the state, and to sell, convey, mortgage, lease, pledge or otherwise dispose of, upon such terms and conditions as the authority may deem advisable, real or personal property, together with such rights and privileges as may be incidental and appurtenant thereto and to the use thereof, including but not restricted to, any real or personal property acquired by the authority in the satisfaction of obligations contained in contracts, leases or other arrangements.

6. To enter into contracts, leases or other arrangements providing for the establishment, operation, development and management of any property or facility under the jurisdiction of the authority.

7. To enter into contracts, leases or other arrangements permitting any person to use any property or facility under the jurisdiction of the authority; permitting such person to build or add facilities or improvements upon such property or facility; and providing, at the discretion of the authority, for the acquisition by the authority of any such facilities or improvements built or added by such person, upon such terms and conditions as the authority may deem advisable.

8. To sell or otherwise make available, upon such terms and conditions as the authority may deem advisable, any product, by-product or service produced in or provided by any facility under its jurisdiction.

9. To fix and collect fees, rentals and charges for the use of any property or facility under its jurisdiction, or for the sale of any product, by-product or service produced in or provided by any such facility, and to establish the rights and privileges created upon payment thereof. Such fees, rentals and charges shall be established by the authority so as to produce revenues sufficient, together with any other funds available to the authority, to meet the expenses of maintenance and operation of the facilities of the authority, to repay any moneys repayable to the state, to fulfill the terms of agreements with the holders of its bonds, notes or other obligations, and to provide funds for such other corporate purposes as the authority may deem appropriate.

10. To enter into any contracts and to execute all instruments necessary or convenient for the exercise of its corporate powers and the fulfillment of its corporate purposes under this title.

11. To borrow money and to issue negotiable bonds, notes or other obligations and to provide for the rights of the holders thereof.

12. To enter into agreements to pay annual sums in lieu of taxes to any municipality or taxing district of the state in respect of any real property which is owned by the authority, leased by the authority to a person and located in such municipality or taxing district, provided, however, that the amount so paid for any year upon any such property shall not exceed the sum last paid as taxes on such property to such municipality or taxing district prior to the time of its acquisition by the authority.

13. To procure insurance, or obtain indemnification from the federal government or other persons, against any loss in connection with the assets of the authority and any liability in connection with the activities of the authority, such insurance or indemnification to be procured or obtained in such amounts, and from such sources, as the authority deems to be appropriate.

14. To accept any gifts or grants or loans of funds or property or financial or other aid in any form from the federal government or any agency or instrumentality thereof or from the state or from any other source and to comply, subject to the provisions of this title, with the terms and conditions thereof.

15. To enter into any lands, waters or premises for the purpose of making borings, soundings, surveys or other investigations necessary to the purposes of the authority or to public health and safety.

16. To engage the services of bond counsel, financial advisors, accountants, engineers, attorneys and other private consultants on a contract basis for rendering professional and technical assistance and advice.

17. To do all things necessary or convenient to carry out its corporate purposes and exercise the powers given and granted by this title.

§ 1856. Acquisition of real property

1. Upon determination by the authority that any real property is necessary for its corporate purposes, the superintendent shall acquire the

same in the name of the state by dedication, by agreement, by condemnation pursuant to the condemnation law, or by appropriation in the manner provided by section thirty of the highway law, and payment therefor shall be made by the authority from the proceeds of sale of its bonds, notes or other obligations, or from other available moneys therefor. The authority shall hold such property in the name of the state and shall have the right to possess and use for its corporate purposes, so long as its corporate existence shall continue, all such real property and rights in real property so acquired.

2. At any time after this title shall become effective, the authority may, by resolution, assume jurisdiction over and hold in the name of the state all or any part of the real property acquired and held in the name of the state by the state office of atomic development. Upon the effective date of such resolution, the authority shall hold any such real property in the name of the state and shall have the right to possess and use for its corporate purposes, so long as its corporate existence shall continue, any such real property.

§ 1857. Officers and employees; transfer, promotion and seniority

1. Officers and employees of state departments and agencies may be transferred to the authority and officers and employees of the authority may be transferred to state departments and agencies without examination and without loss of any civil service status or rights. No such transfer may, however, be made except with the approval of the head of the state department or division involved and the director of the budget and the chairman of the authority and in compliance with the rules and regulations of the state civil service commission.

2. Promotions from positions in state departments and agencies to positions in the authority, and vice versa, may be made from interdepartmental promotion lists resulting from promotion examinations in which both employees of the authority and employees of the state are eligible to participate.

3. In computing seniority for purposes of promotion or for the purposes of suspension or demotion upon the abolition of positions in the service of the authority or in the service of the state, in the case of an employee of the authority a period of prior employment in the service of the state shall be counted in the same manner as though such period of employment had been in the service of the authority, and in the case of an employee of the state a period of prior employment in the service of the authority shall be counted in the same manner as though such period of employment had been in the service of the state. For the purposes of the establishment and certification of preferred lists, employees suspended from the authority shall be eligible for reinstatement in the service of the state, and employees suspended from the service of the state shall be eligible for reinstatement in the service of the authority, in the same manner as though the authority were a department of the state.

§ 1858. Assistance by state officers, departments, boards, divisions and commissions

At the request of the authority, engineering and legal services for such authority shall be performed by the department of public works and the department of law, respectively, and all other state agencies shall upon request by the authority render services within their respective functions.

§ 1859. Deposit, investment and accounting of moneys of the authority

1. All moneys of the authority, from whatever source derived, shall be paid to the commissioner of taxation and finance as agent of the authority, who shall not commingle such moneys with any other moneys. Such moneys shall be deposited in a separate bank account or accounts to be known as the "atomic research and development operating fund." The moneys in such fund may be expended for payment of any and all costs and expenditures as required for the corporate purposes of the authority; provided, until such time as the state of New York is reimbursed in full for all moneys repayable to the state by the authority, all expenditures from this fund shall be subject to the prior approval of the director of the budget of the state of New York. The moneys in such fund when made available shall be paid out on check of the commissioner of taxation and finance on requisition of the chairman of the authority or of such other person as the authority shall authorize to make such requisition. All deposits of such moneys shall, if required by the commissioner of taxation and finance or the authority, be secured by obligations of the United States or of the state of New York of a market value equal at all times to the amount of the deposit and all banks and trust companies are authorized to give such security for such deposits.

2. Notwithstanding the provisions of subdivision one of this section, the authority shall have power, subject to the approval of the commissioner of taxation and finance, to contract with the holders of any of its bonds or notes, as to the custody, collection, securing, investment and payment of any moneys of the authority, or of any moneys held in trust or otherwise for the payment of bonds or notes or in any way to secure notes or bonds, and to carry out any such contract. Moneys held in trust or otherwise for the payment of bonds or notes or in any way to secure notes or bonds and deposits of such moneys may be secured in the same manner as moneys of the authority, and all banks and trust companies are authorized to give such security for such deposits.

3. Any moneys of the authority not required for immediate use may, at the discretion of the authority, be invested by the commissioner of taxation and finance in obligations of the state or of the United States of America or obligations the principal and interest of which are guaranteed by the state or the United States of America.

4. Subject to the provisions of any contract with bondholders and noteholders and to the approval of the comptroller, the authority shall prescribe a system of accounts.

§ 1860. Bonds and notes

1. The authority shall have the power and is hereby authorized to issue at one time or in series from time to time negotiable bonds and notes as, in the opinion of the authority, shall be necessary to provide sufficient moneys for achieving the authority's corporate purposes, including the establishment of reserves to secure the bonds and notes and the payment of interest on bonds and notes, which bonds and notes, however,

shall not exceed an aggregate principal amount of thirty million dollars ($30,000,000), excluding bonds and notes issued to refund outstanding bonds and notes.

2. The authority shall have power from time to time to renew notes or to issue renewal notes for such purpose, to issue bonds to pay notes, and, whenever it deems refunding expedient, to refund any bond by the issuance of new bonds, whether the bonds to be refunded have or have not matured, and may issue bonds partly to refund bonds then outstanding and partly for any other corporate purpose of the authority. Bonds issued for refunding purposes shall be sold and the proceeds applied to the purchase, redemption or payment of the bonds to be refunded.

3. Except as may otherwise be expressly provided by the authority, every issue of bonds or notes shall be general obligations payable out of any moneys or revenues of the authority, subject only to any agreements with the holders of bonds or notes pledging any receipts or revenues.

4. Whether or not the bonds or notes are of such form and character as to be negotiable instruments under the terms of the negotiable instruments law (constituting chapter thirty-eight of the consolidated laws) the bonds or notes shall be and are hereby made negotiable instruments within the meaning of, and for all the purposes of, the negotiable instruments law, subject only to the provisions of the bonds for registration.

5. The bonds and notes shall be authorized by resolution of the authority, shall bear such date or dates and mature at such time or times as such resolution shall provide, except that notes and any renewals thereof shall mature within five years from their respective dates and bonds shall mature within forty years from their respective dates. The bonds and notes shall bear interest at such rate or rates, be in such denomination, be in such form, either coupon or registered, carry such registration privileges, be executed in such manner, be payable in such medium of payment at such place or places, and be subject to such terms of redemption as such resolution or resolutions may provide.

6. Bonds and notes shall be sold by the authority, at public or private sale, at such price or prices as the authority may determine. Bonds and notes of the authority shall not be sold by the authority at private sale unless such sale and the terms thereof have been approved in writing by the comptroller, where such sale is not to the comptroller, or by the director of the budget, where such sale is to the comptroller.

7. In the discretion of the authority any bonds or issue of bonds or notes or issue of notes may be secured by such resolution or by a trust indenture by and between the authority and a corporate trustee which may be any trust company or bank having the powers of a trust company in the state or by a secured loan agreement or other instrument. Such resolution, trust indenture, loan agreement or other instrument may contain any usual or customary provisions, covenants or limitations for bonds or notes of similar nature which shall be a part of the contract with the holders thereof, including such provisions for protecting and enforcing the rights and remedies of bondholders and noteholders as may be reasonable and proper and not in violation of law.

8. Any resolution or resolutions authorizing any notes or bonds or any issue thereof may contain provisions, which shall be a part of the contract with the holders thereof, as to:

(a) pledging all or part of the fees, charges, gifts, grants, rents, revenues or other moneys received or to be received and leases or agreements to secure the payment of the notes or bonds or of any issue thereof subject to such agreements with bondholders as may then exist;

(b) the rates of the fees or charges to be established, and the amounts to be raised in each year thereby and the use and disposition of the fees, charges, gifts, grants, rents, revenues or other moneys received or to be received;

(c) the setting aside of reserves or sinking funds, and the regulation and disposition thereof;

(d) limitations on the purpose to which the proceeds of sale of any issue of notes or bonds then or thereafter to be issued may be applied and pledging such proceeds to secure the payment of the notes or bonds or of any issue thereof;

(e) limitations on the issuance of additional notes or bonds; the terms upon which additional notes or bonds may be issued and secured; the refunding of outstanding or other notes or bonds;

(f) the procedure, if any, by which the terms of any contract with bondholders or noteholders may be amended or abrogated, the amount of notes or bonds the holders of which must consent thereto, and the manner in which such consent may be given;

(g) any other matters, of like or different character, which in any way affect the security or protection of the notes or bonds.

9. It is the intention hereof that any pledge made by the authority shall be valid and binding from the time when the pledge is made, that the moneys so pledged and thereafter received by the authority shall immediately be subject to the lien of such pledge without any physical delivery thereof or further act, and that the lien of any such pledge shall be valid and binding as against all parties having claims of any kind in tort, contract or otherwise against the authority irrespective of whether such parties have notice thereof. Neither the resolution nor any other instrument by which a pledge is created need be recorded.

10. Neither the members of the authority nor any person executing the bonds or notes shall be liable personally on the bonds or notes or be subject to any personal liability or accountability by reason of the issuance thereof.

11. Subject to such agreements with bondholders or noteholders as may then exist, the authority shall have power out of any funds available therefor to purchase bonds or notes at a price not exceeding (a) if the notes or bonds are then redeemable, the redemption price then applicable plus accrued interest to the next interest payment date thereon, or (b) if the notes or bonds are not then redeemable, the redemption price applicable on the first date after such purchase upon which the notes or bonds become subject to redemption plus accrued interest to said date. Bonds and notes so purchased shall thereupon be cancelled.

12. The state does hereby pledge to and agree with the holders of any bonds or notes that the state will not limit or alter the rights and powers

vested in the authority by this title to fulfill the terms of any contract made by the authority with such holders, or in any way impair the rights and remedies of such holders until such bonds and notes, together with the interest thereon, with interest on any unpaid installments of interest, and all costs and expenses in connection with any action or proceeding by or on behalf of such holders, are fully met and discharged. The authority is authorized to include this pledge and agreement of the state, insofar as it refers to holders of any bonds or notes, in any contract with such holders.

§ 1861. Exemption from taxation of the property and income of the authority

The property of the authority and its income and operations shall be exempt from taxation.

§ 1862. Exemption from taxation of bonds and notes

The state covenants with the purchasers and with all subsequent holders and transferees of bonds and notes, in consideration of the acceptance of and payment for the bonds and notes, that the bonds and notes and the income therefrom, and all moneys, funds and revenues pledged to pay or secure the payment of such bonds and notes shall at all times be free from taxation, except for estate and gift taxes and taxes on transfers.

§ 1863. Bonds and notes legal investments for fiduciaries

The bonds and notes are hereby made securities in which all public officers and bodies of the state and all municipalities and municipal subdivisions, all insurance companies and associations and other persons carrying on an insurance business, all banks, bankers, trust companies, savings banks and savings associations, investment companies and other persons carrying on a banking business, all administrators, guardians, executors, trustees and other fiduciaries, and all other persons whatsoever who are now or who may hereafter be authorized to invest in bonds or other obligations of the state, may properly and legally invest funds including capital in their control or belonging to them. Notwithstanding any other provisions of law, the bonds and notes of the authority are also hereby made securities which may be deposited with and may be received by all public officers and bodies of this state and all municipalities and municipal subdivisions for any purpose for which the deposit of bonds or other obligations of the state is now or may hereafter be authorized.

§ 1864. Right of state to require redemption of bonds

Notwithstanding and in addition to any provisions for the redemption of bonds which may be contained in any contract with the holders of the bonds, the state may, upon furnishing sufficient funds therefor, require the authority to redeem, prior to maturity, as a whole, any issue of bonds on any interest payment date not less than twenty years after the date of the bonds of such issue at one hundred five per cent of their face value and accrued interest or at such lesser redemption price as may be provided in the bonds in case of the redemption thereof as a whole on the redemption date. Notice of such redemption shall be published in at least two newspapers published and circulating respectively in the cities of Albany and New York at least twice, the first publication to be at least thirty days before the date of redemption.

§ 1865. Rights and remedies of bondholders and noteholders

The holders of bonds and notes shall have the following rights and remedies, subject to the terms of the resolution authorizing such bonds and notes or any trust indenture, secured loan agreement or other instrument related thereto:

1. In the event that the authority shall default in the payment of principal of or interest on any issue of bonds or notes after the same shall become due, whether at maturity or upon call for redemption, and such default shall continue for a period of thirty days, or in the event that the authority shall fail or refuse to comply with the provisions of this title, or shall default in any contract made with the holders of any issue of bonds or notes, the holders of twenty-five per centum in aggregate principal amount of the bonds or notes of such issue then outstanding, by instrument or instruments filed in the office of the clerk in the county of Albany and approved or acknowledged in the same manner as a deed to be recorded, may appoint a trustee to represent the holders of such bonds or notes for the purposes herein provided.

2. Such trustee may, and upon written request of the holders of twenty-five per centum in principal amount of such bonds or notes then outstanding shall, in his or its own name

(a) by mandamus or other suit, action of proceeding at law or in equity enforce all rights of the bondholders or noteholders, including the right to require the authority to collect fees, rentals and charges adequate to carry out any agreements with the holders of such bonds or notes and to perform its duties under this title;

(b) bring suit upon such bonds or notes;

(c) by action or suit in equity, require the authority to account as if it were the trustee of an express trust for the holders of such bonds or notes;

(d) by action or suit in equity, enjoin any act or things which may be unlawful or in violation of the rights of the holders of such bonds or notes;

(e) declare all such bonds or notes due and payable, and if all defaults shall be made good then with the consent of the holders of twenty-five per centum of the principal amount of such bonds or notes then outstanding, to annul such declaration and its consequences.

3. Such trustee, whether or not the issuance of bonds or notes represented by such trustee had been declared due and payable, shall be entitled as of right to the appointment of a receiver of any property of the authority, the fees, rentals, charges or other revenues of which are pledged for the security of the bonds or notes of such issue and such receiver may enter and take possession of such property, or any part or parts thereof and operate and maintain the same and receive all fees, charges, rentals and other revenues thereafter arising therefrom and exercise such other powers of the authority as the court may deem advisable and perform the public duties and carry out the agreements and

obligations of the authority under the direction of the court. In any suit, action or proceeding by the trustee the fees, counsel fees and expenses of the trustee and of the receiver, if any, shall constitute taxable disbursements and all costs and disbursements allowed by the court shall be a first charge on any fees, charges, rentals and other revenues derived from such properties.

4. Such trustee shall in addition to the foregoing have and possess all of the powers necessary or appropriate for the exercise of any functions specifically set forth herein or incident to the general representation of bondholders or noteholders in the enforcement and protection of their rights.

5. The supreme court shall have jurisdiction of any suit, action or proceeding by the trustee on behalf of such bondholders or noteholders. The venue of any such suit, action or proceeding shall be laid in the county of Albany.

6. Before declaring the principal of bonds or notes due and payable, the trustee shall first give thirty days' notice in writing to the governor, to the authority, to the comptroller and to the attorney-general of the state.

§ 1866. State not liable on bonds and notes

The bonds and notes shall not be a debt of the state of New York nor shall the state be liable thereon and such bonds and notes shall contain on the face thereof a statement to that effect.

§ 1867. Inconsistent provisions of other acts

Insofar as the provisions of this title are inconsistent with the provisions of any other act, general or special, the provisions of this title shall be controlling, provided, however, nothing contained in any provision of this title shall be construed to relieve the authority of the obligation on its part to comply with the provisions of article nine of the public authorities law in force on the effective date of this title, including the obligation to submit an annual report as specified therein.

§ 1868. Termination of the authority

The authority and its corporate existence shall continue until terminated by law, provided, however, that no such law shall take effect so long as the authority shall have bonds, notes or other obligations outstanding. Upon termination of the existence of the authority all its rights, property, assets and funds shall pass to and be vested in the state. For the purposes of this section, any appropriation or advance made to the authority by the state, which has not been repaid, shall not be deemed to be an outstanding obligation of the authority.

§ 1869. Title not affected if in part unconstitutional or ineffective

If any subtitle, section, subdivision, paragraph, sentence, clause or provision of this title shall be unconstitutional or be ineffective in whole or in part, to the extent that it is not unconstitutional or ineffective, it shall be valid or effective and no other subtitle, section, subdivision, paragraph, sentence, clause or provision shall on account thereof be deemed invalid or ineffective.

§ 3. This act shall take effect April first, nineteen hundred sixty-two.

Changes or additions in text are indicated by underline

CIVILIAN NUCLEAR POWER

... a Report to the President—1962

U.S. ATOMIC ENERGY COMMISSION

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON 25, D. C.

OFFICE OF THE CHAIRMAN

November 20, 1962

Dear Mr. President:

I am pleased to submit herewith the report resulting from our "new and hard look at the role of nuclear power in our economy," as requested by you on March 17, 1962. In preparing this report, we have had the benefit of comments and advice from interested offices and individuals within and without the Government. However, the Commission takes full responsibility for the conclusions and recommendations of the report.

The Commission, of course, has concentrated on issues related to the development and use of nuclear power; it has not attempted to appraise the possible effect of major research efforts on the economics of non-nuclear energy sources or on improved transmission methods for either source of energy. However, the study has been greatly aided by the information furnished by the Department of Interior, the Federal Power Commission, and the National Academy of Sciences Committee on Natural Resources.

Those who have participated in the study you requested are agreed that it has proved to be very timely. While the Commission has been proceeding on a considered course in general accord with its 10-year civilian power program adopted in 1958, that program is now on the threshold of attaining its primary objective of competitive nuclear power in high-fuel-cost areas by 1968. However, it became evident with the passage of time that our attention had probably for too long remained focused narrowly on short-term objectives. This restudy made it apparent that, for the long-term benefit of the country, and indeed of the whole world, it was time we placed relatively more emphasis on the longer-range and more difficult problem of breeder reactors, which can make use of nearly all of our uranium and thorium reserves, instead of the less than one per cent of the uranium and very little of the thorium utilized in the present types of reactors. Only by the use of breeders would we really solve the problem of adequate energy supply for future generations.

We believe that it still is necessary for the Government as a interim measure to maintain a substantial program of research and development on advanced types of reactors other than breeder reactors, which are some years away. It appears from the projections made that efficient converter reactors will be required in conjunction with breeder reactors to meet the rapidly growing national demands for electrical power. This Government program over the next several years is also important since it provides the national means for "bridging the gap" between the infancy and maturity of nuclear power. This interim aid will allow the consolidation of the gains made to date and will permit the national nuclear program to proceed in an efficient and sensible manner toward the development of more efficient and economical converter reactors and eventually breeder reactors.

Furthermore, a vigorous national nuclear power program can be pursued without interfering with a growing coal industry; in fact, all our projections indicate that, even assuming an optimistic forecast of nuclear power development, the use of coal by the rapidly expanding electric generating industry will increase severalfold over the next 40 years.

It should be recognized that, largely as a result of early optimism, we have, in a short space of time, developed a competitive nuclear equipment industry which is over-capitalized and under-used at the present time. This optimism has had some good results in terms of bringing many able technical men, manufacturers, and utility executives into the field, and assuring Congressional and industrial support during the development years.

The optimism has also brought about some difficuties in that unless there are new starts on atomic power plants, the atomic equipment industry will probably dwindle down to fewer manufacturers than would be desirable for a healthy and competitive nuclear industry. Fortunately, it now appears that only relatively moderate additional governmental help will be necessary to insure the building of a substantial number of large, water-type power reactors that will be economically competitive in the high-fuel-cost areas of this country and the world. This would increase public acceptance, keep the nuclear industry healthy, and help to furnish the plutonium necessary for a breeder reactor economy as soon as it can be adequately developed.

In summary, nuclear power promises to supply the vast amounts of energy that this Nation will require for many generations to come, and it probably will provide a significant reduction in the national costs for electrical power.

The Commission unanimously concurs in this report.

Respectfully yours,

Glenn T. Seaborg

Glenn T. Seaborg
Chairman

The President
The White House

Enclosure

THE WHITE HOUSE
Washington

March 17, 1962

Dear Mr. Chairman:

The development of civilian nuclear power involves both national and international interests of the United States. At this time it is particularly important that our domestic needs and prospects for atomic power be thoroughly understood by both the Government and the growing atomic industry of this country which is participating significantly in the development of nuclear technology. Specifically we must extend our national energy resources base in order to promote our Nation's economic growth.

Accordingly, the Atomic Energy Commission should take a new and hard look at the role of nuclear power in our economy in cooperation with the Department of the Interior, the Federal Power Commission, other appropriate agencies, and private industry.

Your study should identify the objectives, scope, and content of a nuclear power development program in the light of the Nation's prospective energy needs and resources and advances in alternate means for power generation. It should recommend appropriate steps to assure the proper timing of development and construction of nuclear power projects, including the construction of necessary prototypes. There should, of course, be a continuation of the present fruitful cooperation between Government and industry—public utilities, private utilities, and equipment manufacturers.

Upon completion of this study of domestic needs and resources, there should also be an evaluation of the extent to which our nuclear power program will further our international objectives in the peaceful uses of atomic energy.

The nuclear powerplants scheduled to come into operation this year, together with those already in operation, should provide a wealth of engineering experience permitting realistic forecasts of the future of economically competitive nuclear power in this country.

As you are aware, two major related studies are now or will soon be underway. The study being conducted at my request by the National Academy of Sciences on the development and preservation of all our national resources will focus on the Nation's longer term energy needs and utilization of fuel resources. The other study to be launched soon by the Federal Power Commission will determine the long-range power requirements of the Nation and will suggest the broad outline of possible programs of growth for all electric power companies—both private and public—to meet the great increase in power needs. Your study should be appropriately related to these investigations.

The extensive and vigorous atomic power development programs currently being undertaken by the Commission should, of course, be continued and, where appropriate, strengthened during the period of your study. I urge that your review be undertaken without delay and would hope that you could submit a report by September 1, 1962.

Sincerely,

/s/John F. Kennedy

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Civilian Nuclear Power

a Report to the President

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Introduction

As a result of successes achieved during World War II, it was widely recognized thereafter that nuclear energy could, if properly developed, have important civilian applications. In addition to unique applications in scientific research, in medicine, in agriculture and in industrial operations, it was believed by many that nuclear energy could yield large economic advantages in such massive applications as the generation of electric power. It was also recognized, though not emphasized, that over the long term it would be an important resource, whose timely introduction would help conserve for special uses our finite supply of fossil fuels.

The long-term availability of abundant and economic sources of energy and the development of new techniques and technologies of general applicability are matters of concern to all the people and therefore to the government. Federal responsibility for the peaceful development of civilian uses of nuclear energy—for both short- and long-term ends—within our normal economic and industrial framework was clearly recognized by Congress in the Atomic Energy Act of 1946, and clarified and broadened in the Act of 1954. The latter states in Section 1 (Declaration):

> "It is . . . declared to be the policy of the United States that—
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> "b. the development, use and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise."

And in Section 3—(Purpose):

> "It is the purpose of this Act to effectuate the policies set forth above by providing for—
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> "a. a program of conducting, assisting, and fostering research and development in order to encourage maximum scientific and industrial progress;
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> "d. a program to encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public;" and
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> "e. a program of international cooperation to promote the common defense and security and to make available to cooperating nations the benefits of peaceful applications of atomic energy as widely as expanding technology and considerations of the common defense and security will permit;"

Many sections of the Act and many other acts of Congress expand on the above provisions and provide means and mechanisms for implementing them.

In keeping with the responsibilities assigned it by the legislation, the Atomic Energy Commission has conducted vigorous programs of research, development, and exploitation, directed at realizing the many peaceful benefits potentially to be derived from nuclear energy. Included in the applications are many, such as those of radioisotopes, where nuclear phenomena have special characteristics that are uniquely useful. The major effort has, however, been directed at extraction of energy in large amounts, primarily to accomplish conventional tasks or extensions of them. The most promising, and hence the most vigorously pursued among the various applications, is that of generating electric power. It is with the power program that this report primarily concerns itself.

The Commission has conducted and encouraged a national program, aimed, first, at obtaining the basic scientific and engineering data needed for proof of technical feasibility and safety of the more promising approaches to nuclear power generation and, second, at demonstrating the actual or potential economic feasibility of such approaches. This program has been strongly backed in both the executive and the legislative branches of the Government.

In its early phases the program was largely one of developing the technology. It leaned heavily upon, indeed it started from, knowledge gained from other reactor programs, notably "production" reactors for making plutonium, naval propulsion reactors and "research" and "test" reactors used for scientific purposes. In 1953 the Commission, with the encouragement of the Joint Committee on Atomic Energy, embarked upon a five-year "experimental" program to develop reactors giving promise for civilian power applications. Construction was started on several experimental power-producing reactors on Commission sites, and one "prototype" reactor on a utility grid.*

The revision of the Atomic Energy Act in 1954, which encouraged industrial cooperation, and associated policy decisions by the Government resulted in continued expansion of the program by both government and industry. An important step was the addition, in 1955, of a "Power Demonstration" program under which the Commission and industry have cooperated in building and operating a number of nuclear power plants on utility grids. In one segment of this program, Commission-built and -owned "prototype" reactors are operated by utilities that buy the steam; in another segment utilities are given research and development assistance in designing and constructing their own reactors and, for a few years no charge is made for the lease of Government-owned nuclear fuel.

In 1958, as the five-year experimental program ended, the Joint Committee on Atomic Energy of the Congress published a report, prepared by its staff with the advice of consultants, recommending objectives for an expanded program and various steps that might be taken in furtherance of the program. During that and the following year, the Commission conducted, at the national laboratories and through contracts with the nuclear equipment industry, a series of detailed studies and evaluations of all the reactor concepts believed to hold promise for the development of economic nuclear power. The results were carefully analyzed by the Commission staff and, on two separate occasions, by advisory committees. On the basis of these studies, analyses and recommendations, the Commission published a series of reports, known to the trade as the "Ten-Year Program", which established short-range economic targets as well as long-range goals in economics, resource

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* This Commission-built and -owned reactor, at Shippingport, Pa., provides steam at a plant of an investor-owned utility, which built the power generating equipment and operates the reactor under contract with the Commission.

conservation and international leadership, and outlined a program for achieving these objectives. This has served as a general guide to the Commission during the intervening period.

Meanwhile, beginning with initiation of the "Atoms for Peace" program in 1954, and more intensively since the large International Conference on that subject in 1955, the Commission, in cooperation with the Department of State, has been very active internationally. The United States was the leader in the establishment of the International Atomic Energy Agency which conducts and sponsors cooperative programs throughout the world. The Agency will increasingly be responsible for administering safeguards against diversion of nuclear materials to military use and for developing and recommending international regulations on safety and waste disposal. Cooperation and assistance have been rendered by the United States through formal agreements with such international organizations as EURATOM, and with a large number of individual nations. Western Europe and, more recently, Japan have significant nuclear power programs in being as has the Soviet Union. Considerable interest in nuclear power has also been shown by many of the developing countries.

As a result of the various domestic programs, six sizeable reactors of the more highly developed types are in successful operation on utility grids (two of the largest and one other had no AEC assistance); seven more of small and medium size will be completed by the end of 1963; a few others are under construction or nearly so.

Sufficient developmental and operational experience has been accumulated to permit a reasonably accurate assessment of future possibilities. Nuclear electric power has been shown to be technically feasible, indeed, readily achieved. Power reactors can be reliably and safely operated. However, contrary to earlier optimism, the economic requirements have led to many problems—combining low capital cost with long life and assured reliability; lowering costs by improved efficiency; developing long-lived and, therefore, economic fuels. Attempts to optimize the economics by working on the outer fringes of technical experience, together with the difficulties always experienced in a new and rapidly advancing technology, have led to many disappointments and frustrations. Experiments have not always worked as planned. Many construction projects have experienced delays and financial overruns. Such difficulties led to considerable diminution of the earlier optimism regarding the early utilization of nuclear power, which in turn contributed to the withdrawal of some equipment and component manufacturers from the field.

Happily, more recently much progress has been made toward solutions of these problems. Expectations are being more nearly, and in some cases completely realized. Nuclear power is believed to be on or near the threshold of competitiveness with conventional power for large plants, in areas of the country where fossil fuel costs are high. Further cost reductions are definitely in sight, provided an aggressive program is continued.

The developments to now have verified that, if extensively used, nuclear power could have important implications—as a means of exploiting a large, new energy resource; as an economic advantage, especially to areas where fossil fuel costs are high; as an important contributor to new industrial technology and to our technological world leadership; as a significant positive element in our foreign trade; and, potentially, as a contributor to the nation's defenses. Its potential benefits will actually be realized, however, only if it can be made economically attractive.

To surmount the economic hurdle is the most immediate program goal. Unfortunately the reactors that will do so can extract only about one percent of the energy potentially available in our reserves of nuclear materials. To utilize the rest, which must be done if nuclear energy is to be of lasting usefulness, requires the development to an economic status of more advanced and difficult reactors. This will be a rigorous and expensive task.

How best to pace the short- and long-term efforts, what relative emphasis to give to each, how diversified and intensive the total effort should be—these are the principal program questions.

The stage of development has also brought forward a number of important policy questions. Many of them relate to nuclear fuels. With extensive applications potentially in the offing, the question naturally arises as to the desirability of changing, at a reasonably early date, to private ownership of special nuclear materials. Its adoption would give rise to the corollary question of policy relating to the "toll" enrichment of privately-owned uranium in the government's diffusion plants, a service which private industry cannot economically provide for itself; this question arises internationally in any case. Action must be taken on the Commission's raw uranium procurement program, contracts for which expire in 1966, and on extension and adjustment of its schedule of guaranteed prices for plutonium produced in non-government reactors, which expires in 1963.

Clearly the time has come for a major review and reassessment—a review more of basic policies than of detailed technical activities; a review of where the nuclear electric power program should be headed, at what rate and with what amount of government participation. It is to these ends that this study has been made.

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A study of this nature requires special knowledge in many fields outside the detailed cognizance of the Atomic Energy Commission. Among these are current and projected rates of use of energy, including electric power requirements, our reserves of fossil fuels, and economic trends in these and related fields. We have, therefore, worked closely with, and relied heavily upon, other agencies and groups that are expert in these fields. We have also taken advantage of studies and evaluations that have been, or are being made by others in such fields as the international impact of nuclear energy, the civilian defense and national security aspects of the problem, and the air pollution problems of fossil fuel plants. Of especial value have been recent reports, some in draft form, prepared by the Department of the Interior, the Federal Power Commission, the National Academy of Sciences, the Committee on Interior and Insular Affairs of the United States Senate, the General Advisory Committee to the Atomic Energy Commission, and the Advisory Committee on United States Policy Toward the International Atomic Energy Agency.

We have had helpful discussions on the content of the report with the Bureau of the Budget, the Office of Science and Technology, the President's Science Advisory Committee, the Council of Economic Advisors, the Department of the Interior, the Federal Power Commission, the General Advisory Committee, and the Joint Committee on Atomic Energy of the Congress. However, the contents of the report are the responsibility solely of the Atomic Energy Commission.

During the early weeks of the study a series of seminars was held at which representatives of AEC contractor organizations, various industries and others made presentations of their own civilian power programs.

A list of reports and discussions is given in an Appendix together with acknowledgments of more informal assistance.

Summary

The Need for Nuclear Power

Our technological society requires ample sources of energy. Although large, the supplies of fossil fuels are not unlimited and, furthermore, these materials are especially valuable for many specific purposes such as transportation, small isolated heat and power installations, and as sources of industrial chemicals. Reasonable amounts should be preserved for future generations.

Comparison of estimates of fossil fuel resources with projections of the rapidly increasing rate of energy consumption predicts that, if no additional forms of energy were utilized, we would exhaust our readily available, low-cost fossil fuels in a century or less and our presently visualized total supplies in about another century. In actual fact, long before they become exhausted we will be obliged to taper off their rate of use by supplementing them increasingly from other sources.

In contrast, our supplies of uranium and thorium contain almost unlimited amounts of latent energy that can be tapped provided "breeder" reactors are developed to convert the fertile materials, uranium-238 and thorium-232, to fissionable plutonium-239 and uranium-233, respectively.* Successfully done, this will render relatively unimportant the cost of nuclear raw materials so that even very low-grade sources will become economically acceptable.

The use of nuclear energy for electric power and, less immediately, for industrial process heat and other purposes is technically feasible and economically reasonable. In addition to its ultimate importance as a means of exploiting a large new energy resource, nuclear electric power holds important near-term possibilities: as a means of significantly reducing power generation costs, especially in areas where fossil fuel costs are high; as an important contributor to new industrial technology and to our technological world leadership; as a significant positive element in our foreign trade; and, potentially, as a means of strengthening our national defense.

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*The readily fissionable material found in nature is confined to uranium-235 which constitutes only 0.7% of normal uranium. The energy contained in this isotope in uranium mineable at near present costs is only a small fraction of that contained in our fossil fuel reserves. Fortunately, the so-called "fertile" isotopes, uranium-238, constituting the remainder of normal uranium, and thorium-232 constituting practically all normal thorium can be converted to fissionable plutonium-239 and uranium-233 by absorption of neutrons in a nuclear reactor.

In view of the above we have concluded that: Nuclear energy can and should make an important and, ultimately, a vital contribution toward meeting our long-term energy requirements, and, in particular, that: The development and exploitation of nuclear electric power is clearly in the near- and long-term national interest and should be vigorously pursued.

The Role of the Federal Government

The technological development of nuclear power is expensive. The reactors are complex, and operating units, even of a scaled-down test variety, must of necessity be large and costly. Furthermore, nuclear power does not meet a hitherto unfilled need but must depend for marketability on purely economic advantages that will return the development investment slowly. Hence, the equipment industry could not have afforded to undertake the program by itself. The Government must clearly play a role.

An early objective should be to reach the point where, with appropriate encouragement and support, industry can provide nuclear power installations of economic attractiveness sufficient to induce utilities to install them at their own expense. Once this is achieved the Government should devote itself to advanced developments designed to meet long-range objectives, leaving to industry responsibility for nearer-term improvements. Gradually, as technological maturity is reached, the transition to industry should become complete.

Thus, the proper role of Government is to take the lead in developing and demonstrating the technology in such ways that economic factors will promote industrial applications in the public interest and lead to a self-sustaining and growing nuclear power industry.

The Present Situation

Accordingly, in keeping with national policy, and with the responsibilities assigned to it by the Atomic Energy Act, the Atomic Energy Commission has conducted and encouraged a vigorous program directed toward the development and extensive exploitation of nuclear energy for civilian purposes, with emphasis on nuclear electric power. About $1.275 billion has been expended by the AEC to date* on the civilian power program. This program has included both research and development and a "power demonstration" program, involving aid in the construction and operation of practical reactors on utility

*We estimate that industry has expended approximately $0.5 billion of its own funds, mostly for plant and equipment.

grids. Several reactor types are under development. Most highly developed are "converter" reactors that produce less fissionable material than they consume; much less far along are "breeder" reactors that produce more than they consume.

In one segment of the power demonstration program, Commission-built and -owned "prototype" reactors are operated by utilities that buy the steam; in another segment, utilities are given research and development assistance in designing and constructing their own reactors and, for a few years no charge is made for the lease of Government-owned nuclear fuel. Six sizeable reactors of the more highly developed types are in successful operation on utility grids (the two largest without AEC assistance); seven more will be completed by the end of 1963; a few others are under construction or nearly so.

Experience has shown that nuclear electric power is readily achieved technically but difficulties have been met in developing a technology that is economically competitive with conventional power generation methods. Happily, in recent years these difficulties have been progressively overcome.

Certain classes of power reactors, notably water-cooled converters producing saturated steam are now on the threshold of economic competitiveness with conventional power in large installations in high fossil fuel cost areas of the country. Foreseeable improvements will substantially increase the areas of competitiveness.

Technical Considerations

Saturated steam reactors, however, have certain inherent limitations. They produce relatively low temperature saturated steam which limits their efficiencies and requires the use of large, expensive turbines; they are only moderately effective converters.* Consequently, converter concepts utilizing other moderators and coolants and promising improved economics and fuel utilization are being actively pursued with encouraging results; early competitiveness seems assured for some of them. All of these are "thermal"† reactors. They include the "spectral shift" reactor, the high temperature gas-cooled re-

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*They convert 0.5 to 0.7 as much material as they consume. Compounded, this results in doubling to tripling the energy finally made available.

†In a "thermal" reactor most of the fission neutrons are slowed-down (moderated) before interacting with the nuclear materials; this is accomplished through many collisions with light nuclei such as hydrogen (in water or organic compounds), carbon (in graphite) or beryllium. In a "fast" reactor, little or no moderation is used, so that most of the neutrons retain the high energies and velocities with which they were emitted in the fission process. "Intermediate" reactors lie between.

actor, and the sodium-graphite reactor. All have relatively high efficiencies and excellent economic promise. The first two will have excellent conversion ratios; indeed they may eventually be made to breed in the thorium-uranium cycle.* The sodium-graphite reactor can achieve quite high temperatures, has good safety features and helps develop the liquid sodium technology necessary for fast breeders. The heavy water moderated reactor also shows promise of high conversion ratios but present designs are not so attractive economically as other types in the United States. The organic-cooled and -moderated reactor may have application for process heat. Some of these should be carried to the stage of operating prototypes during the next several years, and some will reach the full-scale operational phase by the early 1970's. Operating reactors of these types will help accelerate the industry, will increase operating experience and will help provide plutonium needed for the breeder program.

Although much technical progress has been made, breeder reactors have not yet reached an economically useful stage of development. Even when they do, they will not, initially at least, make new material fast enough to provide the fuel for new plants at the rate required if nuclear power is to increase its proportional share of the national electric power load. Hence, even after breeders become available, it will be necessary to fuel some portion of the installations with uranium-235 until such time as improved breeding gains and reductions in the relative rate of growth in power consumption enable the breeders to be self-sufficient. For the thermal reactors used to make U-233 from thorium, this need can be met by substituting U-235 for U-233 in some of them, at a sacrifice in fuel produced. A similar procedure would, however, be uneconomic in the "fast" reactors required to breed plutonium. Hence, in the transition stage, which will last for many decades, fast breeders that burn as well as make plutonium will probably be augmented by thermal converters burning U-235 and producing plutonium at a slower rate. This need will enhance the desirability of the more advanced converters both for economic reasons and because it is important that the combination of breeders and converters reaches an overall net breeding capability, or very nearly so, while relatively cheap fuel supplies are still available.

In our opinion, economic nuclear power is so near at hand that only a modest additional incentive is required to initiate its appreciable early use by the utilities. Should this occur the normal economic processes would, we feel, result in expansion at a rapid rate. The Government's investment would be augmented manyfold by industry. Equipment manufacturers could finance major technical developments, thus reducing the future need for Government participation.

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*See footnote, page 7.

Continuation of the Commission's present effort, with some augmentation in support for the power demonstration program, and with program adjustments to give added emphasis to breeders, would, we believe, provide industry with the needed stimulus to build a significant number of large reactors in the near future, would bring nuclear power to a competitive status with conventional power throughout most of the country during the 1970's, and would make breeder reactors economically attractive by the 1980's.

Under these conditions, we estimate that by the end of the century nuclear power would be assuming the total increase in national electric energy requirements and would be providing half the energy generated.* This rate of progress, projected into the next century, would be an important step in conservation of the fossil fuels and, unless breeders lagged the converters much more than we predict, would raise no problems in nuclear fuel supplies.

Under conservative cost assumptions, it is estimated that by the end of the century the above projected use of nuclear power would result in cumulative savings in generation costs of about $30 billion.† The annual saving would be between $4 and $5 billion. High cost power areas would no longer exist, since, in the absence of significant fuel transportation expenses, the cost of nuclear power is essentially the same everywhere. This would be an economic boon to areas of high cost fossil fuels and, by enabling them to compete better, should increase the industrial potential of the entire country.

More generally, the introduction of nuclear power technology on a significant scale would add to the health and vigor of our industry and general economy. Technical progress would assist the space and military programs and have other ancillary benefits. Our international leadership in the field would be maintained, with benefit to our prestige and our foreign trade. Nuclear power could also improve our defense posture; it would not burden the transportation system during national emergencies; furthermore, the "containment" required for safety reasons could, if desired, be achieved at little, if any, extra cost by underground installations, thus "hardening" the plants against nuclear attack.

A substantially lesser program would sharply reduce these benefits. Too great a slowdown could result in losing significant portions of industry's present nuclear capability thereby seri-

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*Since, by Federal Power Commission estimates, the total use of electric energy will grow tenfold in the same period, fossil fuel consumption for this purpose would still increase by a factor of from four to five.

†At 5% interest these cumulative savings would have a discounted value of about $10 billion in 1970.

ously delaying the time at which it would assume a major share of the development costs.

On the other hand we do not believe that a major step-up in the whole Commission program is appropriate. Taken as a whole, support of the scientists and engineers engaged in developmental work is about adequate and, in view of the country's other needs, it would seem unwarranted to increase appreciably such manpower in this field.

To summarize we have concluded that the nuclear power program should continue on an expeditious basis. Commission support should continue with added emphasis on stimulating industrial participation. The program should include: (1) early construction of plants of the presently most competitive reactor types; (2) development, construction and demonstration of advanced converters to improve the economics and the use of nuclear fuels; (3) intensive development and, later, demonstration of breeder reactors to fill the long-range needs of utilizing fertile as well as fissile fuels.

An important corollary area is the development of economical chemical reprocessing methods whereby useful fissile and fertile materials are recaptured from used fuel assemblies and the fission products are removed. Another important line of work concerns the ultimate storage or disposal of the large amounts of radioactive fission products that will be generated when a major power industry comes into being.

An overriding consideration is that of safety. Not only must inherent safety be assured in fact but its existence must be conclusively demonstrated to the public. With adequate technical improvements and the accumulation of satisfactory experience, it should be possible gradually to remove many of the siting restrictions in force today, thus permitting plant locations closer to the large load centers.

Possible Construction Program

A composite construction program for the next dozen years might entail the following: (1) the construction and placing into operation of seven or eight power-producing prototype reactors, approximately half of which would be advanced converters and the rest breeders; most of their cost would probably be borne by the AEC; (2) assistance, as necessary, to industry in the construction of 10–12 full-scale power plants of improving design as time goes on; hopefully, industry will concurrently bear full costs of many more of well proven design.

This construction would, of course, be backed by specific development programs directed at the more advanced reactor types, especially breeders, and by research and development related to the underlying technology.

Legal, Financial and Administrative Matters

Careful attention must be paid to several legal, financial and administrative questions, among them (1) private ownership of nuclear materials and related policies on fuel pricing and "toll enrichment"; (2) policies relating to the raw material and other supporting industries; (3) licensing and regulation, including reactor siting criteria.

The commission has recommended that private ownership of special nuclear materials be authorized at an early date, thus permitting the free play of normal economic forces and minimizing economic distortions of the technology. To prevent sudden dislocations such ownership should not be made mandatory for a decade or so.

The Commission further believes that a policy of "toll enrichment" or equivalent should be adopted. Industry could then buy its raw materials on the open market, use privately owned plants to prepare them for enrichment, and depend upon the Government only for the actual enrichment in the diffusion plants. This service should also be extended to our friends abroad, subject to proper safeguards against diversion for military use.

Before and during the period of transition to private ownership the value set by the Commission on enriched uranium for lease or sale should, as at present, be determined by the actual cost, with appropriate allowances for depreciation and other indirect expenses. The Commission has recommended that prices for the purchase of plutonium be in accordance with its "near-term" value as a reactor fuel. We believe that consideration should be given to scaling the price in accordance with the content of fissionable isotopes. The same pricing policies should apply to purchases abroad of plutonium made from uranium enriched in the U. S.

The Commission's contracts with uranium miners and processors expire at the end of 1966. Since it seems probable that the requirements for new uranium for weapons, the dominating use to date, will decrease in the next decade, careful planning is necessary to so guide further procurement that the uranium industry will be kept viable during any slack period before civilian power creates another large demand. With this in mind the Commission is planning to offer the industry a "stretch-out" program under which an AEC commitment to purchase additional material after January 1, 1967 would be used as an incentive to induce industry to delay until after that date delivery of part of the uranium presently under contract. If successful, this program would result in a leveling-off process that should carry through the period of slack use without injuring the industry substantially or resulting in an unreasonably large surplus.

The Commission intends to continue and extend encouragement to the industrial activities ancillary to the major equipment industry. Many that could start on a small scale are already well underway. There are, however, a few activities, such as the chemical separation of used fuels, that are attractive to industry only on a fairly substantial scale and for which there will be little private business until civilian reactors have operated for an appreciable period. Strong encouragement is being given to private industry to embark in these fields with some prospect of success. As rapidly as a private capability comes into being the Commission should withdraw from all such work deriving from industry and should utilize private plants to fill its own requirements except, perhaps, for those related to materials for weapons.

Recognizing that simplifying and streamlining licensing and regulatory procedures can be a major help in encouraging the utility industry to adopt nuclear power, the Congress and the AEC have been taking steps in this direction. A major step is the recent enactment of laws that will reduce greatly the number of mandatory public hearings for reactor licensing. The Commission is studying means of simplifying its own licensing procedures by reducing the volume and complexity of administrative processes. Further operating experience should reduce the time and effort required for technical analysis and review.

Objectives for the Future

Clearly: The overall objective of the Commission's nuclear power program should be to foster and support the growing use of nuclear energy and, importantly, to guide the program in such directions as to make possible the exploitation of the vast energy resources latent in the fertile materials, uranium-238 and thorium.

More specific objectives may be summarized as follows:

1. The demonstration of economic nuclear power by assuring the construction of plants incorporating the presently most competitive reactor types;

2. The early establishment of a self-sufficient and growing nuclear power industry that will assume an increasing share of the development costs;

3. The development of improved converter and, later, breeder reactors to convert the fertile isotopes to fissionable ones, thus making available the full potential of the nuclear fuels.

4. The maintenance of U. S. technological leadership in the world by means of a vigorous domestic nuclear power program and appropriate cooperation with, and assistance to, our friends abroad.

The role of the Commission in achieving these objectives must be one of positive and vigorous leadership, both to achieve the technical goals and to assure growing participation by the equipment and utility industry as nuclear power becomes economic in increasing areas of this country and the world at large.

The Need for Nuclear Power

Nuclear Energy as a Resource

Next to the land, the water, and the air, without which we could not exist at all, energy is by far the most important of our terrestrial resources. Without it our industrial society would be impossible. In common with the other three it has no substitute.

Today's society depends almost entirely upon energy originating in the sun. The vast bulk of this has been stored during hundreds of millions of years in the form of fossil hydrocarbons such as coal and oil. The storage process proceeds so slowly that, in terms of foreseeable human history, replenishment must be considered negligible. Although the supply is vast, we are consuming these materials at such a rapidly increasing rate that if not supplemented they will begin to approach exhaustion within the span of a few generations.

The domestic fuel situation can be understood by reference to Figures 1 and 2, showing on an annual rate and on a cumulative basis respectively, various estimates* of future use of fossil fuels in the U. S., and, in Figure 2, authoritative estimates of our total reserves.

The total energy contained in our recoverable fossil fuels of all grades is variously estimated to be between 30 Q† (Energy Study by the Committee on Natural Resources of the National Academy of Sciences; National Fuels and Energy Study of the Committee on Interior and Insular Affairs of the United States Senate) and 130 Q (Energy Policy Staff; Department of the Interior).‡ The primary causes of the spread are apparently differences in estimates as to the quantity of "marginal resources" (e.g., coal in thin veins and/or at great depths), differences in assessments of the feasibility and cost of recovering such mar-

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*As indicated by dashed lines on the figures we have extrapolated somewhat farther than did the authors of the estimates. In doing so, we have used the same mathematical formulae as did they, although, of course, they did not assert them to have validity for such longer term extrapolations.

†In discussing total energy reserves or cumulative energy consumption, unwieldy numbers are avoided by using a very large unit, the Q (for quintillion) equal to one billion-billion British thermal units (BTU) or 25 billion-billion kilocalories of energy. This is equivalent to the energy available in approximately 40 billion tons of average high-grade coal. The U. S. currently consumes about $1/_{20}$ Q per year.

‡Geological Survey Bulletin 1136, "Coal Reserves of the United States" estimated remaining recoverable reserves of fossil fuels in the U. S. at 25.7 Q. (Page 98).

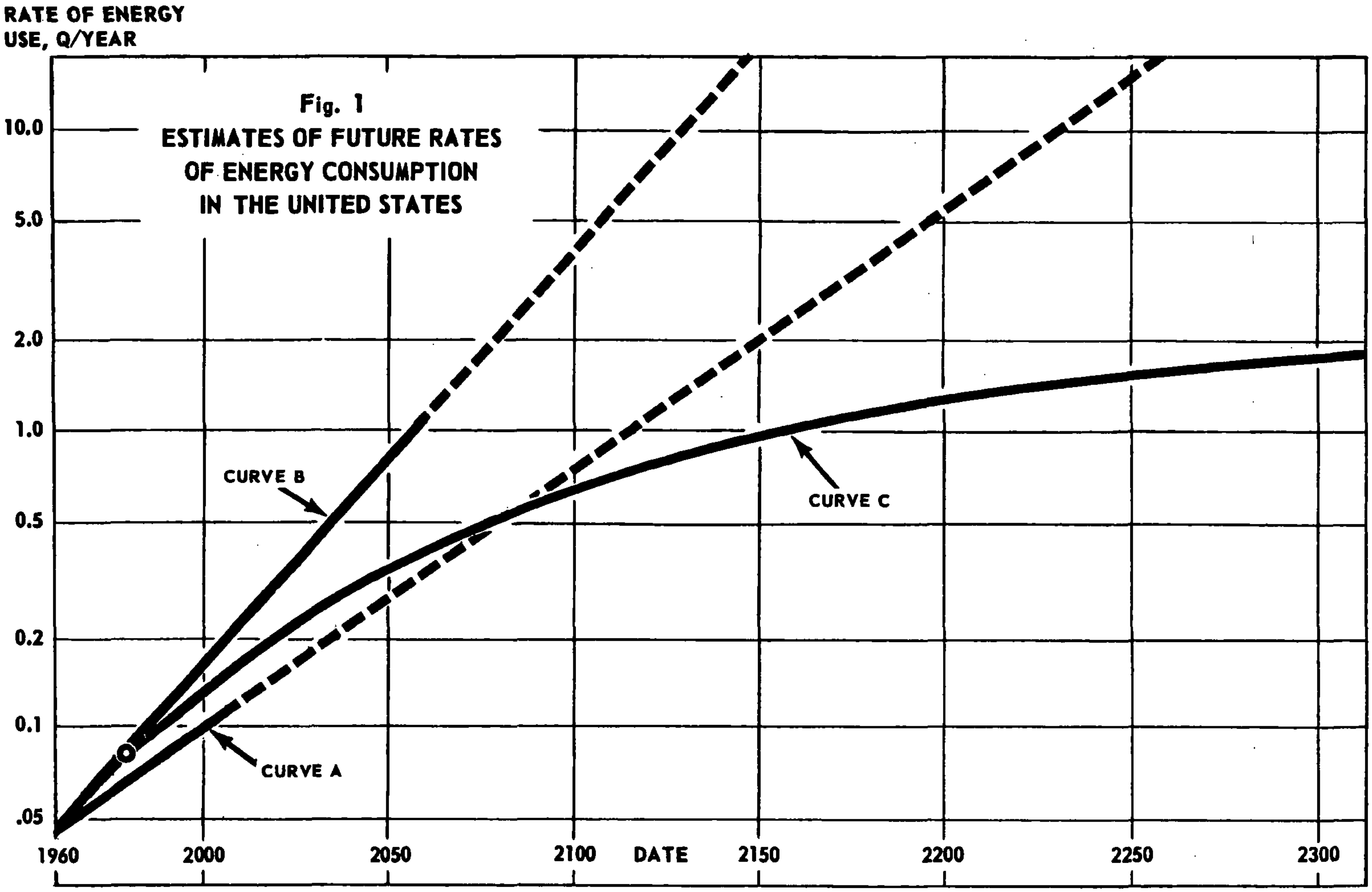

Fig. 1
ESTIMATES OF FUTURE RATES OF ENERGY CONSUMPTION IN THE UNITED STATES

CURVE A is an extrapolation of the experience of the last 50 years. It is based on Fig. 15 in the 1962 report "Energy Resources," prepared for the National Academy of Sciences Committee on Natural Resources.

CURVE B is an exponential curve, by the Department of the Interior, passing through the value ○ estimated for 1980 in the September 21, 1962 "Report of the National Fuels and Energy Study Group, on an Assessment of Available Information on Energy in the United States, to the Senate Committee on Interior and Insular Affairs."

CURVE C has the same initial rate as Curve B but incorporates downward trends in relative rates of growth in population and per capita use as explained in the text.

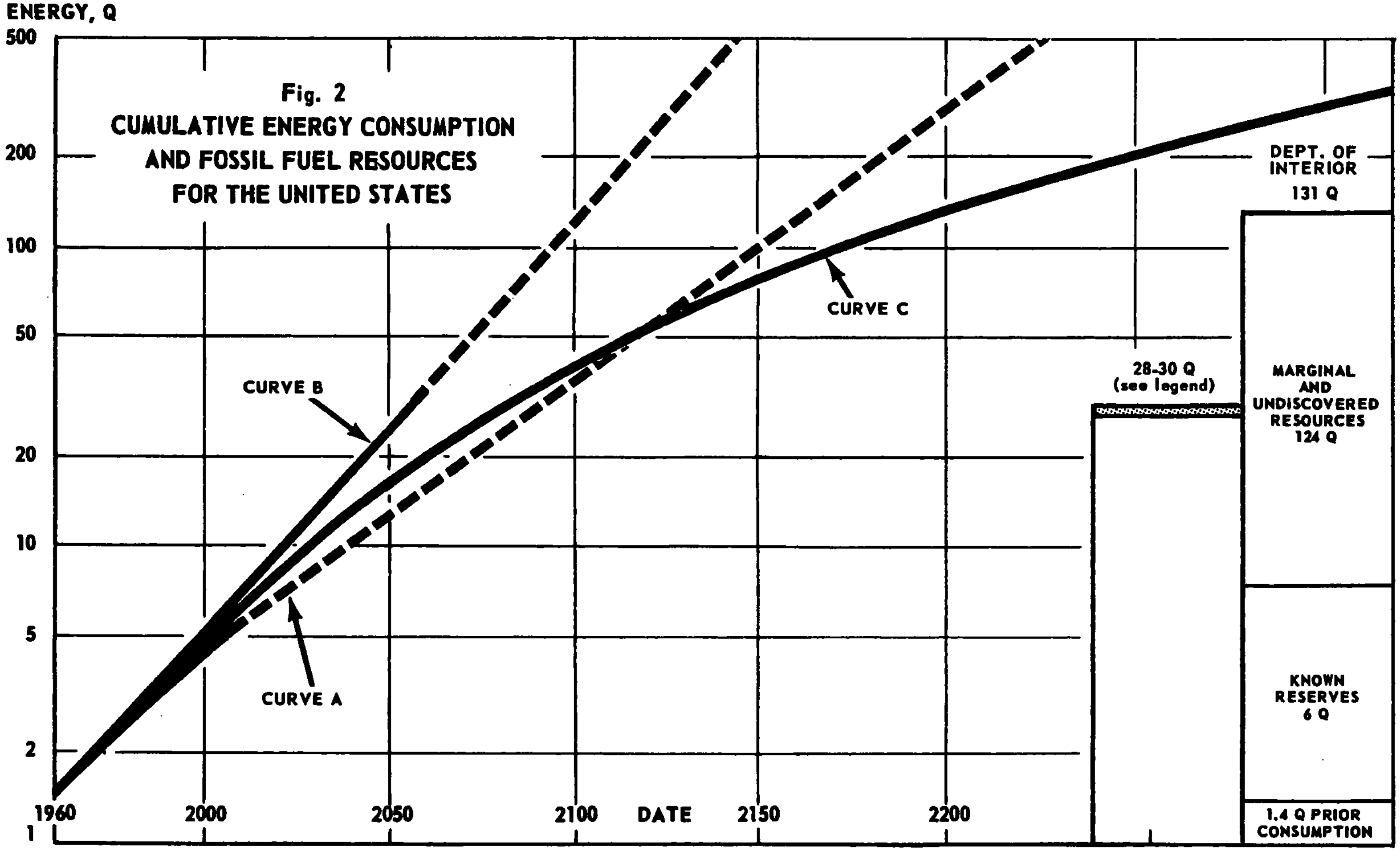

Fig. 2
CUMULATIVE ENERGY CONSUMPTION AND FOSSIL FUEL RESOURCES FOR THE UNITED STATES

CURVES A, B, and C represent cumulative energy use at the corresponding rates from Fig. 1

Fossil fuel resource estimates are indicated by the bars on the right. The estimates of 28-30 Q are given or implied by: the September 21, 1962 "Report of the National Fuels and Energy Study Group, on an Assessment of Available Information on Energy in the United States, to the Senate Committee on Interior and Insular Affairs;" the 1962 report "Energy Resources," prepared for the National Academy of Sciences Committee on Natural Resources; and the estimate of recoverable reserves in the 1961 Geological Survey Bulletin 1136, Page 98.

The Department of the Interior has indicated an informal opinion that, of its estimate of 124 Q in undiscovered and marginal resources, perhaps 24 Q can be recovered with improved technology at costs up to 10-15% above present levels. The remainder would probably be increasingly expensive, to a degree depending upon the effectiveness of new technology.

ginal resources, and different assumptions as to the fraction actually recovered in a given operation; there is little disagreement on the amount of readily recoverable reserves. The Interior Department believes that of its total estimate about 6 Q can be mined at present cost with known technology and, say, an additional 25 Q at 10% to 15% higher costs, provided the technology of mining exploration and extraction is much improved by further research. The remainder would presumably be increasingly expensive with inaccessibility, to a degree depending upon the effectiveness of new technological methods.

Although our current consumption of slightly less than .05 Q per year is small compared to the above figures, the rate is increasing so rapidly as soon to be far from negligible. Estimates of future consumption use past experience to derive estimates of future growth in population and in per capita use of energy. For example, curve A in each figure represents an extrapolation of experience during the past 60 years, when the average increase in annual fuel consumption was 2.04%, or a doubling every 30 years. It is probably conservative, at least for the next few decades, since the past increases would have been much greater had it not been for improved efficiency of use which is now beginning to approach theoretical limits in certain important fields.

The estimate represented by curve B is based on more recent experience. It is an extrapolation of an estimate for the year 1980, made by the National Fuels and Energy Study of the Committee on Interior and Insular Affairs of the United States Senate and is the mean, in terms of relative increase in consumption, among several estimates furnished us by the Department of the Interior. It can be thought of as a composite of the 1.75% annual rate of population growth during the past decade and a 1.5% annual rate of increase in per capita use.* This seems to us a reasonable estimate for the next few decades, but population pressures and a tendency to saturation in per capita use seem likely to result in a leveling-off process in the more distant future. For illustrative purposes we have constructed curves C, in which the average decrement in the relative rate of population growth since 1850 has been applied to the extrapolated population figures† and an arbitrary decrement has been applied to the relative rate of increase in per capita consumption such as to halve it each 100 years. (The latter would still result in tripling the per capita use during the next century.)

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* The average annual increase in per capita use during the past decade was about 1%.

† The annual rate of population increase declined from approximately 3.5% per year in the 1850's to 1.75% during the 1950's. The formula used predicts a population of about 320 million in 2000 A.D. and, if extended indefinitely, would saturate at about one billion.

As can be seen, different combinations of the estimates of fuel reserves and of cumulative uses would predict that, if no supplementary forms of energy were utilized, we would exhaust our readily available, low-cost supplies of fossil fuels in from 75 to 100 years and our presently visualized total supplies in from 150 to 200 years. Even if ultimate exhaustion of these materials were made tenable by the introduction of acceptable substitutes for every purpose, the transition would not be made suddenly. Long before the point of exhaustion of the fossil fuels, we would be obliged to taper off their use, passing through a maximum, perhaps within the life-span of persons now alive.

The fossil fuel resources of the world at large are relatively more limited. With but 6% of the world's population, it is estimated that the United States has approximately 30% of the world's reserves of fossil fuels.* The remainder of the world is consuming its reserves at approximately the same fractional rate as we but has been increasing its consumption two to three times as rapidly.† The rapid growth of technology in the less advanced areas—which we are endeavoring to foster—will tend to accelerate this relative increase. Hence, unless we export fuel, the non-U. S. supply will be exhausted considerably before our own. In any case, it seems certain that dependence on foreign sources cannot assist materially the long-range conservation of our total domestic resources of fossil fuels.‡

The long-range prospect should concern us even when considered only in the gross. It is more impressive in detail. In many important applications the fossil fuels have special advantages that are not matched, at least directly, by their foreseeable large-scale substitutes such as fission, fusion, or solar energy. Such substitutes are not directly applicable, for example, to small mobile power units such as the internal combustion engines that drive our autos and our aircraft, although in time effective energy conversion schemes may be developed to make them indirectly so. Fossil hydrocarbons are essential in the iron and steel industry and other metallurgical applications. Furthermore, these hydrocarbons represent a priceless heritage of complex molecular substances, the possible uses for which are only beginning to be realized.

The conclusion seems inescapable: <u>We should, with reasonable expedition, supplement the use of fossil fuels in those applications for which technically satisfactory and reasonably</u>

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*Estimate of the Energy Study of the Committee on Natural Resources of the National Academy of Sciences.

†Consumption rates from the United Nations Statistical Papers "World Energy Supplies," Series J, No. 1 to 5. The estimates have taken account of present import rates.

‡This statement does not necessarily apply in detail, for example, to petroleum; however, oil represents only a small fraction of the total resources.

economic substitutes can be utilized on a significant scale.*

As implied in the above conclusion, the ability of any potential source appreciably to supplement our total energy supply rests on positive answers to two questions: (1) Are there technically feasible and economically reasonable ways to utilize the source, and (2) are the potential uses and the available supply of sufficient size to be quantitatively significant? Such positive answers are indeed applicable to important uses of nuclear energy.

Of the two forms of nuclear interactions from which energy can presently be derived, fission and fusion, only the former can now be made to occur in a controlled manner. Whether or not methods of producing controlled and useful fusion reactions can also be developed is not yet predictable. It seems likely that, at best, useful controlled fusion devices are far in the future and that, if they do eventuate, they will be economically feasible only in extremely large installations. Accordingly, our discussions will be confined to the fission reaction.

A major portion of our consumption of fossil fuels is for the simple purpose of providing heat — heat to make steam for driving turbines, heat for use in industrial processes, heat to warm buildings. Now the nature of a nuclear fission reactor is such that most of the fission energy ultimately appears in the form of heat, applicable to the same purposes as that derived from fossil fuels.

There are, to be sure, certain limitations. It is characteristic of nuclear reactors that they must, at best, be relatively large and must usually be surrounded by massive radiation shields. Furthermore, the unit costs for energy become attractive only on a large-scale basis. Hence, their feasible uses are confined to fixed installations — or to large, mobile units such as ships — where there is a large local need or where some energy distribution method can be utilized efficiently.† Another restriction, hopefully diminishing with knowledge and experience, results from the fact that, for safety reasons, prudence now dictates placing large reactors fairly far away from population centers.

Two large-scale industrial applications of nuclear energy are technically feasible — electric power generation and process heat. These uses of fuel now account respectively for approximately 20% and 30% of the fossil fuel consumption in the country and electric power is rapidly increasing its fraction. Nuclear

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*Though recognizing the possibilities, the Commission has not given detailed attention to the corollary matter of conserving fossil fuels through more judicious use, e.g., by encouraging the use of less powerful, and hence less wasteful, automobile engines.

†This analysis does not consider such applications as in space, where shielding is unnecessary, or that and certain military applications where economics are a secondary consideration.

energy is economically reasonable for both. Indeed, in high-cost fuel areas of the country, nuclear electric power is on or near the threshold of being competitive in large units now. Undoubtedly, it could, in the relatively near future, also become competitive for many large-scale process heat applications if aggressively developed. In the more distant future nuclear reactors may well also provide an important direct source for space heating in areas of concentrated use, provided attention is given to appropriate distribution methods and safety can be assured. Furthermore, at any time the economics permit, nuclear energy can provide heat through an electric link.

Thus nuclear energy is directly applicable to a significant fraction of our total energy needs. There remains the question as to whether or not our supplies of nuclear fuel are sufficient to meet all, or a substantial fraction, of this need over a long period of time. The answer is complicated. The fissionable material found in nature is confined to uranium-235, constituting only $^7/_{10}$ of 1 percent of natural uranium. The fission energy derivable from this isotope in the known and estimated United States reserves of uranium that could be mined at costs not much in excess of those of the high-grade ores being mined today is estimated to be less than 1 Q. (See columns 1 and 2 of Table I.) Thus, if this were our only potential source, the contribution to our total energy reserves would scarcely be worth the developmental cost. Fortunately, however, this is but a fraction of the story. A reactor containing uranium-238 or thorium in addition to its fissionable material, can be made to create additional fissionable material, part of which is "burned" in situ; the remainder can be reclaimed to serve as fuel in the same or other reactors. The new fissionable materials made by this "conversion" process are plutonium, made from uranium-238, and uranium-233, made from thorium.* Furthermore, some classes of reactors can be made to produce more fissionable material than they consume. This process is known as "breeding."

Breeding will make available as potential fuel all the uranium and all the thorium instead of only the uranium-235. Thus, the potential of a given amount of uranium is multiplied by, say, 100, there being some inevitable losses in the cycling process. Furthermore, and importantly, this factor renders relatively unimportant the original cost of mining the uranium or thorium, thus opening up for potential use vast quantities of low-grade ore (Table I). Indeed, uranium and thorium in only trace amounts, as in the granite rocks, can be considered part of the economical reserves which, on this basis, are almost limitless.†

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*Because of this potentiality, uranium-238 and thorium are referred to as "fertile" materials.

†Even at only 50 grams of uranium or thorium per ton of rock, the energy required for processing is small compared to that latent in the nuclear fuel.

TABLE I—FISSION ENERGY CONTENT OF DOMESTIC NUCLEAR RESOURCES[1]

Cost Range, $ per Pound of Oxide[2]	Energy in U-235, Q: Reasonably Assured Resources	Energy in U-235, Q: Estimated Total Resources[3]	Total Energy Content, Q: Reasonably Assured Resources	Total Energy Content, Q: Estimated Total Resources[3]
I Uranium				
0–10	0.16[4]	0.4[4]	22[4]	50[4]
10–30	0.17	0.3	24	40
30–100[5]	5	10	700	1,400
100–500[5]	220	900	30,000	120,000
II Thorium				
0–10	does not apply		6[6]	25[6]
10–30	does not apply		6[6]	13[6]
30–100[5]	does not apply		700	2,200
100–500[5]	does not apply		63,000	190,000

[1]The magnitude of the resources has been estimated by the USAEC. The energy unit, the Q, equals one billion billion BTU, or 0.252 billion billion kilocalories. The fission energy content is presented on the basis that all the resource material will ultimately fission after being recycled through reactor cores in refabricated fuel. The figures do not take account of losses during fuel recycling and other relatively minor losses.

[2]Present Commission contracts call for a price of $8.00 per pound of uranium oxide. Its present open market price would be somewhat less. Market prices have not been established for thorium oxide on a significant scale.

[3]Includes geologic estimates of future discoveries.

[4]Includes uranium already mined, most of which still exists as uranium.

[5]Cost based on recovery of both uranium and thorium from granite, and only uranium from shale and phosphate rock.

[6]Incomplete estimate because of lack of data.

The enormous size of the nuclear fuel reserves, dwarfing as they do the fossil fuels, makes their development and exploitation of increasing and long-lasting importance; they can meet our energy needs for the indefinite future. Nuclear energy will account for a larger and larger share of our energy consumption and ultimately will predominate. As need arises and technology and economics permit, its use can be expanded by energy conversion methods, for example, by increased dependence on electric power as an intermediate link and by the use of chemical fuel cells for small mobile units. Properly utilized nuclear energy will make it possible to reserve substantial quantities of fossil hydrocarbons to meet long-range needs for which they are especially suited.

Thus, the utilization of nuclear energy fulfills our three conditions. It is technically feasible, it is economically reasonable, and it can be done on a massive scale. We conclude, therefore, that nuclear energy can and should make an important and, eventually a vital contribution toward meeting our long-term energy requirements.

Benefits of Nuclear Electric Power

Granted the long-term need for exploiting nuclear energy as a necessary resource, let us examine the nearer-term advantages to be derived from nuclear-electric power. As with any new technology, its development and widespread use would add to the health and vigor of our general industrial economy. The technical developments would continue to interact with those directed toward space and military applications of atomic energy, to the mutual benefit of all. The availability of an alternative economic energy source would allow flexibility in methods of approach to different situations and lend the possibility of opening up new fields. For example, the developments to date have brought to light the promising possibility of utilizing reactor heat for the economic large-scale desalinization of water by the distillation process. An additional, competitive source of energy would give a healthy stimulus to our conventional power and fuel supplying industries. It would provide incentive, as indeed the prospect has already, for greater efforts to improve technology and minimize the costs of conventional power.

A feeling for the magnitude of the potential impact of our technology and economy can be gained from the fact that the annual rate of spending for new plants by the utility industries, currently about 10% of that for all industrial construction, is expected to reach approximately $6.5 billion by 1980 and $20 billion by 2000 A.D. Approximately 60% of this would be for the steam generating equipment. At projected conventional rates the annual cost of generating electric power is expected to exceed $15 billion by 1980 and to approach $50 billion by the year 2000.

There can be substantial savings to consumers from the use of nuclear power. The first to be forthcoming results from a unique economic feature. The generating cost of nuclear power is almost entirely independent of the area in which it is installed, since transportation costs for fuel are relatively minor. In contrast, for conventional power fuel transportation costs cause a range of nearly three to two in unit generating costs between the most expensive and the cheapest areas. As a result the average cost for power generation in the country is approximately 20% higher than in the areas of lowest cost. With the present power distribution and at the present differential rates, this 20% would, if continued, amount to almost $3 billion annually in 1980 and $10 billion in the year 2000.

In our opinion, nuclear power is on the threshold of being competitive with conventional power in the highest fuel cost areas. With further cost reductions it can, if used, increasingly reduce the inter-area differential in power generation costs and eventually place the entire country on an equal basis.* Such a change would be an economic boon to the regions where costs of fossil fuels are high. In addition to saving substantial sums for the consumers, it would encourage additional industrial development in such regions and hence increase the industrial and economic potential of the nation. An interesting technological effect would be that the reduction in electric rates relative to fuel rates would tend to encourage increased use of electric power for industrial and space heating purposes.

There are important international implications. As stated earlier, the United States has more than its proportionate amount of the world's resources of the fossil fuels; many parts of the world have none at all. Consequently, nuclear power has even greater application in many other countries than in this; indeed, in some there is an immediate need. There are vigorous nuclear power programs in Western Europe and in Japan, which must import most of their fuel. India and other less technologically developed nations are embarking on important programs. With a few exceptions the various countries look to us and to a very few others for technological assistance and as a source of nuclear power equipment. So far the United States has led in the sale of such equipment.

The maintenance of a position of technological leadership in nuclear power will enable us to maintain an important position in the affairs of the International Atomic Energy Agency. In our opinion, the role of this Agency should be a vital one when nuclear power comes into widespread use. In particular, through its safeguards systems, it will be the best mechanism to assure that nuclear materials are not diverted to military purposes in nations not otherwise possessing resources for a nuclear weapons program.

Thus it is clearly to the advantage of the U. S. to maintain world leadership in the nuclear power field. A vigorous domestic power program will help enable us to do so.

Nuclear power could also have a bearing on the defense posture of the country. The nature of the fuel makes transportation requirements very small. Hence, in periods of national emergency, nuclear installations would not put a burden on our transportation systems; in case of actual attack upon the country, installations that survived need not be paralyzed for lack of fuel, even though the transportation system actually broke down. Furthermore, it would be quite feasible and relatively cheap to locate our power installations underground so that many of them could continue operation even after a large-scale attack. Even though the distribution systems were

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*The introduction of nuclear power will, of course, be gradual. The power generated by conventional plants will continue to increase for at least several decades, and consumption of fossil fuels, especially coal, will increase accordingly. See page 61.

temporarily disrupted, the existence of operable plants would greatly hasten post-hostility recovery.

A further advantage of nuclear power relates to the increasing smoke pollution of the atmosphere as the use of coal increases. Nuclear power does not contribute to this problem. Its waste disposal problem is of a different nature; it will be discussed in a later section.

In summary we see that nuclear-electric power holds enormous possibilities—as an important means of exploiting a large new energy resource; as an economic advantage, especially to areas where fossil fuel costs are high; as an important contributor to new industrial technology and to our technological world leadership; as a significant element in our international posture; and potentially as a means of strengthening our defense posture. From all these and other factors we conclude that the development and exploitation of nuclear-electric power is clearly in the short- and long-term national interest and should be vigorously pursued.

The Role of Government

The continuing availability of abundant and economic sources of energy is a matter of concern to all the people. To assure that availability is, therefore, clearly a responsibility of Government. The Atomic Energy Act recognizes this responsibility in the case of nuclear energy.

Unlike such revolutions as those introducing the railroad, the automobile, the airplane, the telephone, the radio, and, indeed, electric power itself, the large-scale use of nuclear energy for electric power generation will not result in qualitatively new capabilities. Its public marketability will be based almost completely on economic factors. Hence, working within our free economy, the Government can best assure widespread use of nuclear energy by fostering developments that make such use economically attractive.

The economics has two aspects: (1) The costs of initially developing the technology; and (2) the costs of manufacturing and using nuclear power plants vis-a-vis the costs of more conventional methods.

The development of even a fairly simple nuclear reactor concept is an expensive process, both because of the complexities involved in the development of individual components and processes, especially those involving radiation, and because operating units, even of a scaled-down test variety, must of necessity be large and costly. Hence, a large investment was required of someone before safe and efficient operating units could be designed and built. Since the product does not meet some hitherto unfilled need but rather must depend for its marketability upon purely economic advantages which, for some time, will be small compared to the investment, industry could not have afforded to undertake the development by itself. The Government must clearly play a role.

Even a well-developed nuclear technology would not be utilized unless its manufacturing and operating costs were at least competitive with those of more conventional methods. Hence the task of government includes assuring that technological developments are carried to the point where, with appropriate encouragement and support, industry can provide nuclear power installations of overall economic attractiveness sufficient to induce public- and investor-owned utilities to install them at their own expense. Once this is achieved, and nuclear power becomes a profitable endeavor, normal economic incentives will bring about a growing business. The Government's investment will be augmented manyfold by industry. The equipment manufacturers can finance major technical development programs, reducing, and finally removing, the burden on the Government.

Hence, the creation of a self-sustaining and growing nuclear power industry should be a prime objective of the program.

The developmental and promotional programs to attain these ends must, of course, be carried out in such a way that both short- and long-term goals are reached—that the economic, technological and other immediate benefits are expeditiously realized, that the total energy latent in our nuclear reserves is made available and that a significant contribution is made toward conservation of our fossil fuels. Hence, it is essential that, within a reasonably short time, the goal should be attained of making breeder reactors technologically and economically attractive. The Government must take the lead in this regard.

Thus, the proper role of Government is to take the lead in developing and demonstrating the technology in such ways that natural economic forces will promote industrial applications and lead to a self-sustaining and growing nuclear power industry; the program should be guided in such directions that those economic forces will work toward ends in the public interest, including the long-range conservation of both our fossil and our nuclear fuel resources.

The Present Situation

In bringing the civilian nuclear power program to its present stage, the Atomic Energy Commission has carried out and encouraged a national program, aimed first at obtaining the basic scientific and engineering data needed for proof of technical feasibility of the more promising approaches to nuclear power generation, and second at demonstrating the actual or potential economic feasibility of such approaches. The program has leaned heavily upon, indeed it started from, technical knowledge gained in other reactor programs—notably "production" reactors for making plutonium, naval propulsion reactors, and "research" reactors used for scientific purposes. It has also been vitally assisted by the existence of several AEC production facilities, notably the large and efficient gaseous diffusion plants for enriched uranium-235, the production reactors for plutonium, and the chemical separation plants.

The scope of the program to date has been purposely kept very broad. Not only has it included a whole spectrum of reactor classes from almost pure burners to fast breeders, but, in each general class, technical and economic uncertainties have prompted many avenues of approach. The program has included two distinguishable but interlocking phases:

1. A research and development program on a laboratory scale to investigate and understand the basic science and to develop and prove out the general technology. This program, predominantly at AEC expense, has included work in the National Laboratories and other Government-owned facilities and in laboratories of the nuclear industry. It includes basic and applied research in physics, chemistry and metallurgy; development work on reactor components such as fuel elements, structural materials, moderators, coolants, and such external system components as heat exchangers, pumps, etc.—and the development of processes such as chemical reprocessing, fuel fabrication and waste disposal. Knowledge of reactor behavior is acquired through "exponential" and "critical" experiments to investigate the physics of the chain reaction and through reactor "experiments" to study the behavior of complete reactor systems.

2. A "power demonstration" program of utility installations to verify technology in actual practice, to yield economic information and to provide experience on which to base improvements. This includes Commission-owned, public utility-operated "prototypes", usually reduced in scale from current utility practice, and utility-owned installations which the Commission has assisted to various degrees.

The arrangement for the Commission-owned prototypes, usually on publicly-owned utility grids, has been that steam produced in a Commission-built and -owned reactor is fed to electric generating facilities owned by the utility. The utility operates the entire installation with appropriate financial arrangements covering operating costs and the market value of the steam. Most such operating contracts are of 5-year duration, with the utility holding an option to purchase the reactor at a price commensurate with its utilitarian value at the end of that period. An exception is the Commission-owned reactor at Shippingport, Pennsylvania, operated by the investor-owned Duquesne Electric Company which, during the first 4 years of operation, absorbed a significant portion of the operating loss.

Various forms of assistance have been given to investor-owned utilities to encourage them to construct their own nuclear plants. These include research and development assistance to the fabricator; the use of government-owned fuel at government interest rates, plus a charge for fuel consumed and, in some instances, a waiver of interest ("use") charges during the first five years of operation. Offers of assistance have been made in such a way as to encourage various utilities, especially those requiring small plants, to adopt a variety of reactor plants and thus help demonstrate their feasibility.

To date, the Commission has spent approximately $1.275 billion* specifically on the civilian power program, including $275 million for the development, construction and operation of Commission-owned reactors on utility grids, and $37 million for development assistance on utility-owned installations. The present annual rate of expenditure is approximately $200 million.* During the past several years industry has spent approximately $500 million, mostly for plant construction but also for laboratory and other development facilities and for development work.

Significant progress has been made in the 9 years since authorization of the Shippingport reactor, the first built primarily for the generation of central station power. In addition to great technical progress all along the line, costs have been reduced, from the first actual experience of about 50 mills per kwh at the Shippingport prototype reactor in 1958 to less than 10 mills per kwh for full-scale plants now in existence and an estimated 5.5 to 6 mills for a large plant to be built in the near future at Bodega Bay, California.

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*These figures are somewhat indefinite since they include a rather arbitrary assignment of the costs of research and development programs contributing technical results to other programs as well.

In addition to the Government-owned Shippingport pressurized water reactor,* which has generated 1.36 billion kilowatt hours of electric power, and privately-owned "Yankee" pressurized water reactor in Massachusetts, and the "Dresden" boiling water reactor plant, built without Government assistance in Illinois, have generated 1.45 and 2.43 billion kilowatt hours, respectively.† Recently placed in operation are the Consolidated Edison pressurized water reactor plant in New York, also built wholly with private capital, an AEC-owned sodium-graphite reactor in a plant of the Consumers Public Power District of Nebraska and a boiling water reactor owned by the Consumers Power Company in Michigan. They will bring the total nuclear electric generating capacity in the country to approximately 850,000 kilowatts, about 0.5% of our total installed capacity. Seven other central station nuclear power plants are scheduled to start operation in the next few months. Table II lists these and other less complete power installations, together with their capacities and types. The list does not include five small experimental plants, of which two are privately owned.

In addition to the previously mentioned assistance gained from other technical programs and from AEC production facilities, the program has been aided by a number of circumstances, including: (1) The policy of both the Executive Branch and the Congress to bring industry actively into the development; (2) the optimism, indeed the over-optimism, on the part of many people in the early years; (3) the prestige to be derived by private utilities from engaging in this development rather than leaving it entirely to public bodies; and (4) the incentive of international prestige and international trade; this was accentuated by the Suez crisis of 1956-57 which made all Europe more concerned about its fuel supply and spurred them to vigorous efforts, in many of which the U. S. has actively participated. (Continental European countries alone have spent some $200 million in their first five years of operation and the United Kingdom has spent even larger sums and is presently spending nearly $100 million per year.)

Experience has verified the fact that at the present time construction costs and, hence, capital charges assignable to generating costs are higher for nuclear than for conventional plants,‡ though the margin is decreasing. On the other hand, fuel cycle costs are lower for nuclear plants in appreciable

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*The various reactor types named here and in Table II are described in a subsequent technical section.

†These totals are as of October 29, 1962.

‡Estimated near-term costs for large installations are roughly $125 to $150 per kilowatt for conventional plants and $160 to $190 per kilowatt for nuclear plants.

TABLE II—NUCLEAR POWER PLANTS OPERABLE AND BEING BUILT[1]

NAME	REACTOR OWNER	OPERATOR	NUCLEAR CAPACITY, KWE[2]	TYPE OF REACTOR
Part I Operating Reactors				
Shippingport Atomic Power Station	AEC	Duquesne Light Company	67,000[3]	Pressurized Water
Yankee Nuclear Power Station	Yankee Atomic Electric Co.[4]		165,000	Pressurized Water
Consolidated Edison Thorium Reactor	Consolidated Edison Co. of N. Y.		202,000[5] (164,000)	Pressurized Water
Dresden Nuclear Power Station	Commonwealth Edison Company		209,000	Boiling Water
Big Rock Point Plant	Consumers Power Company[4]		50,000	Boiling Water
Hallam Nuclear Power Facility	AEC	Consumers Public Power District of Nebraska	82,000	Sodium Cooled and Graphite Moderated
Part II Reactors to be completed by the end of 1963				
Elk River Reactor	AEC	Rural Cooperative Power Association	18,000[6] (16,000)	Boiling Water
Humboldt Bay Power Plant	Pacific Gas and Electric Company		50,000	Boiling Water
Carolinas-Virginia Tube Reactor	Carolinas-Virginia Nuclear Power Associates[4]		16,000[7] (15,700)	Heavy Water Cooled and Moderated
Enrico Fermi Atomic Power Plant	Power Reactor Development Company[4]		65,900	Fast Breeder
Piqua Organic Moderated Reactor	AEC	City of Piqua, Ohio	12,500	Organic Cooled and Moderated
Pathfinder Atomic Power Plant	Northern States Power Company[4]		66,000	Boiling Water, with Nuclear Superheat
Boiling Nuclear Superheat Reactor	AEC	Puerto Rico Water Resources Authority	17,300	Boiling Water, with Nuclear Superheat
Part III Reactors to be completed after 1963				
Experimental Gas Cooled Reactor	AEC	TVA	29,400	Helium Cooled and Graphite Moderated
La Crosse Boiling Water Reactor	AEC	Dairyland Power Cooperative	53,500	Boiling Water
Peach Bottom Atomic Power Station	Philadelphia Electric Company[4]		42,200	Helium Cooled and Graphite Moderated

[1] This table includes only plants operated by utilities. It does not include a few small plants whose power is used on site or sold in small quantities.

[2] The gross electrical generating capacity (KWE) is given for each reactor. For plants equipped with fossil-fired steam superheaters, this gross nuclear electric capacity is determined by prorating the gross electric output of the plant in accord with the respective heat outputs for the nuclear reactor and the fossil-fired superheater; the alternate figure for capacity given in parentheses assumes the reactor could achieve 28% efficiency in converting reactor heat to electricity.

[3] The plant will operate at a thermal output equivalent to 150,000 KWE in 1964.

[4] AEC provided assistance on research and development, and waived use charges.

[5] A fossil-fired superheater brings gross capacity to 275,000 KWE.

[6] A fossil-fired superheater brings gross capacity to 23,000 KWE.

[7] A fossil-fired superheater brings gross capacity to 19,000 KWE.

areas of the country. For new plants that can now be built, these differences plus other minor ones approximately offset each other for large plants in the highest fuel cost areas. The unit cost of power, of course, decreases with increased plant capacity in both cases, but somewhat more rapidly for nuclear than for conventional plants. Hence, nuclear plants become economically more competitive as the size of plant increases. The growing trend to very large installations* thus favors nuclear power.

In order to assess the competitiveness of nuclear plants, it is convenient to express that competitiveness in terms of fuel costs for fossil fuel plants having the same total generating cost. Nearly all of the central station power in the U. S. is generated at fuel costs between 15¢ and 38¢ per million BTU. At efficiencies now achieved in first-rate large plants, each cent per million BTU adds approximately .085 mills per kilowatt hour (m/kwh) to the generating cost. For such plants, other elements in the cost, which are nearly independent of plant location, amount (for an enclosed plant) to approximately 2.8 to 3.0 m/kwh. Hence, total costs range, approximately, from 4.1 to 6.2 m/kwh.

Manufacturers' current estimates indicate that a large water-cooled nuclear plant initiated now could initially generate power at approximately 6 m/kwh or less and, therefore, compete with about 36¢ fuel or even lower. However, over plant lifetime the average generating costs could go down appreciably for two reasons: (1) If research and development are vigorously pursued, "burn-up", i.e., the energy extracted from a given fuel loading, could be improved and thus reduce the frequency of fuel reprocessing and fabrication; this, plus technical advances in fabrication and reprocessing techniques, would reduce the overall cost for fuel; (2) the operating power level, which tends to be set very conservatively initially, could be increased, thus decreasing the fixed charge, operating, and maintenance cost per kilowatt hour.† We estimate that the sum of these effects could decrease the total cost by an average of 0.5 or 0.6 m/kwh, thus making the plant, over its lifetime, competitive with about 30¢ or 31¢ fuel. If so, such a plant would be competitive with conventional plants built at the same time in areas which now account for approximately one-third of the electrical

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*At present about two-thirds of the total electric energy in the U. S. is generated in plants of 300 megawatt (300,000 kilowatt) capacity or greater and 40% in plants of 500 mw capacity or greater. Plants as large as 1 million kilowatts are now being considered by utilities and equipment manufacturers.

†Conventional plants—utilizing as they do, a highly developed technology—cannot reduce unit generating costs over plant lifetime nearly as much as can nuclear plants in the present stage of their development.

energy consumption in the country.* Potential savings would be from zero in 31¢ fuel areas to about 10% of the total generating costs in 38¢ fuel areas.

In our opinion the above facts will, when demonstrated to their satisfaction, give to an appreciable fraction of the utility industry sufficient economic incentive to bring about extensive installation of nuclear electric power. A few full-scale plants will, we believe, provide that demonstration. Indeed, increasing numbers of utilities in high fuel cost areas are considering nuclear plants. For example, the Pacific Gas and Electric Company is moving forward on a plan for an entirely self-financed 325 megawatt installation at Bodega Bay, California, in one of the highest fuel cost areas. Relatively modest expenditures for assistance by the AEC will, we believe, be sufficient to assure the construction of additional plants, in other areas.

Thus we conclude that nuclear power is on the threshold of economic competitiveness and can soon be made competitive in areas consuming a significant fraction of the nation's electrical energy; relatively modest assistance by the AEC will assure the crossing of that threshold and bring about widespread acceptance by the utility industry.

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* Electrical energy consumed in the U.S. is distributed roughly uniformly over the range of fossil fuel costs (38¢ – 15¢ = 23¢ per million BTU). Hence, once nuclear power is competitive in the areas of highest fuel costs, each 0.1 mill/kwh reduction in its cost will add 0.1/(23 × .085) = 5%, to the fraction of the energy consumption for which it is competitive.

Reactor Systems

Several types of reactors are in various stages of development. They include both "converters" that produce less fissionable material than they consume, and "breeders" that produce more than they consume. The following sections will describe briefly several of the more promising of the various types.

Converters

The most highly developed reactors for electric power generation are reactors that are cooled and moderated* with "light" or "normal" water and produce saturated steam. They are of two sub-types: (1) "Pressurized-water" reactors in which the reactor and a closed primary cooling "loop" are entirely filled with water so that no steam is formed therein; steam to drive the turbines is formed in a secondary loop coupled to the primary through a heat exchanger. (2) Boiling water reactors, in which steam is formed in the reactor proper. Sometimes this steam is used directly in the turbines; sometimes a secondary loop is used.

All of the large and many of the medium and small power installations built thus far are of these types. Although there is still room for improvement, such as attainment of higher temperatures, higher power density, and greater fuel "burnup", they have definitely "arrived". They are reliable and safe. It is believed that large reactors of these types could now be built and operated in high cost fuel areas with a lifetime promise of greater economy than conventional plants. Even better economics can undoubtedly be achieved in the future from better fuel performance and other general improvements.

Although at present the most economical and reliable, these reactors have certain inherent limitations. They suffer from the fact that they produce relatively low temperature saturated steam, which limits their ultimate efficiencies and requires the

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*The neutrons emitted from a fissioning nucleus have very high velocities and are spoken of as "fast". They are said to be "moderated" when they have been slowed down through many collisions with light nuclei such as hydrogen (in water or organic compounds), carbon (in graphite), or beryllium. If moderated enough to reach equilibrium at the temperature of the reactor, they are referred to as "thermal". Because their behavior depends markedly on the neutron energy spectrum, reactors are characterized as "thermal", "intermediate", or "fast".

use of large and expensive turbines. Furthermore, they do not have the potential of breeding and, hence, cannot make appreciable use of the fertile materials on which we must depend in the long-range future. Consequently, other converters, promising improvements in these respects, are being actively pursued.

Among the more highly developed of these improved types are water-cooled reactors producing super-heated steam. Variants of this basic idea include systems in which (1) steam is produced in one reactor and superheated in another; and (2) steam is produced and superheated in the same reactor. In some of the latter type the steam-producing portion of the reactor has a thermal neutron spectrum and the superheater has a fast one. The superheat concepts offer fairly extensive economic incentives because of the higher temperatures, and hence higher thermal efficiencies, than in saturated steam reactors and because smaller, less expensive turbines can be used. The major problem seems to be development of materials to withstand the superheated steam. The "Bonus" and "Pathfinder" prototype reactors are of this type.

Also fairly well-developed though not so extensively as the saturated steam reactors are a number of converters utilizing other moderators and coolants. Most promise better economics, many of them markedly so. Others have improved conversion ratios. Still others have special characteristics such as the type of fuel they use or the tasks they can perform. Some reactors combine two or more of these characteristics. Among these potentially better converters are:

1. The organic-cooled and -moderated reactor, utilizing organic liquids for moderation and for cooling, in order to reduce the pressure and increase the temperature in the reactor vessel. Although showing early promise, this development has been plagued by a tendency of the fluids to "foul"; that is, to form gummy substances that coat the metal surfaces and interfere with heat transfer. This fouling increases markedly with temperature. Although this problem will undoubtedly be solved, at least for moderate temperatures, it is not clear that this reactor has better potentialities than the light water ones for power generation, though it may for process heat because the liquids used do not become radioactive. The Piqua "prototype" reactor is of this type.

2. Reactors using "heavy" water; that is, water incorporating deuterium instead of normal hydrogen. Although not so effective a moderator, heavy water has the advantage of absorbing fewer neutrons, making possible the use of natural rather than enriched uranium. If enriched fuel is used, the neutron economy can result in higher conversion ratios and greater fuel economy than in light water reactors. A principal drawback is the high cost of heavy water, requiring large capital investment and extreme measures to prevent leaks and, hence, economic losses. In enriched reactors, this draw-

back can be reduced, at the expense of part of the neutron economy, by using heavy water only as the moderator, and cooling with organic liquid or with normal water. Heavy water reactors are being energetically developed by the Canadians who have a 20 megawatt reactor under utility operation and a 200 Mw one in construction. We are co-operating closely with them.

3. The "Spectral-shift" reactor combining light and heavy water. In this concept a freshly charged reactor is cooled and moderated by a mixture of predominantly heavy water. This results in "under-moderation" and a higher than thermal neutron energy spectrum, leading to high conversion ratios. As the fuel is used, and neutron absorbing fission products accumulate, the ratio of light to heavy water is increased, maintaining the chain reaction at its initial level. This procedure avoids the necessity for expensive control rods or chemical solutions that waste the neutrons and reduce the fuel economy. Thus quite high conversion ratios can presumably be achieved over the fuel cycle. This concept is especially promising for the thorium-uranium cycle. It could, presumably, move to the construction stage quite quickly.

4. The "sodium-graphite" reactor, cooled by liquid sodium and moderated by carbon in the form of graphite. This reactor has potential for achieving quite high temperatures, and hence thermal efficiencies, and could also be a somewhat improved converter. The fact that molten sodium absorbs iodine almost quantitatively will substantially ease the siting problem of this type of reactor by minimizing the dispersion of radioactive material in case of a reactor accident. Importantly, the technology of liquid metals such as sodium will be vital to the ultimate fast breeders, so that this development has strong future implications. The Hallam reactor is of this type.

5. Gas-cooled reactors. Such reactors incorporate cooling with such gases as helium, hydrogen or carbon dioxide and moderation by a solid such as graphite or beryllium. They give substantial promise for high temperatures and fairly high conversion ratios. High temperature gas-cooled reactors are especially promising for the thorium-uranium cycle, where conversion ratios of nearly, if not quite, one seem feasible. The Peach Bottom reactor, near Philadelphia, is of an advanced gas-cooled type.

Breeders

In our discussion of nuclear resources we have seen that the energy contained in fissionable uranium-235 in the supplies of relatively low-cost ores is so limited that the fertile materials must be extensively exploited if nuclear energy is to be of widespread and lasting benefit. Hence, there is a fairly near-term, though not immediate, need for reactors that produce more fissionable material than they consume.

Breeder reactors are of two general kinds, "fast breeders", utilizing the uranium-plutonium cycle and "thermal" breeders utilizing the thorium – U-233 cycle. Unfortunately, none of these are nearly so well developed at this time, either technically or economically, as the converters are.

The nuclear properties of uranium-235 and plutonium are such that more neutrons are released from fissions brought about by fast than by slow neutrons. Indeed, the difference is so great as to make breeding feasible in fast, but not in thermal reactors utilizing these materials.* Unfortunately, there are combined technical and economic difficulties in fast reactors. Good breeding gains obviously require that the fuel material be not overly diluted with other substances that absorb or moderate the neutrons.† Hence, to avoid large and expensive fuel inventories, the power that they generate must be concentrated in small volumes. This gives rise to engineering and safety problems of removing heat at the necessary rate. Furthermore, it is difficult to develop concentrated fuels that will endure until a substantial fraction of the fuel has been consumed and hence minimize expensive refabrication of the fuel elements. So far these factors have combined to make fast breeders quite expensive. Fortunately, there are promising developments for greatly improved fuels. These include "ceramic" fuels such as uranium- and plutonium-oxides and carbides. In the farther future is the possibility of utilizing molten plutonium.

Most effort in fast breeders has involved utilizing molten sodium or sodium-potassium alloys as the coolant. This has required a complex and expensive new technology, including development of pumps, heat exchangers, and the like, of com-

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*In a "thermal" reactor the number of neutrons emitted per neutron absorbed varies from somewhat below to slightly above 2 for both U-235 and plutonium, depending on the degree of moderation. The corresponding figures for unmoderated fission neutrons are 2.45 for U-235 and 2.94 for plutonium. In each case, of course, one neutron is required to keep the chain reaction going. There are inevitably some losses through leakage and absorption in other reactor materials. Hence, whereas thermal reactors fueled with U-235 or with plutonium probably cannot breed at all, fast reactors might technically achieve breeding gains of, say, 1.2 when fueled with U-235 and as much as 1.6 when fueled with plutonium. Economic considerations will, however, reduce these figures appreciably.

†In addition to producing fewer neutrons per neutron absorbed in the fissile material, slow neutrons are more readily absorbed by other materials, including the fission products.

patible materials. Fortunately, development work for the sodium-graphite reactor has also contributed to this technology.

In the thorium–uranium-233 cycle, the situation is quite different. U-233 emits more neutrons in thermal fission than does U-235; on the other hand, it is only slightly better in fast fission than in slow.* Hence, thermal breeders offer greatest promise, minimizing as they do the power density and fuel endurability requirements. However, thermal breeders have a different complication in that fission products act as strong absorbers of slow neutrons, requiring that these products not accumulate too much. Among the most promising solutions of this difficulty is to use the fuel in fluid form, thus permitting continuous extraction and reprocessing to remove the fission products. Various fluid fuels have been studied for this purpose. The currently most promising approach is the use of fused uranium salts which can be circulated, both for reprocessing purposes and for heat transport. This technology is, however, in a fairly early stage.

Probable Trends

Even when breeder reactors become economic and begin to be installed there will be a complication regarding fuel supplies. At least for some time to come, economic breeders will have breeding gains so low that they will produce not more than 3% or 4% of their fuel inventory each year.† Hence, since the annual growth in energy consumption is about 6%, it will be necessary, if nuclear power increases its fractional share of the total load, to fuel some portion of the installations with fissionable uranium-235.

This leads to no great problem in the thorium-uranium thermal breeders. The fuel demand can be fulfilled simply by charging some of them, initially at least, with U-235, though at

*At thermal energies, the average number of fission neutrons emitted per neutron absorbed in U-233 is 2.3. This number is 2.58 for unmoderated neutrons and more like 2.35 or 2.4 for the neutrons in any actual fast reactor.

†In thorium-uranium breeders, the inherent nuclear constants confine economic breeding gains to not much more than one so that the excess production is a very small fraction of the fuel consumed, and the relative rate of increase in U-233 is very low. In the "fast" reactors used as plutonium breeders, higher breeding gains are feasible, but the fuel inventory required is much larger compared to the consumption rate, resulting again in low relative rates of increase. It is usually customary to express the relative production rate in terms of the "doubling time", that is, the time required for a reactor to produce enough excess material to fuel a second reactor. This will probably be 15 to 20 years, or even longer for the first economic breeders.

some sacrifice in economics and in the amount of U-233 that they produce.*

On the other hand the "fast" reactors required to breed an excess of plutonium are economically attractive only when plutonium rather than U-235 is used to fuel them. Hence the most promising arrangement for incorporating them in a rapidly expanding nuclear power economy would undoubtedly be to use thermal converters to help provide the plutonium needed for added installations. This combination would continue until increases in the relative "yield" of plutonium from the breeders, together with a lower relative rate of growth of electrical energy consumption enabled the breeders to catch up and produce enough plutonium by themselves.

This requirement enhances the need for the high efficiency converters mentioned in an earlier paragraph. Not only will their continued employment into the breeder era increase the importance of their better economics, but their higher plutonium yield† will increase the rate at which new breeders can be built and, hence, enrich the breeder-converter mixture. This could be especially important if the requirement for converters to complement the breeders extends beyond the duration of our supplies of cheap uranium. Ultimately, of course, there must be a net breeding gain for the nuclear power industry as a whole.

Breeders will, of course, be attractive to the utilities only if they compete economically with the best available converters. This will depend on the relative capital costs, the operating efficiencies and, importantly, on the relative abundance and values of the various nuclear fuels. Considering all the facts, we believe that fast breeders will become competitive with converters in the next decade or two, and will be built on an increasing scale along with additional converters. The economics of the various fuels on a free market basis will, we feel, automatically assure a proper ratio. Scarcity of plutonium and/or abundance of uranium would lead to more converters and vice-versa.‡ As breeders improve in economic breeding ratio and uranium-235 costs mount with exhaustion of cheap

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* When charged with U-235 such reactors will probably have a conversion ratio less than one and hence will not then be breeders.

† The "yield" of plutonium in a converter is the difference between that produced and that burned in situ. Long burn-up times, important economically, increase the fraction of plutonium burned in situ.

‡ At the expected economic breeding gains (less than 1.1) and fuel values the economic advantage given to the breeders by the additional plutonium they produce is more than offset by the added carrying charges resulting from their large fuel inventory. Hence high plutonium values are unfavorable to them. The situation would reverse at sufficiently high breeding gains.

ores, the proportion of fast breeders will increase, at a rate limited only by the plutonium supply.

Meanwhile, thorium–uranium-233 breeders will, if vigorously developed, no doubt also become economic. Neglecting the possible use of plutonium in such breeders, the situation is less complicated than in the plutonium cycle, since only thermal reactors are involved. The scale of use of such breeders will, therefore, depend largely on the economics of the total situation. Initial economic pressures may well, however, tend to favor the uranium-plutonium cycle since plutonium will be an immediate product of the converters that will constitute the bulk of the initial power reactor installations.

Much developmental work and several generations of reactors, involving many decades, will no doubt be required to reach the point where improved economic breeders, together with possible reductions in the relative rate of growth in power needs, will make the breeders sufficient to themselves. When that point is ultimately reached, new uranium will be required only to provide the uranium-238, although use will, of course, be made of the uranium-235 that it contains. By that time, or even sooner, advantage can be taken of our large supplies of "depleted" uranium from which the major fraction of the uranium-235 has been extracted in the diffusion plants.

Thus, the future program should include the vigorous development and timely introduction of improved converters and especially of economic breeders; the latter are essential to long-range major use of nuclear energy.

Assessment of the Degree of Urgency

Granted that there is an ultimate requirement for nuclear power that, extensively used, it could provide important near-term benefits and that Government should play a leading role in its development, we should assess the degree of urgency, taking into account the present stage of advance, the cost of future development and the magnitude of the benefits to be derived.

It is perhaps worthwhile to recapitulate our assessment of the present situation. As a result of comprehensive research and development programs over the past dozen years much of the technology has reached a highly developed stage. Water reactors can now be built that, over their lifetime, will be competitive with conventional power in significant areas of the country; improved converters can be brought to the same stage in a relatively few years; although much remains to be done, definite progress is being made on breeders. Practical experience is being accumulated from a number of reactors in operation on utility grids and much more will become available in the near future. There exists a substantial nuclear equipment industry that is eager and well able to build nuclear power plants on a scale considerably larger than that for which there is a present demand. There is widespread and growing interest abroad in the utilization of nuclear power and an increasing tendency to turn to American industry as a manufacturing source. Nuclear power seems to be on the threshold of coming into being on a significant scale.

It must be realized, however, that the development of a mature nuclear power technology and its utilization on an extensive scale will be a long process. As in any other technology, progress is brought about not only by research and development but also through experience. Operating units must be used and tested throughout their normal lifetimes. Unlike devices normally used intermittently, such as cars, airplanes and radios, the process cannot be shortened by speeding up the tests. Hence successive generations in the development are even decades long.

There is also the factor of psychology. Before committing a substantial fraction of their installations to nuclear technology, utility executives will want to be convinced, themselves, that nuclear power is economical, reliable and safe. With few exceptions this conviction will require observation of results of actual installations operating for periods that are significant in terms of the normal lifetime of power installations.

There is, of course, no absolute yardstick by which to measure goals for nuclear power. The relative advantages of progressing more or less swiftly are matters of degree. Perhaps the most convenient method of assessment would be to use the present Commission program as a frame of reference.

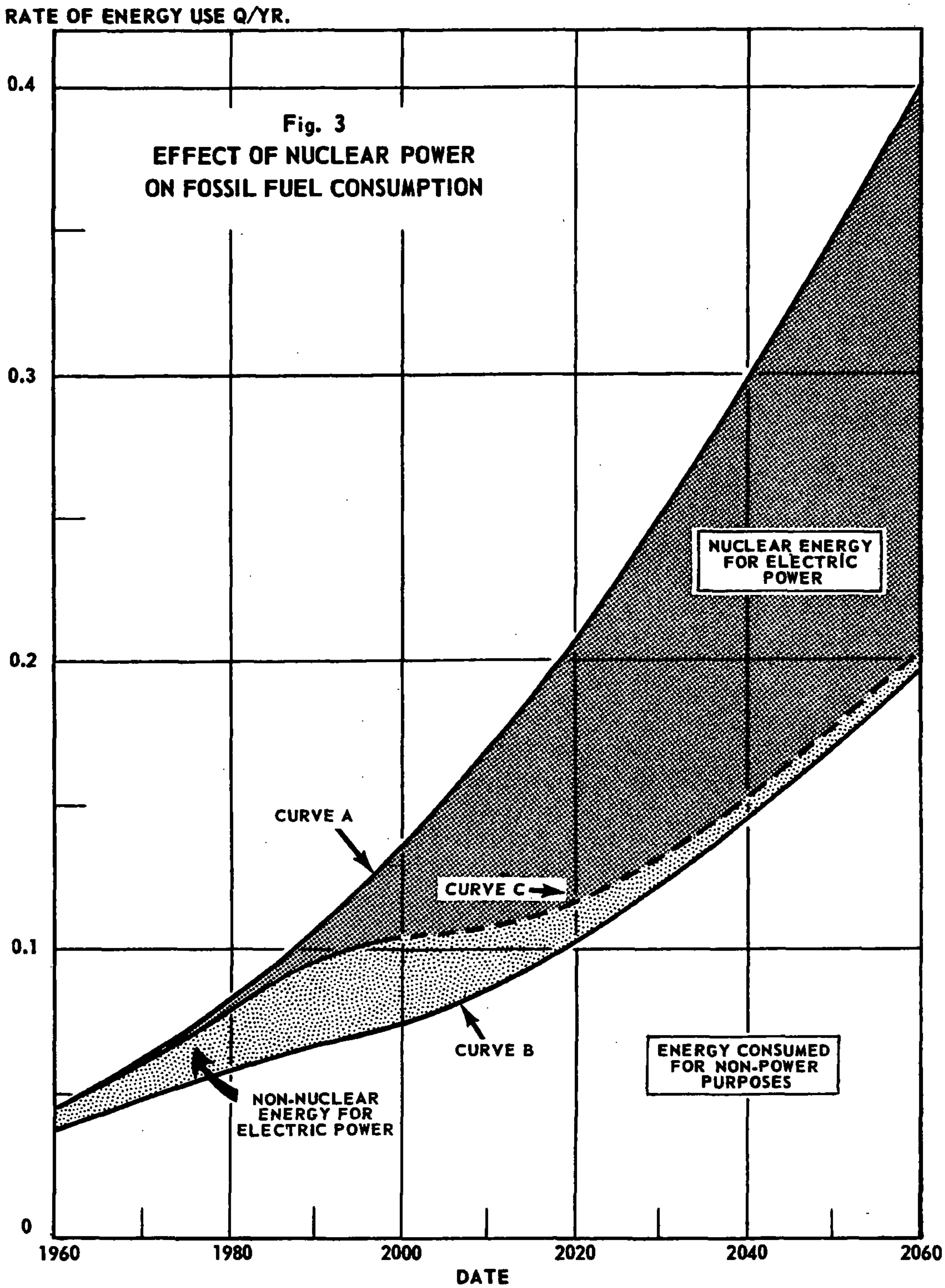
Continuation of that effort, with some augmentation in support for the power demonstration program,* and with program readjustments to give added emphasis to breeders, would, we believe, provide industry with the needed stimulus to build a significant number of large reactors in the near future, would bring nuclear power to a competitive status throughout most of the country during the 1970's, and would make breeder reactors economically attractive by the 1980's.

Assuming this result, we estimate that by 2000 A.D., nuclear power would be assuming the total increase in electrical energy production, and, taking account of the Federal Power Commission's estimates, that about two-thirds of the energy then being produced would be from plants built at a time when nuclear power was more economical than conventional power in their locations. Clearly, not all of these will actually be nuclear. A given area will not always need a large plant when nuclear power first becomes competitive. Furthermore, there will be a natural reluctance to utilize a new technology, rather than a tried and true one, until the economic difference becomes appreciable. Allowing for these effects, we have crudely estimated that by the century's end nuclear installations might actually be generating approximately half the total electric energy in the country.† This fraction could be expected to increase over the following several decades so that by mid-century all the energy would be of nuclear origin except a small fraction generated in special purpose plants, including, perhaps, some built for peak load purposes.

The rate of growth described is illustrated in Figure 3. Curve A plots on a linear scale the rate of use of energy shown logarithmically by the corresponding curve of Figure 1. Curve

* The "power demonstration" program, as the term is used here includes research and development and operational activities, as well as construction costs, related to utility installations, whether Commission- or utility-owned.

† The nuclear plant capacity would, undoubtedly, be appreciably less than half, since the relationships between capital costs and fuel costs would encourage using nuclear power more for base loading and conventional power more for peak loading purposes.



CURVE A represents total energy on the same basis as Curve C in Fig. 1.
CURVE B represents energy consumption for other purposes than generating electricity.
CURVE C is obtained by deducting from Curve A the total nuclear energy consumed in generation of electricity.

B is obtained by subtracting estimates* of fuel energy to be consumed for electric power from the values represented by curve A. Curve C divides the consumption for electric energy into two parts: That above the curve is due to nuclear power and that below is due to fossil fuels. Thus, if no other use were made of nuclear energy, curve C would be a measure of the rate of use of fossil fuels.

For conservation of our fossil fuels, this rate of progress would appear to be sufficient, if by mid-century nuclear energy were also contributing appreciably to filling other needs, either directly or through the use of electric power for tasks not now performed by it.† Any appreciably slower rate of growth could result, however, in undue short-term consumption of our fossil fuels, especially if the more conservative views of their availability and ultimate recovery costs should turn out to be correct. Fortunately, provided the nuclear technology is developed in a timely manner, the economic pressures of a coming scarcity of fossil fuel would tend to accelerate its use.

Provided our assumptions regarding breeders are reasonably accurate, the estimated growth of nuclear power described above would raise no problem with respect to the supply of nuclear fuels. By the year 2000 approximately the amount of uranium listed in the 0–10 dollars per pound category of Table I would have been mined. Of the .4 Q of energy originally contained in the uranium-235, approximately half would still exist in reactor inventories and in stockpiles of depleted uranium. By that time the ratio of breeders and converters would be such that a major fraction of the energy produced would be coming from what was originally uranium-238 and thorium, so that somewhat higher ore prices would have no appreciable effect on the cost of power. On the other hand, should breeders be seriously delayed, for example by as much as a few decades, the high grade uranium ore might be exhausted while large amounts of uranium-235 were still required. Hence, it is important that the breeder technology be developed expeditiously.

The financial benefits of such a growth would soon begin to be appreciable. Using the same assumptions as above, the savings in generating costs are estimated to be approximately $2 billion to $2.5 billion per year by 1990, and between $4

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* This projection was made by utilizing the Federal Power Commission estimates of electric power needs to the year 2000. Thereafter the relative use of electric power was further increased (from 47% of the total consumption in 2000 A.D.) until it reached 50% and was held at that fraction thereafter.

† Under the assumptions used, consumption of energy for purposes other than nuclear power would, by mid-century, be about 10 Q and the annual rate would be about 0.35 Q per year. By 2100 total consumption would be between 25 and 30 Q.

billion and $5 billion* per year by 2000. By the latter date the cumulative savings would approximate $30 billion.† The savings would not be in direct proportion to the amount of nuclear energy actually used since if that amount were smaller a greater proportion of it would be in the areas where the greatest unit savings would accrue.

Thus highly worthwhile results could be anticipated from a continuation of the Commission effort with additional early support of the power demonstration program. Industry would be brought into full financial, as it has been in technical, partnership in the enterprise, thus reducing the future need for government participation. The development of the new technology would add additional health and vigor to our industry and would stimulate our whole economy. Our international leadership in the field would be maintained with benefit to our prestige and to our foreign trade. Substantial financial savings would accrue to consumers of electric energy; properly designed and installed nuclear power plants could add to our defense posture. An enormous new source of energy would be tapped in a timely manner.

An appreciably lesser effort would, in our opinion, result in substantially reduced benefits. The reduction in financial savings would be more than proportional to the reduced federal expenditures. If the program slowed too much, our international leadership in this field could be lessened or even lost. Too much delay could dissipate the potential benefits to national defense.

It would be particularly unfortunate to fail to take advantage of the present opportunity to stimulate a rapid industrial development that would permit industry to assume increasing responsibility for future development in this field. Should the program falter too long, the nuclear power equipment industry would suffer severe setbacks; many companies would no doubt withdraw and turn their talents elsewhere, leaving the field with

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* These calculations have conservatively assumed that the unit cost of nuclear power does not fall below that for conventional power in the low-cost areas during this century. Larger savings would, of course, result if it should do so. Allowance has been made for projected decreases in the capital and operating costs of conventional plants and for increased efficiency in the conversion of heat energy to electrical energy. In the latter connection it is assumed that by the year 2000 conventional plants will achieve 50% efficiency and nuclear plants 40% efficiency. No account has been taken of such possible new techniques as the use of magneto hydrodynamics which would be equally applicable to both nuclear and conventional plants. It is assumed that the plant-side costs of fossil fuel remain unchanged, i.e., that on the average, changes in recovery costs and in transportation costs cancel each other.

†At 5% interest these cumulative savings would have a discounted value in 1970 of approximately $10 billion.

too few companies. Technical skills and experience would be dissipated. If this should happen, it would take time to rebuild the capability and the program could be delayed far longer than would be implied by the slow-down in the Commission program proper.

Contrariwise, there would be, in our opinion, no virtue in a greatly enlarged governmental program at this time. Taken as a whole, support of the scientists and engineers engaged in developmental work is about adequate, though there should be program readjustments in the near future. In view of the country's research and development needs it would seem unwarranted to increase appreciably such manpower in this field. Only in the area of support of operating prototypes and full-scale operating units does there seem to be a need for significant increase, and that only for the near-term future. The increased technical manpower needed for the industrial growth would be largely design and production, rather than research and development personnel.

To summarize, we have concluded that the nuclear power program should continue on an expeditious basis with added emphasis on stimulating industrial participation; there should be some augmentation of support for the power demonstration program and program readjustments to give additional emphasis to the development of breeders.

Statement of Objectives

Taking account of the need for nuclear power, the responsibilities of the Atomic Energy Commission, the state of nuclear power technology, its future possibilities, and the existence and potentialities of the nuclear industry, we have arrived at the following statement of objectives:

The overall objective of the Commission's nuclear power program should be to foster and support the growing use of nuclear energy and, importantly, to guide the program in such directions as to make possible the exploitation of the vast energy resources latent in the fertile materials, uranium-238 and thorium.

More specific objectives may be summarized as follows:

1. The demonstration of economic nuclear power by assuring the construction of plants incorporating the presently most competitive reactor types;

2. The early establishment of a self-sufficient and growing nuclear power industry that will assume an increasing share of the development costs;

3. The development of improved converter and, later, breeder reactors to convert the fertile isotopes to fissionable ones, thus making available the full potential of the nuclear fuels.

4. The maintenance of U. S. technological leadership in the world by means of a vigorous domestic nuclear power program and appropriate cooperation with, and assistance to, our friends abroad.

The role of the Commission in achieving these objectives must be one of positive and vigorous leadership both to achieve the technical goals and to assure growing participation by the equipment and utility industry as nuclear power becomes economic in increasing areas of this country and the world at large.

The Future Program

We have concluded earlier that a logical progression to achieve the objectives of the nuclear power program will involve three overlapping phases: (1) The immediate utilization of reactor types that are, or can readily be made, economically competitive with conventional power installations; (2) a transitional stage, characterized by improving economics through higher temperatures, longer fuel life and other technical improvements and by the introduction of improved converter types with better economics and higher conversion ratios; (3) a long-range phase utilizing breeders that multiply by a large factor the energy extracted from the nuclear fuel, hence freeing the technology of any marked dependence on the cost of raw materials and opening up vast energy reserves; converters burning U-235 will continue to be essential until such a time as breeders produce enough new fissionable material to fuel the necessary additional reactors; in the interval, conversion ratios will become increasingly important as the costs of raw materials rise.

As seen in an earlier section, the technical programs now under way include reactor types appropriate to each of these three phases. Their complete development involves four progressive steps: (1) Conceptual studies of feasibility and methods of approach; (2) reactor experiments to study and to optimize the reactor system concept; (3) construction and useful operation of prototype power-producing systems, usually on a reduced scale; in general these are not economically competitive and hence must be built or strongly supported by the Government; (4) encouragement, and, if necessary, some financial support of full-scale installations built by utilities; information gained from their operation is, of course, fed back to assist future development and design.

The following sections will discuss our concept of the future reactor development program. This program must be backed, of course, by continuing and vigorous research and development of the basic technology, and subjected to periodic re-evaluation.

A Program for the Immediate Future

The principal objectives in encouraging immediate full-scale applications are to gain experience and knowledge from actual operations, to get a growing nuclear equipment industry really under way, and to convince utilities of the future economic benefits that they can gain from increasing use of nuclear power.

Saturated steam reactors have reached a stage where, provided they are built and used, industry can and should increasingly assume the major cost of their improvement; only such things as fuel and component development need be pursued by the government;* benefit will, of course, continue to be derived from advances in space and military programs, and from general technological developments.

The Intermediate Program: Improved Converters

Successful as they are, saturated steam reactors provide an adequate basis to achieve the general objective of bringing nuclear power utilization into being. Hence appreciable Government financial support should be given to other converter types only if they: Promise early marked improvement in unit costs for power; are markedly higher ratio converters; have direct, important technical bearing on breeder systems; or offer potential for other applications such as process heat. The Commission is reviewing the entire spectrum of non-breeder reactors in the light of these criteria to determine which should be continued or redirected and which should be discontinued or phased out. In some instances reliance can be placed on programs in other countries. For example, at least in the immediate future, we expect to depend primarily on the Canadian program for heavy water, natural uranium reactors in which we are cooperating at a modest level.

Several systems give promise of meeting the criteria. For example, the spectral shift, the high temperature gas-cooled, the sodium graphite and the nuclear superheat reactor systems all show excellent economic promise. The first two are excellent converters and may be made to breed in the thorium–uranium-233 cycle. Heavy water reactors are also excellent converters but are less promising economically. The sodium graphite reactor utilizes the liquid sodium technology necessary for fast breeders and its iodine absorbing quality is attractive from the safety standpoint. The organic cooled and moderated reactor can be economically competitive with saturated steam water reactors and may have application for process heat generation.

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*An exception is the so-called "seed and blanket" reactor in which zones of natural uranium are interspersed with zones of fully enriched uranium. Developmental studies and experiments relating to this concept are deemed worthwhile since, although leading to no marked advances in conversion ratio, this reactor type is less dependent on the somewhat uncertain costs of fuel reprocessing and since, in the event of large-scale disarmament, it could take advantage of the large supplies of highly enriched uranium produced for weapon purposes. Furthermore, information gained could be of value in other types with discontinuous zones, such as those using differing degrees of enrichment in different zones or, farther in the future, reactors using breeder blankets.

The Commission must continue to evaluate these systems carefully against the criteria described. Some should be carried to the stage of building operating prototypes during the next several years, but only when significant advantages seem reasonably assured. Hopefully a few will ultimately warrant full-scale construction by utilities. In addition to shedding light on the specific systems in question, operating reactors of these types will help accelerate the industry, will add additional operating experience and will help provide plutonium to get the breeder program going.

Program for the Long-Range Future

Although breeding in the thorium—uranium-233 cycle can build upon experience gained with less advanced reactors (indeed one or more of the latter might even breed, though barely), vigorous and specific efforts will be required to attain breeding on a significant scale. Both fuel and blanket systems must be pushed. Attention should be directed at methods of continuous removal of fission products, including the use of fluid fuels (such as fused uranium salts) and blanket materials. Experimental reactors designed to breed must be built and operated. Hopefully, within the next several years the program will achieve the stage where operating prototypes will be appropriate.

In contrast, the fast breeders needed for the uranium-plutonium cycle are quite different from the thermal reactors now in use. Increased effort must be placed on their development. Promising fuels such as the carbides must be pursued with vigor. The plutonium utilization program should be oriented with the fast breeder program well in mind. Economic methods of handling and fabricating this difficult and dangerous metal must be developed. Improvements in heat removal can be of very great importance in fast breeders. Additional experimental reactors must be built in the near future to serve the usual purposes, with emphasis upon control and safety problems. It can be hoped that in the later 1960's or early in the following decade, the stage of operating prototypes will be reached.

With luck and adequate effort, practical and economic full-scale breeder reactors might be achieved by the late 1970's or early 1980's. When they are, adequate steps must be taken to see that they are built and utilized.

A Possible Construction Program

A composite construction program for, say, the next 12 years (FY-1964 through FY-1975) might entail the following: (1) The construction and placing into operation of seven or eight power-producing prototype reactors approximately half of which would be advanced converters and the remainder breeders. Most of their cost would probably be borne by the AEC. (2) Assistance to industry in the construction of ten to twelve full-scale power plants, of improving design as time goes on; hopefully, industry will concurrently bear full costs for many more of well-proven design.

This program of construction would, of course, be backed by specific development programs directed at the more advanced reactor types, especially breeders, by research and development related to the underlying technology, and by general safety programs.

To encourage construction of full-scale power installations by utilities, the support of research and development and the temporary waiver of fuel charges have recently been augmented by the offer of reimbursement of design costs for fuel installations of 400 megawatts or more. Both public-* and investor-owned utilities are eligible. It is hoped that these forms of assistance will suffice to bring about a marked increase in the number of full-scale installations. If it does not, further efforts should be made to search for more attractive forms of incentives or other means to assure that such large-scale installations are actually constructed. Although a few examples should be enough to start the program going, it may well be necessary, in future years, to offer incentives to encourage industry to install newer and improved reactor types that have not yet had opportunity to prove themselves. An attractive incentive program may be needed to encourage timely use of breeder reactors when they reach the stage of full-scale application.

The demonstration prototypes involve a different situation. Here the principal objective is to prove out in actual practice a new and untried system which, in general, will not be economically competitive at the stage of development reached and the capacity involved. To achieve this best they should be under AEC technical direction. Depending on the cost, the degree of confidence, and the level of the competitiveness, a major fraction, or possibly all the cost of the reactor proper will generally be borne by the Commission. We believe that participation in such ventures should be open to publicly-owned utilities, as in the "Second Round," and to investor-owned utilities as in the case of Shippingport. In some instances of very advanced prototypes it may be best for the Commission to build and operate the installation on a government site, using the power for internal purposes.

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*It is recognized that there are very few non-federal, publicly-owned utilities that require installations of 400 megawatts or more. However, the City of Los Angeles Water and Power Board has expressed considerable interest in this offer.

Supporting Technical Programs

In an earlier section we have described various reactor systems that give reasonably early promise of producing economic nuclear power. This section will discuss briefly the supporting research and development that is essential to success and to the development of improved systems in the future. It also will describe the very important safety programs and their bearing on reactor siting, and the program of handling the fission products resulting from reactor operations.

General Technology

The general technology is being pushed with vigor. Unusual problems are involved. In the reactor proper, one must find fuel systems, moderators, and coolants that are mutually compatible for long periods at high temperatures and in intense radiation fields, while minimizing neutron losses by absorption and permitting efficient heat transfer. In fast reactors, coolants, structural materials, and fuel diluents must not moderate appreciably.

Great progress has been made toward achieving these objectives all along the line. Perhaps most striking is the development of many kinds of fuels and fuel assemblies, including: metals and metallic compounds encased in almost foil-like containers of stainless steel or more exotic metals; thin sandwiches containing alloyed fuel in the inner layer; thinly-coated pellets to maximize the heat transfer area; simple uncoated fuels such as uranium in oxide or carbide form dispersed in a graphite matrix; and fluid fuels containing fissile material as a solution or a suspension slurry or in a molten compound. Each has its application and its promise. Parallel problems relating to coolants, moderators, and structural materials are by no means minimal.

Difficult problems are also present in the external system, particularly where new coolants are involved. Pumps, heat exchangers, valves, and piping must be compatible with the coolant, and have high reliability. Where radioactivity is involved, especially in the circulating liquid fuels, many safety precautions must be taken.

Most of this development is done in the laboratory and in "test" reactors, where the effects of radiation are studied by long exposure of small material samples, full-scale fuel elements and, where appropriate, "loops" for fluid circulation.

In a corollary but important area lies the development of economical chemical reprocessing methods whereby useful fissionable and fertile materials are recaptured from used fuel assemblies and the fission products are removed for storage or disposal or, in some cases, for useful applications.

Not to be forgotten is the development of reliable instruments and control systems to monitor reactor performance and assure no misbehavior.

Reactor Safety: Siting Problems

Vigorous efforts must be made to maximize the inherent safety of reactor installations, both through careful design of the reactors proper and through methods to provide protection in the unlikely event of serious malfunction. A major program involves deliberately letting trial reactors "run away" in order to study their self-control mechanisms and the degree of damage if self-control is insufficient. The efficient design of containment vessels must be studied and exploited with a view to decreasing costs. Continuing study must also be made of the possible spread of fission products in case they do escape from the reactor and its containment vessel.

The effectiveness of the solution has important economic implications going beyond the installation costs themselves. Until experience is gained and adequate safeguards are proved out, prudence dictates that large reactor installations be fairly far removed from population centers. This adds both to transmission system costs and to expensive power losses in the lines. It also reduces the availability of sites, already low for large plants because of the need for ample supplies of cooling water.

Not only must developments be pursued with vigor and inherent safety rigorously assured, but also convincing demonstration must be made that the desired results have actually been achieved. Such demonstration will, in the final analysis, probably depend upon proof by actual operation. The accumulation of enough operating experience to permit statistical evaluations should help eliminate much of the subjective type of safety evaluation required today. With adequate technical improvements and the accumulation of satisfactory experience, it should be possible to gradually remove many of the siting restrictions in force today.

One of the attractive possibilities to provide safe containment is that of placing the installation underground. The technical problems of such installations are solvable and, at least in many locations, the costs would not differ greatly, if at all, from well-contained above-ground plants. In addition to providing adequate containment this technique offers the special advantage of affording considerable protection to the plant against damage in case of nuclear attack.

Waste Management

With a growing atomic industry, two problems in waste management will assume growing importance. These are the disposal or concentration of large volume, low-activity wastes, and the permanent storage of concentrated, high-level wastes.

When nuclear activities were small in scale, wastes involving very low specific activities could be discharged to the environment without unduly raising the radiation background level. Freedom to so dispose of them may be increasingly restricted in the future, primarily because of the rapidly increasing amounts and, secondarily, because acceptable environmental limits have been reduced. Hence, it will be necessary for the waste management research and development program to develop, on an expeditious basis, improved and more efficient methods for decontaminating large volumes of low-activity waste and concentrating the radioactive materials removed. In a related sphere, continued support must be given to environmental investigations to: (1) determine the ultimate fate of specific radionuclides in land, in water and in air environments; (2) establish reasonable technical criteria for safe disposal of very low level radioactive effluents into the environment. Such programs are, and must be, pushed with vigor.

Of equal importance is the program of developing methods for ultimate storage, or other safe disposal, of concentrated high-level wastes. The problem is technically soluble but costs are not accurately known. The present approach is to convert such wastes to inert, water insoluble solid forms, case them in corrosion resistant containers, and store them in specific, stable and dry, geological formations, such as salt domes or other safely-containing media. This method must, in the near future, be carried from the research stage to that of pilot plant demonstration and field experiment. Aside from the central reactor development program proper, no other phase of the entire program is more important than that of waste disposal.

The fission products resulting from reactor operations also have a beneficial side. Certain of them are useful on an appreciable scale as sources of nuclear radiation for scientific, medical, agricultural and industrial applications. Others can serve as sources of heat to generate small amounts of electric power in satellites or in remote, unattended terrestrial devices such as buoys and automatic weather stations that transmit their data by radio. Considerable research and development is being conducted on applications and on packaging methods, the latter being closely related to similar developments for waste disposal purposes.

Legal, Financial and Administrative Matters

The success of the program and particularly its acceptance by industry will be strongly affected by decisions relating to a number of legal, financial, and administrative matters relating to: (1) Nuclear materials; (2) encouragement of the service industries; and (3) licensing and regulation, including reactor siting criteria.

Policies Relating to Nuclear Materials

Ownership of Special Nuclear Materials. Careful attention has been given to the relative desirability of removing the present legal requirement for Government ownership of special nuclear materials. Originally this policy was adopted primarily as a protective measure against the possibility that such materials would be diverted for military purposes. Although this reason still has force, it is believed that at the present time controls and regulations can give adequate protection.

The present system has both advantages and disadvantages to industry. The Government monopoly subjects industry to rigid control and price-fixing by the Government of the materials most basic to the utilization of reactors. Furthermore, policies in these regards are not completely predictable in advance by industry, thus leading to uncertainties. On the other hand the utility industry enjoys certain advantages under the present system since: (1) Because of the Government's large enrichment plants the costs serving as the base for lease and "burn-up" charges for enriched uranium are less than could have been attained by industry alone for many years to come;* (2) the lease charge rate for the fuel inventory is less than carrying charges under private financing; and (3) it is not necessary for a utility to raise the large amount of capital required for the fuel inventory, at a time when it must raise funds for construction of a plant that is more costly than conventional ones.

A change permitting private ownership would be a step toward substituting the natural laws of supply and demand for Government control of prices and of availability. Indeed, for reactor products, plutonium and uranium-233, the step would be complete; prices for these products would seek their natural level and one source of distortion of the technology would be removed. A complication is, however, that for a considerable

*An offsetting factor is that the AEC is presently committed to purchase raw uranium at prices somewhat above the open market value.

time, at least, the Government would have an actual, though not a legal, monopoly on the means for producing enriched uranium-235 and thus would fix the price of this basic and most widely-used material. Hence, the situation would be one permitting private ownership but not constituting free enterprise in its broadest sense.

The Government would benefit from private ownership in that it could free itself from the obligation of owning rapidly increasing supplies of materials being used by other parties. A growing investment running ultimately to many billions of dollars could be avoided.

On balance we believe it is a step that should be taken and consequently we have recommended that legislation be enacted to permit private ownership of these materials. In order, however, to prevent any sudden dislocation, we recommend that such ownership not be made mandatory for a decade or so, in order that appropriate adjustments can be made by industry. Meanwhile, we will adjust our prices to be consistent with the true value of the materials.

Toll Enrichment. A further step to be considered is that of undertaking "toll enrichment." With this available, industry could buy its raw materials on the open market, use privately-owned plants to prepare them for enrichment, and depend upon the Government only for the actual enrichment process in the diffusion plants. Since there is ample capacity and since Commission policy has been to do such service work at cost, industry could be assured of adequate supplies at prices in which the only element in Government control would be relatively small and would be reasonably stable and predictable. Assuming that private ownership is indeed made possible, the step of providing toll enrichment service, an equivalent purchase and sale arrangement, or some other alternative should certainly be taken. Such a step would, of course, affect future AEC uranium procurement policies. Any toll enrichment service should be extended to our friends abroad, subject to proper safeguards against diversion for military use.

Plutonium Prices. A related problem is that of the values set upon special nuclear materials for leasing purposes, the prices paid by the Commission for such materials produced in private reactors and, if and when private ownership is permitted, the prices to be charged in the sale of such materials. At the present time, the value assigned to enriched uranium for leasing purposes is approximately the cost to the Commission, taking appropriate account of overhead, plant depreciation, etc.

We expect to continue this policy in the future. Values for U-235, which have been reduced twice in the past 18 months, now run from approximately $5 per gram for very low enrichments to $12 per gram for very high enrichments.

The guaranteed plutonium prices (or, more properly, allowances, in view of mandatory government ownership), which by law are set at "fair value for the intended use", have gone through several changes. For several years they followed a sliding scale depending on isotopic constitution. More recently the value has been fixed at $30/gram regardless of isotopic content. This price is guaranteed until June 30, 1963.

The Commission has recently concluded that, following that date the guaranteed base price should be in accordance with the "near-term value" for plutonium as reactor fuel. This is calculated to be approximately $9.50/gram, for average reactor product in metallic form, using the cost of U-235 as a base, and assuming that the plutonium would be used in thermal reactors. We believe that consideration should be given to scaling the prices in accordance with the isotopic content,* and that the same policy should apply to purchases abroad of plutonium made from uranium enriched in the United States.

A similar basis would be used for setting the value of U-233; a sliding scale might well be used because of the extra handling and processing costs when radioactive U-232 is present.

If and when private ownership is permitted, the Commission would continue for a time to set a guaranteed price, but, of course, the utility producing the material would be under no compulsion to sell it to the Commission, so that the offered price would constitute a market floor. Presumably that price would be adjusted from time to time in accordance with the market value.

Uranium Procurement. Through a very successful series of bonuses and guarantees of long-term contracts, the uranium mining and milling industry was built from almost nothing in 1950 to a point where the country is now self-sufficient in this field and need not depend on foreign sources. This industry has, to date, relied almost entirely on the military program. Since new weapons can utilize the nuclear materials from retired, obsolescent ones, it is almost inevitable that the requirements for new uranium for weapon purposes will decrease within the next decade, even without the hoped-for success of disarmament negotiations. On the other hand our projections for nuclear power predict a significant and rapidly increasing need for such material beginning in the 1970's. By, perhaps, the early 1980's the requirements will equal or surpass present rates of use. There will, however, be an interval of decreased

*The Pu-240 is not fissionable, though it is fertile. Hence it is a diluent reducing the fuel value of the material.

requirement for perhaps a decade centered around the early 1970's.

Present contracts with uranium miners and processors, which carry to the end of 1966, will presumably result in a modest surplus of material by that time. If the same level of procurement were carried forward into the period of diminished requirements, the surplus could grow considerably. The Commission is, therefore, faced with the problem of how best to sustain the uranium industry during the slack period without accumulating too great a surplus. That it be sustained is vital to the future interests of the country; a strong industry will be required for the later period of accelerated commercial need. Furthermore, without the prospects of a sustained market following 1966, there might be a tendency among the miners to "high grade" during the next few years and sooner or later to abandon the lower grade mines with consequent permanent loss of substantial quantities of these vital resources.

Consequently, the Commission has decided to offer a "stretch-out" program to the industry. A commitment to purchase additional material after January 1, 1967 will be offered as an incentive to induce a company to delay until after that date delivery of part of the uranium presently under contract. If successful, this program will result in a leveling-off process which should carry through the period of slack use without injuring the industry substantially or resulting in an unreasonably large surplus.

Service Industries

In addition to a major equipment industry, a large-scale nuclear power program will require the building up of industry engaged in such activities as the fabrication of fuels, the manufacture of nuclear instruments and control equipment, and the chemical processing of used reactor fuels to recover the nuclear materials from the fission products and other wastes. Many of these are already underway since they could start on a small scale, and since they have been given considerable business by the AEC. They should be encouraged in every reasonable way. The AEC should give them as much of its own business as reasonable economy will permit, and, on no account, should it compete with them for private business, except as an accommodation to industry in cases where no private capability exists.

A special case is that of the chemical separation of used fuels, which is attractive to industry only on a fairly substantial scale, and for which there will be little private business until civilian reactors have operated for an appreciable period. The Commission, which has large plant capacity related to its weapon program, has been doing all such work. Strong encouragement is being given to private industry to embark into this field, with promise of success. As part of the encouragement the AEC has informally indicated willingness to provide sufficient business to require 100 operating days per year in a fair-sized private plant. We believe that as soon as sufficient private plant capacity exists, the Commission should withdraw from all such work deriving from industry and should utilize the private plants to fill its own requirements except, perhaps, for those related to materials for weapons.

Licensing and Regulation

Steps are being undertaken to simplify and streamline the licensing and regulatory procedures. A major step is the recent enactment of legislation that will reduce greatly the number of mandatory public hearings. The Commission is studying means to simplify its own licensing procedures by reducing the volume and complexity of administrative processes.

The Commission is also studying ways to modify current regulations so that better guidance can be given to utilities on the suitability of specific reactor sites prior to their making substantial monetary outlays.

In the future, efforts will be made to reduce the number of technical reviews required and to concentrate the reviews on those features which have a potential effect on the health and safety of the general public. This will be easier to accomplish as reactors become more standardized. Increased emphasis on the responsibility of the designer will permit him to exercise more scientific and engineering judgment. As standardization of reactors proceeds, published guides can provide assistance to manufacturers as to format and coverage required in site reports, hazard reports and technical specifications so that the quality of these reports can be improved and the cost can be reduced.

When sufficient data are available to permit statistical treatment of the probability and potential results of possible equipment failures, we will be better able to evaluate the economic impact of special safety features and hence address ourselves to steps to minimize their costs.

Possible Industrial Impacts of the Nuclear Power Program

An important consideration in a transition such as that herein proposed is its possible impact on various segments of industry. We have already mentioned the fear that the existing nuclear equipment industry might suffer severely if construction of full-scale nuclear power plants does not accelerate at least somewhat. The strengthening of this industry through such an acceleration would not only improve the prospects for nuclear power but it would add strength to our general technological and industrial base and in particular would give added flexibility and capability for the construction of reactors needed for other purposes such as defense and the space program.

It is clear that no matter how great the acceleration in the nuclear power equipment field, there need be no fear of dislocation in the conventional power equipment industry in the light of the rate of growth in total power requirements. Furthermore, a substantial fraction of the companies in the nuclear power field are also engaged in the manufacture of conventional power equipment.

The Coal and Transportation Industries

Concern has been expressed lest conversion to nuclear power might cause severe dislocations in the coal industry and hence on transportation, especially the railroads. This is definitely not the case.

We have seen from earlier discussions, and from the curves of Figure 3, that even absorption of the total power industry by nuclear installations would still leave no dearth of markets for fossil fuels. Only a miraculous switch to nuclear energy by other industries as well could slow a rapid growth in those markets. Furthermore, the electric industry itself is growing at such a rapid rate that no possible growth of nuclear installations could prevent power generation from consuming greatly increasing amounts of fossil fuels for several decades—not, indeed, until the absolute rate of growth of nuclear power equals that of total power. By that time the consumption of fossil fuel for electric power alone will be several times what it is today. Curve A of Figure 4 illustrates that consumption, assuming Federal Power Commission predictions on rates of use of electrical energy (to 2000 A.D.) and our estimate of the rate of growth of nuclear power, as illustrated in Figure 3.

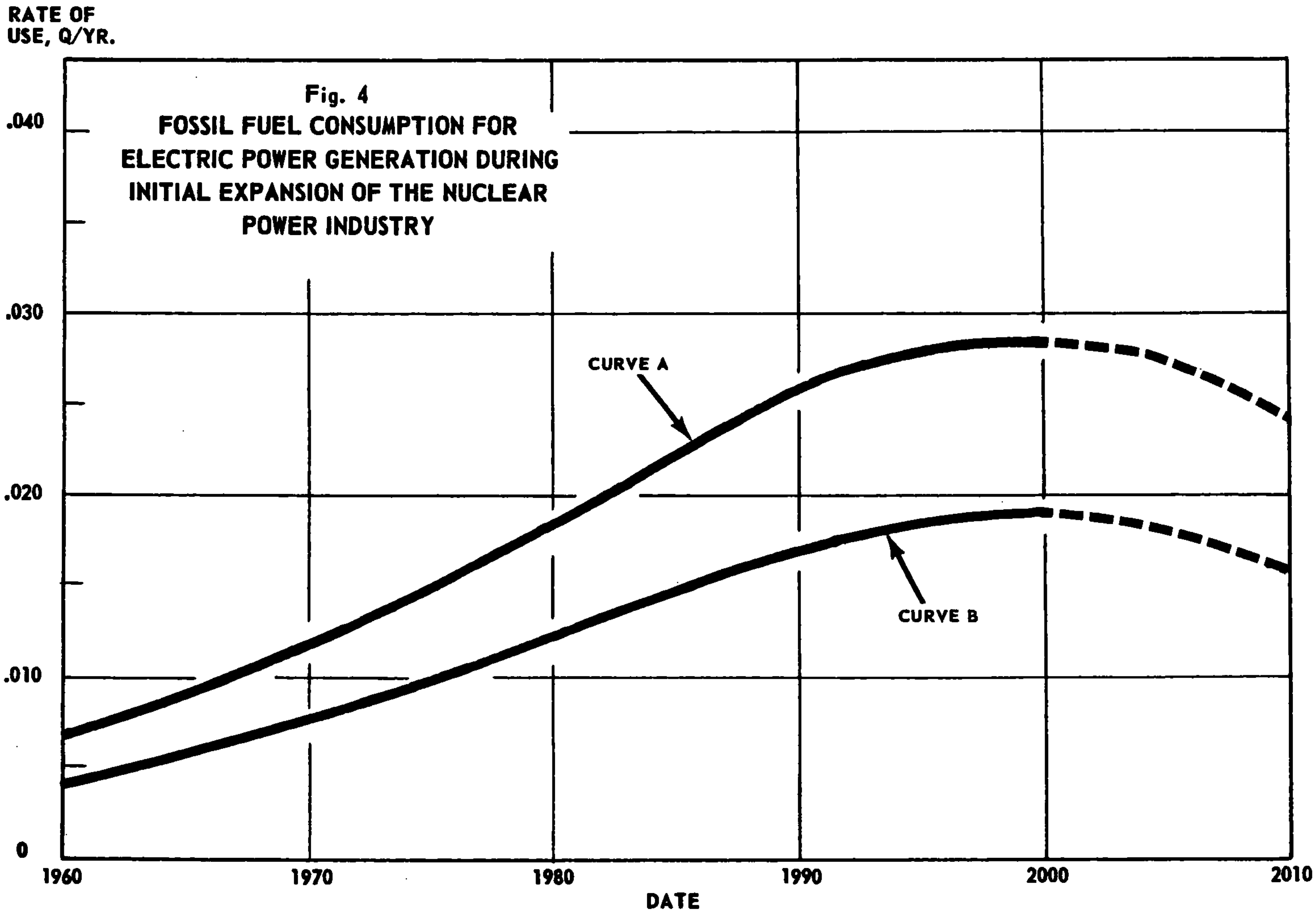

Fig. 4
FOSSIL FUEL CONSUMPTION FOR ELECTRIC POWER GENERATION DURING INITIAL EXPANSION OF THE NUCLEAR POWER INDUSTRY

CURVE A shows the consumption of fossil fuels in producing electric power. It is obtained from total energy requirements for electric power generation by deducting our estimates of nuclear electric generation, and the hydroelectric generation predicted by the Federal Power Commission.

CURVE B shows the consumption of fuel by coal-fired steam-electric plants on the basis that coal maintains its present fraction of the fossil fuel for power generation.

The concern of the coal industry has been brought about primarily by two factors. During the first decades of this century, marked increases in efficiency, especially in power generation, reduced the consumption required to carry out a given task. Although there is still room for improvement, this effect can never be so great again.

More recently the major factor in the decline of coal consumption has been a loss of markets to other forms of fossil fuels. During the past 15 years, annual consumption of coal decreased from 550 million tons to 375 million tons, in spite of an increase from 86 million to 180 million tons used for electric power generation.* The decrease was brought about by an essentially total loss of the railroad market and other heavy losses in manufacturing and home heating. The result is that, whereas in 1947 the electric utilities consumed only about 16 percent of all the coal, in 1961 they accounted for almost half. Even though the other losses should continue (many have shrunk so far there is not much more to lose), the growth in power installations will inevitably more than offset the loss.

In 1960 fuel burning electric plants in the United States derived 66 percent of their energy from coal, 26 percent from gas, and 8 percent from oil. These figures have remained constant within 2 or 3 percent for a decade or more, with coal changing very little and gas increasing slightly at the expense of oil. In view of the large reserves of coal compared to oil and gas and the preferred use of the last two for other purposes it seems certain that within a relatively short time the fraction of electric power based on coal will increase appreciably. This trend will be increased by the major, and successful, efforts of the coal industry to reduce transportation costs and by the possibilities inherent in the trend to very large centralized power plants which can in many instances be placed close to coal supplies. The probability of this trend is borne out by the fact that, whereas average coal prices to utilities have decreased some 20 percent (in constant value dollars) over the last 8 years, those for gas, its principal competitor, have increased by 40 percent.

Curve B of Figure 4 illustrates the rate of consumption of coal for electric power, using the figures of curve A for consumption of all fossil fuels for power and, conservatively, assuming the present distribution ratio between the various fossil fuels. It is readily apparent that, even though coal did not increase its share, a very large increase in coal consumption would nevertheless occur. Indeed, by 1970, consumption for this purpose alone would exceed all coal consumption at the

*Statistics in this section were supplied by the Department of the Interior.

present time. The increase would continue for 40 years or more and even under our assumptions would not recede to present values until the middle of the next century, if then. Well before that time the dwindling supplies of oil and gas will force increased coal consumption in other industries; coal and coal products will begin to recapture the markets they have lost. Indeed, as seen before, our concern is not that coal demands will be too small but rather that they will be so large that our supplies will be too rapidly exhausted.

Appendix

Sources of Information

Recent published reports used during the course of this review included:

"Report of the National Fuels and Energy Study Group on an Assessment of Available Information on Energy in the United States," a September 21, 1962 study prepared for the Committee on Interior and Insular Affairs of the United States Senate.

U. S. Geological Survey Bulletin 1136, 1961, "Coal Reserves of the United States—A Progress Report, January 1, 1960," by Paul Averitt.

"Appraisals of Future Nuclear versus Conventional Electric Power Costs by Leading Industry and Government Organizations Released by the Joint Committee on Atomic Energy," press release No. 368 from the Office of the Joint Committee on Atomic Energy. The release is dated July 30, 1962.

"Development, Growth, and State of the Atomic Energy Industry," Hearings before the Joint Congressional Committee on Atomic Energy on March 20, 21, 22, and 23, 1962.

"Report of the Advisory Committee on U. S. Policy Toward the International Atomic Energy Agency," a May 19, 1962 report of an Advisory Committee Appointed by the Department of State.

"Report of the Ad Hoc Committee on Atomic Policy," a March 1962 report of the Atomic Industrial Forum.

"Report to the Panel on Civilian Technology on Coal Slurry Pipe Lines," a May 1962 report of Department of the Interior.

"Steam-Electric Plant Construction Cost and Annual Production Expenses, Thirteenth Annual Supplement, 1960, FPC-S-149" Federal Power Commission.

"Steam-Electric Plant Factors, 1961," Twelfth edition, July 1962, National Coal Association.

Other reports and communications used during the course of this review included:

"Supplies, Costs, and Uses of the Fossil Fuels," a June 29, 1962 report prepared for the Atomic Energy Commission by the Department of the Interior Energy Policy Staff. (Some information in this report was updated subsequently and informally by the Department of the Interior.)

A letter report of June 8, 1962 to the Atomic Energy Commission from Joseph C. Swindler, Chairman, Federal Power Commission.

"Summary Report on Natural Resources," an August 1962 draft of a report being prepared by the Committee on Natural Resources of the National Academy of Sciences.

"Energy Resources," a draft report prepared by a panel of the National Academy of Sciences Committee on Natural Resources.

"A Comparison of the Nuclear Defense Capabilities of Nuclear and Coal-fired Power Plants," BNL-6080, a May 1962 report prepared by members of the staffs of Brookhaven and Oak Ridge National Laboratories, assisted by the architect-engineer firms: Burns and Roe, and Sargent and Lundy.

A draft of "Economics of Permanent Disposal of Power Reactor Wastes in Tanks" by Stockdale, Arnold, and Blomeke. This report is expected to become available as ORNL-2873 in a few months.

Seminars on Civilian Nuclear Power were held at AEC Headquarters in order to provide the Commission and the Commission staff with as much current information as possible. Representatives of AEC contractor organizations and others made presentations of their own on prospects for civilian nuclear power. Presentations were evaluated by consultants and advisors to the Commission: members of the Subcommittee on Reactors of the General Advisory Committee were present at all seminars, and staff scientists and engineers from various National Laboratories were present as appropriate. The subjects and dates of these seminars were:

Boiling and Pressurized Water Reactors	April 19–20, 1962
Heavy Water and Organic-cooled Reactors	April 26, 1962
Gas-cooled Reactors	May 4, 1962
Liquid Metal Cooled Reactors	May 9, 1962
Plutonium Recycle and Thorium Utilization	May 10, 1962
Advanced Reactor Concepts	May 14, 1962

Many of the reports and presentations were identified as containing proprietary information. A number of the reports were incomplete in themselves, and intended to accompany the oral presentation. Since they were intended for the use of the AEC rather than for publication, they are not identified individually in this Appendix. However, they were helpful and they are acknowledged.

In addition to the discussions acknowledged in the Introduction, Members and Staff of the Atomic Energy Commission had helpful discussions with organizations such as the Atomic Industrial Forum, and with many individuals during the course of this review.

ENERGY RESOURCES

A Report to the
Committee on Natural Resources
of the
National Academy of Sciences—National Research Council

by
M. King Hubbert
Chairman of the Energy Resources Study

Publication 1000-D
National Academy of Sciences—National Research Council
Washington, D. C.
1962

ENERGY RESOURCES

A Report to the
Committee on Natural Resources

National Academy of Sciences

National Research Council

This is one of seven special reports supporting a research study of natural resources conducted by the National Academy of Sciences—National Research Council at the request of the President of the United States. Each of these seven supporting documents was prepared under the supervision of a member of the Academy-Research Council Committee on Natural Resources, who called upon the expert advice of a number of consultants to assist in identifying the research needs and opportunities relating to the particular resource area or problem under consideration.

The seven reports of supporting studies are as follows:

A. Renewable Resources
B. Water Resources
C. Mineral Resources
D. Energy Resources
E. Marine Resources
F. Environmental Resources
G. Social and Economic Aspects of Natural Resources

The general conclusions and recommendations of the Committee as a whole are presented in a summary report which has been forwarded to President Kennedy, together with the supporting studies.

The grateful thanks of the Committee on Natural Resources and of the Federal Government, for which these special reports were prepared, are due those whose experience and ideas are reflected in this report.

Committee on Natural Resources

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December, 1962

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CHAPTER I

INTRODUCTION

If we are to appreciate the significance of energy resources in the evolution of our contemporary society it will be necessary not only for us to understand the principal physical aspects of the conversion of energy in the complex of activities transpiring on the earth, but also to view these activities in a somewhat longer historical perspective than is customary. For those of us who live in the more industrialized areas of the world—particularly in the United States—it is difficult to appreciate the unique character of the industrial and social evolution in which we are participating. During our own lifetimes, and during the immediately preceding period of history with which we are most familiar, the pattern of activity we have observed most consistently has been one of continuous change, usually continuous growth or increase. We have seen a population begun by a small number of European immigrants to North America expand within a few centuries to over 200 million, while still maintaining such a growth-rate, even now, as to double within the next 40 years. We have seen villages grow into large cities. We have seen primeval forests and prairies transformed into widespread agricultural developments. We have seen a transition from a handicraft and agrarian culture to one of complex industrialization. Within a few generations we have witnessed the transition from human and animal power to continent-wide electrical power supernetworks; from the horse and buggy to the airplane.

Out of this experience it is not surprising that we have come to regard continual growth and increase as being the normal order of things.

However, if we are to appraise more accurately what our present position is in our social and industrial evolution, and what limitations may be placed upon our future, it is necessary that we consider, not only for the present but in historical perspective, certain fundamental relationships which underlie all our activities. Of these the most general are the properties of matter and those of energy.

From such a viewpoint the earth may be regarded as a material system whose gain or loss of matter over the period of our interest is negligible. Into and out of this system, however, there occurs a continuous flux of energy in consequence of which the material constituents of the outer part of the earth undergo continuous or intermittent circulation. The material constituents of the earth comprise the familiar chemical elements. These, with the exception of a small number of radioactive elements, may be regarded as being nontransmutable and constant in amount in processes occurring naturally on the earth.

For the present discussion our attention will be directed primarily to the flux and degradation of a supply of energy, and secondarily to the corresponding circulation of the earth's material components.

Flux of Energy on the Earth

The overall flux of energy on the earth is shown qualitatively and diagrammatically in the flow-sheet of Figure 1.

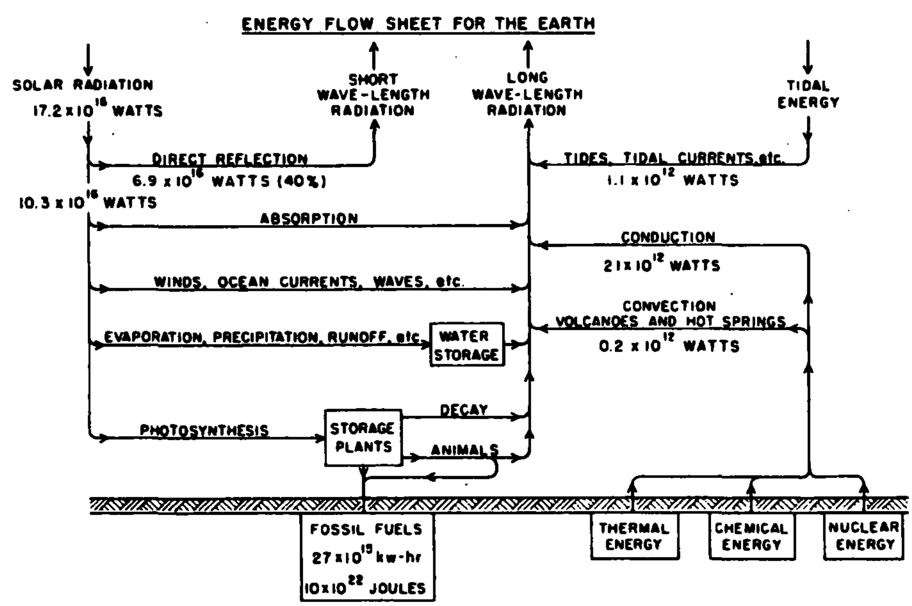

Figure 1. Energy Flow Sheet for the Earth

The energy inputs into the earth's surface environment are principally from three sources: (1) the energy derived from the sun by means of solar radiation, (2) the energy derived from the mechanical kinetic and potential energy of the earth-sun-moon system which is manifested principally in the oceanic tides and tidal currents, and (3) the energy derived from the interior of the earth itself in the form of outward heat conduction, and heat convected to the surface by volcanos and hot springs. Secondary sources of energy of much smaller magnitude than those cited are the energy received by radiation from the stars, the planets, and the moon, and the energy released from the interior of the earth in the process of erecting and eroding mountain ranges.

No definite quantity can be assigned to the energy from any of the foregoing sources because we are confronted not with a fixed quantity of energy but a continuous flux of energy from the various sources, at nearly constant rates. The rate of energy flux is measurable in terms of power, defined by

$$\text{power} = \frac{\text{energy}}{\text{time}},$$

and if the energy is measured in terms of the work unit, the joule, and the time in seconds, the power is then in joules per second, or watts.

Energy from Solar Radiation

The rate of energy flux from the sun, or the solar power, intercepted by the earth is readily obtainable from the solar constant, and the area of the earth's diametral plane. The solar constant is the quantity of energy which crosses unit area normal to the sun's rays in unit time in free space outside the earth's atmosphere, at a distance from the sun equal to the mean distance to the earth. It is, accordingly, the power transmitted by the sun's rays per unit cross-sectional area at the mean distance of the earth.

In heat units, the value of the solar constant, I, has been found to be 1.94 calories per minute per square centimeter (Landsberg, 1945, p. 929). This can be converted explicitly to power units by noting that 1 calorie of heat is equal to 4.19 joules of work, and 1 minute is 60 seconds. The solar constant in $watts/cm^2$ is, accordingly, given by

$$I = \frac{1.94 \times 4.19 \text{ joules/cm}^2}{60 \text{ seconds}}$$

$$= 0.135 \text{ watts/cm}^2.$$

The total solar power intercepted by the earth is then

$$P = IA = I\pi r^2,$$

where A is the diametral area of the earth and r, equal to 6.37 x 10^8 cm, is the mean radius of the earth. Supplying the numerical values of I and r, we then obtain for the total solar power incident upon the earth

$$P = 17.2 \times 10^{16} \text{ watts.}$$

For comparison, the installed generating capacity of all the electric utilities in the United States in 1959 amounted to 15.7 x 10^{10} watts (Dept. of Commerce, 1961, p. 525). Hence, the power of the solar radiation intercepted by the earth is about a million times the power capacity of all the electric utilities in the United States in 1959.

Energy From the Earth's Interior

The second largest input of energy into the earth's surface environment is that which escapes from the interior of the earth, which is estimated to be at a rate of about 21 x 10^{12} watts. Of this, about 99 per cent is by thermal conduction, and only about 1 per cent by convection in volcanos and hot springs.

Tidal Energy

The tidal energy is derived from the combined potential and kinetic energy of the earth-moon-sun system. The total rate of dissipation of this energy, as indicated by the rates of change of the earth's period of rotation and the moon's period of revolution, is estimated by Harold Jeffreys (1952, p. 227, 231) to be about 1.4 x 10^{19} ergs/sec, or 1.4 x 10^{12} watts. Of this, about 1.1 x 10^{12} watts, or about 80 per cent, is estimated to be accounted for by oceanic tidal friction in bays and estuaries around the world.

Thus, tidal power is about an order of magnitude smaller than that of the heat escaping from the earth's interior, and both together are less than one-thousandth of the power impinging upon the earth from solar radiation.

Energy Flow-Sheet

In view of its predominance, our principal concern is in tracing the flow of the 17.2 x 10^{16} watts of solar power that is being shed continuously on the earth. About 40 per cent of this, or 6.9 x 10^{16} watts (Landsberg, 1945, p. 933), known as the albedo, is directly reflected back into space. This leaves about 10.3 x 10^{16} watts which are effective in propelling the various material circulations occurring on the earth.

No further quantitative breakdown will be attempted. However, a part of the remaining solar power is absorbed directly by the atmosphere, the oceans, and the lithosphere, and is converted into heat. A large part of this heat is immediately reradiated back into space as long-wavelength thermal radiation. Another part, however, sets up differences of temperature in the atmosphere and the oceans, in such a manner that convective currents of both water and air are generated, producing the winds, ocean currents, and waves. The oceans and the atmosphere serve in this manner as the working fluids of a world-girdling heat engine whereby a fraction of the thermal energy from sunshine is converted into mechanical energy. The mechanical energy of the wind, waves, and currents is again dissipated by friction into heat at the lowest temperature of the surroundings.

Still another part of the solar energy follows the evaporation, precipitation, and surface run-off channel of the hydrologic cycle. Heat energy is absorbed during the evaporation of water, but it is again released when the water is precipitated. However, the water vapor, being a part of the atmosphere, is convected to high elevations by means of the convective energy already discussed; and, when precipitation occurs at these elevations, the water possesses potential energy, which again is dissipated back to low-temperature heat on the descent to sea level. It is this energy, however, that is responsible for all precipitation on the land, and for the potential and kinetic energy of surface lakes and streams.

A final fraction of incident solar radiation is that which is captured by the leaves of plants by the process of photosynthesis. Although enormously complex in detail, this is the driving mechanism for the synthesis of common inorganic chemicals, such as H_2O, and CO_2, into the chemical compounds of living plants. Schematically this process is represented by the reaction

$$\text{Energy} + CO_2 + H_2O \rightarrow \text{Carbohydrates} + O_2,$$

during which solar energy becomes captured and stored as chemical energy. By the reverse reaction, as in the burning of wood,

$$O_2 + \text{Carbohydrates} \rightarrow CO_2 + H_2O + \text{Heat},$$

and the stored energy is released as thermal energy.

The energy-flow channel whose first step is photosynthesis is that which sustains the entire complex of organisms on the earth. We have the familiar food chain:

$$\text{Plants} \rightarrow \text{Herbivores} \rightarrow \text{Carnivores} \rightarrow \text{Parasites} \rightarrow \ldots.$$

in which the energy of each link is a small fraction of that of the preceding, the remainder being dissipated by heat. The end-product of this chain is the complete degradation of the photosynthetic energy to heat at the ambient temperature, and the conversion of the material constituents back to their initial inorganic state.

The Fossil Fuels

If the energy stored in plants by photosynthesis could be systematically retained, as for example in the form of firewood, it is clear that the aggregate amount would increase without limit, and could, in a few decades or centuries, become very large indeed. Actually, in the natural state, the rate of decay of organic compounds and the release of their stored energy as low-temperature heat is very nearly equal to the contemporary rate of photosynthesis. However, in a few favored places such as swamps and peat bogs, vegetable material becomes submerged in a reducing environment so that the rate of decay is greatly retarded and a storage of a small fraction of the photosynthesized energy becomes possible.

This, in principle, is what has been happening during the last 500 million years of geologic history. During that time a minute fraction of the existing organisms have become buried in sedimentary muds under conditions preventing their complete decay. These accumulated organic remains comprise our present stores of the fossil fuels: coal, petroleum and natural gas, and related products, the energy content of these fuels being derived from the solar energy of this 500 million-year period which was stored chemically by contemporary photosynthesis.

Summary

The energy flow-diagram, which we have just reviewed, represents, in broad outline, all the major channels of energy flux into and out of the earth's surface environment. By the First Law of Thermodynamics, the quantity of energy in any particular channel, although repeatedly transformed in transit, remains constant in amount. It follows, therefore, that, with the exception of an insignificant amount of energy storage, the energy which leaves the earth by long-wavelength thermal radiation into space must be equal to the combined energy inputs from solar and stellar radiation, from tidal forces, and from the earth's interior.

By the Second Law of Thermodynamics, however, this flux of energy is unidirectional and irreversible. It arrives as short-wavelength electromagnetic radiation, corresponding to the temperature of the sun; or as mechanical energy of the tides; or as thermal energy from a temperature higher than that of the earth's surface environment. By a series of irreversible degradations it ultimately is reduced to thermal energy at the lowest temperature of its environment, after which it is radiated from the earth in the form of spent, long-wavelength, low-temperature radiation.

During this energy flux and degradation the material constituents of the earth's surface, while remaining essentially constant in amount, are circulated. The wind blows; oceanic currents, tides, and waves are formed; rain falls and rivers flow; volcanos erupt and geysers spew; and plants grow and animals eat, move about, procreate, and die.

But for this energy flux none of these things would or could happen and the matter of the earth's surface would be as dead or inactive as that of the moon.

Biologically, the human species is simply a member of the energy-consuming chain which begins with the energy capture and storage of plants by photosynthesis. Man is both an herbivore and a carnivore, and, as such, is merely another member of the biological complex, depending for his essential energy supply—his food—upon other members of the complex, and ultimately on the energy from the sun captured and stored in plants by photosynthesis.

In addition, however, man has been able to do what no other animal has ever achieved; he has learned to tap other channels of the energy flow-sheet, and he has managed to divert the energy flow from its customary path into other channels appropriate to his own uses.

An understanding of these processes is essential if we are to appreciate the significance of energy resources in determining what is possible and what is impossible in human affairs.

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CHAPTER II

EVOLUTION OF MAN'S ABILITY TO CONTROL ENERGY

Since energy is an essential ingredient in all terrestrial activity, organic and inorganic, it follows that the history of the evolution of human culture must also be a history of man's increasing ability to control and manipulate energy.

Consider the earliest stages of this evolution. From geological and archeological evidence, organic evolution had proceeded far enough that by about a million years ago one of the ape-like species had reached the stage where his few skeletal remains are now classed as those of early man. How many of this species there may have been at that time can only be conjectured, but from the scarcity of the remains it may be surmised that the numbers were not large—possibly comparable to those of gorillas or chimpanzees at the present time.

This species must have coexisted in some sort of ecological adjustment with the other members of the biologic complex of which it was a member, and upon which it depended for a share of the solar energy essential to its existence. At this hypothetical stage its sole capacity for the utilization of energy was limited to the food it was able to eat—the order of 2,000 kilocalories per capita per day.

Between that stage and the dawn of recorded history, this species distinguished itself from all others in its inventiveness of means for the capture of a larger and larger fraction of the available flux of energy. The invention of clothing, the use of tools and weapons, the control of fire, the domestication of animals and plants, and other similar developments all had this in common: Each increased the fraction of the contemporary flux of solar energy which was available for the use of the human species, and each upset the ecological balance in such a manner as to favor the increase in the human population, with corresponding adjustments in all other populations of the biologic complex.

Although little is known about the time when many of these developments first occurred, tool making and the use of fire date back at least as far as Peking man (estimated at about 500,000 years ago), but from the length of time involved the rate of change must have been extremely slow (Harrison, 1954). The pace quickened, however, at about 10,000 to 12,000 years ago when, with the domestication of animals and the cultivation of plants, man began to change from a food-gathering to a food-producing species (Childe, 1954).

After a few thousand years of cultural incubation, there followed almost simultaneously in each of three localities, the Tigris-Euphrates delta and the Indus and the Nile valleys, at about 3500 B. C., the rise of cities with populations estimated at 8,000-10,000 supported by an intensive agriculture.

At least as early as about 1900 B. C. the use of oxen for ploughing is depicted in paintings in Egyptian tombs (Harrison, 1954, Fig. 43). Similarly, pictures of sailing ships of advanced design occur in Egypt as early as 1500 B. C. (Childe, 1954, Fig. 32).

This quickening of pace continued for the next few thousand years, but the energy supply available was dominantly that which was tapped from the biological channel of solar energy. It permitted a very large increase in the population density in favorable agricultural areas, and a corresponding increase of the total human population as the new culture spread geographically, but throughout this period the energy available per capita was still not much more—possibly only two or three times greater—than that of the food consumed.

Energy from a nonbiological source was first obtained when the energy of the winds and the hydrologic cycle was tapped for human uses. This apparently occurred first with the use of sails for the propulsion of boats and ships. Then followed water mills and windmills.

According to Forbes (1956a), both the water mill and the windmill are thought to have originated in the Middle East, the water mill during the last century or so B. C., but the windmill not until about 900-1000 A. D. The first water mills were small affairs, with a horizontal wheel and vertical shaft requiring a continuous stream of water and capable of turning small family-size grain mills. This type of mill was improved by the Roman, Vitruvius, during the first century B. C. by making the wheel vertical and gearing the horizontal shaft to a vertical shaft turning the millstone.

However, water mills were not extensively used by the Romans before near the end of the Roman Empire. From this time forward, even during the Dark Ages, the use of the water mill spread throughout Western Europe, until by the sixteenth century it had been adapted to every kind of industrial use requiring stationary power. This use has continued subsequently in both Europe and North America.

However, it has only been since about the beginning of the twentieth century that advancing technology, particularly the transmission of power by electricity, has made it practical to build water mills larger than the tens-to-hundreds of kilowatts range of power capacity. This new technology made the small mills obsolete at the same time that it rendered practical the building of water-power plants in the hundreds-of-megawatts range.

Windmills appear to have been first developed in the Persian province of Seistan about the tenth century A. D. Windmills began to be built in the Low Countries and elsewhere in Western Europe about the thirteenth century, but whether as an independent invention, or introduced by the Muslims by way of Morocco and Spain, is uncertain. In any case, since the thirteenth century, windmills have been used in Western Europe and later in North America and the West Indies for such uses as grinding grain, pumping water, and operating mills for crushing sugar cane.

Escape from this dependence upon contemporary solar energy with its inherent limitations in the quantity utilizable per person was not possible until a new and hitherto unknown source of energy should become available. Such a source was represented by the fossil fuels. Although Marco Polo reported that the Chinese used "black rocks" for fuel (Nef, 1957), and recent studies indicate that the Chinese may have used coal in small amounts for two or three millenia previously, the use of coal as a major source of energy did not begin until about the twelfth century, when the inhabitants of the northeast coast of England discovered that certain black rocks found along the seashore, and thereafter known as "sea coles," would burn.

Since this initial discovery coal has been mined continuously, first in England and shortly thereafter in present Belgium, France and Western Germany, and finally in all coal-bearing areas of the world, in ever-increasing amounts. Then, about a century ago, first in Romania in 1857 and then in the United States in 1859, petroleum in commercial quantities began to be produced, thus tapping the second of the great stores of energy preserved in the fossil fuels. Other fossil fuels, large in amount, are the tar sands and the oil shales. Although oil has been obtained in limited quantities from oil shale for more than a century, the period of large-scale exploitation of the tar sands and the oil shales is still in the future.

Finally, only within the last two decades a way has been found to tap a still larger and more concentrated reservoir of potential energy, that of nuclear energy.

While the evolution of the means of controlling energy had been proceeding at a gradually accelerating rate for many millenia, it did not reach its crescendo stage until after the exploitation of the fossil fuels had begun. Once it was learned that "sea coles" would burn, it did not take long to discover that these loose chunks found along the shore had been derived from the outcropping strata in the sea cliffs above, which were gradually being undercut by the waves. The digging of these strata, first along the cliffs, and then by means of holes sunk to the beds from above, initiated the mining of coal in Western Europe.

So superior was this fuel to wood and peat that the digging proceeded apace. It is recorded that in 1234 King Henry III confirmed a privilege for the mining of coal granted to Newcastle-upon-Tyne by King John (Forbes, 1956b). At this time coal was already being transported by barge to London, where by 1273 the smoke from coal burning had become so obnoxious as to provoke complaints from the gentry. In addition to its use as a domestic fuel, coal was promptly adopted as a fuel for lime burning, and was used by blacksmiths and for other post-smelting metallurgical purposes, and for glass making.

Statistics of early production are few, but it is recorded that coal shipments from Newcastle-upon-Tyne in the year 1563-1564 amounted to 32,951 tons. By 1658-1659, nearly a century later, the yearly production had increased to 529,032 tons—more than 16-fold. Between 1580 and 1660 the imports of coal to London increased 20-25-fold. In the meantime, coal mining in Britain had become general in England, Scotland, and Wales, and the annual production for the whole country by 1660, or shortly thereafter, had reached about 2 million tons per year, which is estimated to have been five times as much as the production of the rest of the world (Nef, 1957, p. 77). By 1750 the annual production had reached 7 million tons (Ritson, 1958, p. 79).

This rapid increase in the mining of coal immediately created grave technological problems. The influx of water into the mines forced the development of continually larger and better pumps. First, water was removed by bailing, then by pumps powered by human labor, and finally by animal power, with pumps driven by as many as 100 horses on treadmills.

Ultimately, so desperate had this problem become that attention was directed to the powers of steam and the newly discovered properties of a vacuum (Dickinson, 1958). This led in 1698 to the development by Thomas Savery of the first successful water pump powered by steam. Water was lifted through a vertical pipe to fill the vacuum induced by the condensation of steam in an otherwise closed chamber. By the repetition of this cycle, with the opening and closing of appropriate valves, water could be pumped indefinitely.

This was followed shortly by the "atmospheric engine" of Thomas Newcomen in 1712, which was the first practical steam engine to be developed. This consisted of a walking beam, to one end of which was attached the plunger of a pump, and to the other the piston rod from a vertical steam cylinder. Steam at atmospheric pressure filled the cylinder during the nonworking stroke, and the work was done by atmospheric pressure on the piston when a vacuum was created in the cylinder by the injection of a jet of water.

The use of this engine for pumping water spread rapidly throughout Britain and also to the Continent. However, as it had no rotary motion it did not meet the needs of mills driven by water, except as a means for pumping water from the tailrace to the mill pond, permitting rotary power to be extracted by the water wheel.

Fundamental modification of the Newcomen engine did not occur until more than 50 years later when James Watt introduced a succession of radical improvements, including a separate condenser, a double-acting cylinder and piston, a governor, and, most important of all, a rotary shaft and fly wheel, making the engine suitable for the driving of all types of rotary machinery.

It was only after this, late in the eighteenth century, that the steam engine was able to compete with, and eventually to displace, water as a principal source of industrial power.

A second problem that was made critical by the mining of coal was the land transportation of heavily laden wagons of coal. While the principal transportation of coal was by water, that from the collieries to the docksides was by horse-drawn wagons. This led to the development of railroads with longitudinal wooden rails, but with the wagons drawn by horses. Finally, the idea of putting the steam engine on wheels and making it self-propelling was successfully accomplished by Richard Trevithick in 1802. Shortly thereafter, the use of the steam engine for the propulsion of boats was successfully accomplished by Robert Fulton and others.

Thus, by the second decade of the nineteenth century the steam engine had been adapted to supply all contemporary needs for mechanical power: the pumping of water, the driving of stationary industrial machinery, and transportation by water and land. However, the transmission of power was still limited to mechanical means, and hence to short distances.

The end of this era was foreshadowed when, in November 1831, Michael Faraday announced his epoch-making discovery of electromagnetic induction. Within a year Hippolyte Pixii publicly exhibited in Paris the first magnetoelectric machine, a hand-cranked magnetoelectric generator. After this, the further development of magnetoelectric generators and equipment proceeded in England, France, and Germany at a rapid rate. By 1857 a successful experiment of powering an arc light with a steam-driven generator of about 1-1/2 kilowatts capacity was demonstrated by Holmes in London. In 1858 illumination of a lighthouse in this manner was accomplished. By 1875 in France, and by 1878 in London, whole buildings were being illuminated (Jarvis, 1958). Finally, in 1881 the generation and public distribution of electric power by a central-power station was initiated when Thomas A. Edison installed the Pearl Street power station and its associated distribution network in New York. From that time forward, the steady advance of the technology of electrical-power generation, distribution, and utilization has advanced to the extent that it has rendered obsolete most other forms of stationary power.

Another major use of the energy from coal, of which scant mention has been made, has been in the smelting and processing of metals. The working of metals has been one of the major uses of coal since the beginning, but it was not until about the middle of the eighteenth century that coal supplanted charcoal for smelting. This was made possible only after it had been discovered how to rid coal of its injurious sulfur and gases by coking—a procedure quite analogous to the manufacture of charcoal from wood. Since the eighteenth century the metallurgical industries, principally iron and steel, have become almost solely dependent upon coal as a source of fuel, and thus among its largest consumers.

Oil and natural gas, as was mentioned earlier, came into commercial production during the last half of the nineteenth century, first for heat and light, and then as fuel for steam-power plants and to some extent in metallurgical industries. A dominant new use for petroleum was generated with the development in the 1880's of the high-speed, internal-combustion engine. This led immediately to the development of motorized vehicles for travel by land, water, and eventually by air. Gradually, oil and natural gas have succeeded in large measure in displacing coal as the traditional fuel for steamships, railroad locomotives, and even for central electric-power plants.

Finally, by 1962, progress is well underway in the controlled use of the last and largest known source of potential energy, the atomic nucleus. During the brief period since the attainment of the first controlled fission of uranium at Chicago on December 2, 1942, central power plants in the hundred-megawatt range have been built and are already in operation in the United States, Great Britain, and the U. S. S. R.; nuclear-propelled ships and submarines are also in operation.

Growth of Human Population

As was pointed out earlier, the human proclivity for capturing an ever larger fraction of the total flux of the energy on the earth, and eventually for tapping the large supplies of stored energy, has had the effect of continuously upsetting the ecological equilibrium in the direction of an increase in the human population. The magnitude of the upset and the rates at which it has occurred are best seen by plotting the estimates of the human population graphically as a function of time.

This has been done in Figure 2 for the period from 1000-2000 A. D., inclusive, using Putnam's (1953, Figs. 2-2, 2-9) graphs of

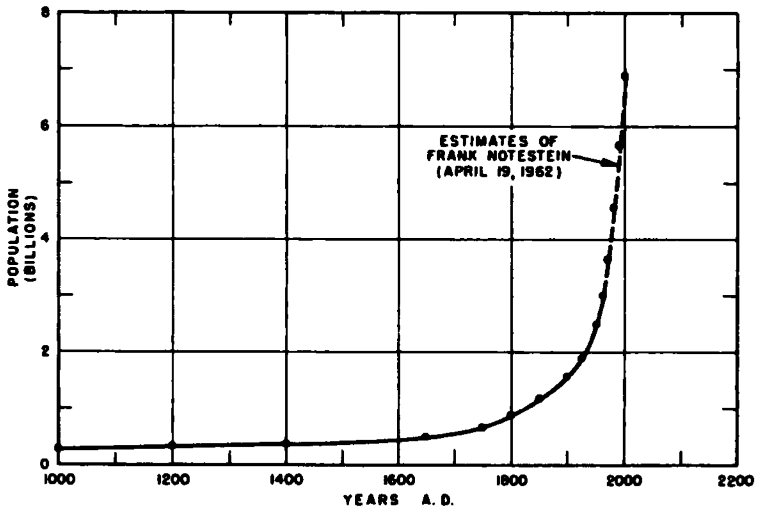

Figure 2. Growth of World Population

the means of various demographic estimates for the period 1000-1890, inclusive, United Nations (1958, p. 23) estimates for the period 1900-1950, inclusive, and estimates of Frank W. Notestein (1962) for the period from 1960 to 2000. These data are given numerically in Table 1.

For the period earlier than that shown in Figure 2, Putnam (1953, p. 7-11) estimates the world population for the year 10,000 B. C. to have been about 1 million and that at 1 A. D. at about 275 million, with a maximum of around 290 million about 225 A. D. and a minimum of 270 million at about 700 A. D.

For the period earlier than 10,000 B. C. about all we have to go on is the archeological evidence that the culture was Paleolithic and the subsistence was by hunting and food-gathering rather than food-producing, and the ecological evidence that the gradual evolution of Paleolithic culture should have been, on the whole, in the direction of a population increase with time.

We infer, therefore, that the human population at 1 million B. C. must have been less than that at 10,000 B. C., but equal to or greater than 2, the least number biologically possible. However, since this population did not arise by "creation," but by continuous evolution from its immediate forebears, and since for very small numbers of a population the chances of extinction are

TABLE 1

World Population Estimates

Year	Population (Millions)	Source
10,000 B.C.	1 ± x 10	Putnam
1 A.D.	275 ± 80	"
225	290 Max.	"
700	270 Min.	"
1000	295	"
1200	310	"
1400	350	"
1650	493	"
1750	694	"
1800	887	"
1850	1,170	Carr-Saunders
1890	1,500	Putnam
1900	1,550	U. N.
1925	1,907	"
1950	2,497	"
1960	2,996	Notestein
1965	3,297	"
1970	3,655	"
1975	4,080	"
1980	4,562	"
1985	5,096	"
1990	5,687	"
1995	6,278	"
2000	6,919	"

Putnam, Palmer Cosslett, 1953, Energy in the Future: New York, D. Van Nostrand Co., Inc., p. 16-17.

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very high, it is doubtful that a population as small as two individuals ever existed. What the minimum number may have been is unknown, but it is improbable that it was ever as small as 1,000.

Assuming 1,000 as a minimum number at 1 million B. C., we have a basis for judgment concerning the rates of growth of the population during the principal divisions of subsequent history. An initial population of 1,000 would only have to be doubled 21.5 times to reach 3.0 billion, which is the estimate of the world population in 1960. Accepting Putnam's estimates of populations of 1 million at 10,000 B.C. and 275 million at 0 B.C., then the first 10 of these 21.5 doublings would have occurred by 10,000 B.C., and 18 by 0 B.C. The remaining 3.5 doublings have occurred between the beginning of the Christian Era and the present time.

Consider, however, the lengths of time required for the successive doublings. If only ten doublings occurred during the million years prior to 10,000 B.C., then the average length of time required for each must have been 100,000 years. A change in a population increasing at such a rate would probably not be detectable by two censuses taken a thousand years apart. We do not assume that the population during this period actually grew in this manner. It probably fluctuated up and down with famines, plagues, and climatic changes, but its average growth rate over the whole time must have been not very different from this.

For the period from 10,000 B.C. to 0 B.C. about 8 doublings occurred with an average length of time for each of 1,250 years. This plainly shows the quickening of the growth rate over that of the preceding period—an increase of about 8-fold.

Then, during the Christian Era, 3.5 more doublings have occurred with an average length of about 560 years. This, however, fails to tell the whole story, because the time for each successive doubling has been shorter than for the one before. Thus, the first doubling after 0 A.D. occurred at about 1690, the second at about 1845, and the third at about 1937. Thus, during the interval since 0 A.D. the first doubling required 1,690 years, the second 155, and the third only 92.

That this reduction of the doubling period, or increase in the rate of growth, is still continuing may be seen by the population increase for the decade 1950-1960. The United Nations (1958) estimate of the population in 1950 is 2.497 billion. By 1960 this had increased to an estimated 2.996, or roughly 3.0 billion. This corresponds to a rate of increase of 1.82 per cent per year, at which rate the population would double in only 38.2 years. The instantaneous rates of growth and the corresponding lengths of time which would be required for the population to double are plotted graphically in Figure 3 for the world population data as given in Table 2.

What emerges from this examination is the very great contrast between the population growth during the last 1,000 years, particularly during the last few decades, and all preceding history. If we may define the term "normal" as describing a state of affairs

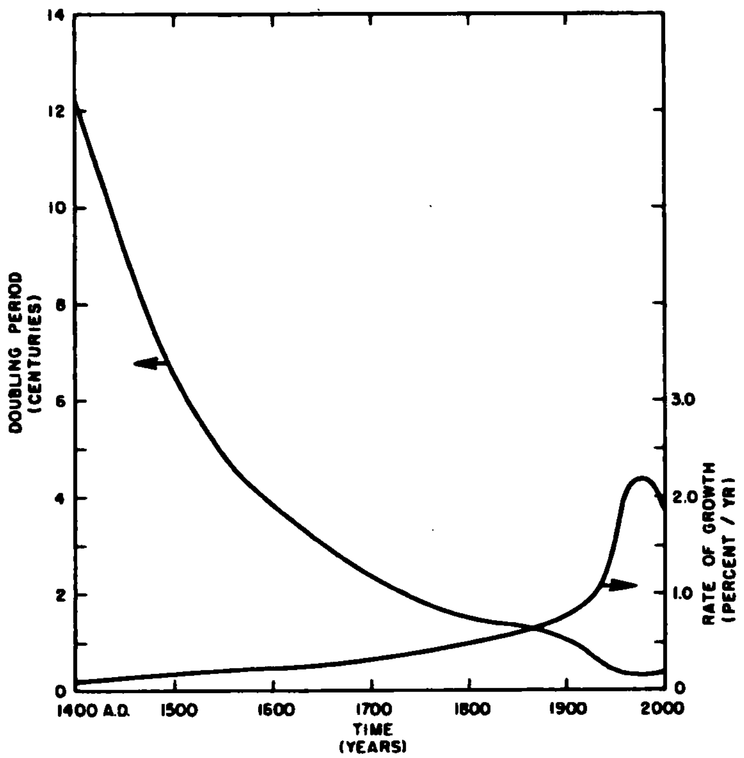

Figure 3. Decrease of Doubling Period and Rate of Increase of World Population

which subsists most of the time, then we must recognize that the normal state of the human population, and of biologic populations in general, is a state of extremely slow secular change. We must, accordingly, regard the rate of growth of the human population and the concurrent disturbances of all other biologic populations during the last few centuries as being extremely abnormal. It represents, in fact, one of the greatest biological upheavals known in geological as well as in human history.

TABLE 2

Rate of Population Growth

Time (Years)	Δt (Years)	Population (Billions) N	$\frac{N_t}{N_{t-\Delta t}}$	Exponential Constant a	Doubling Period (Years)
1000 A.D.		0.295			
1200		0.310			
1400		0.350*		0.000565*	1,225*
1500		0.382*		0.001064*	650*
1600		0.442*		0.00177*	390*
1700		0.570*		0.00263*	267*
1800		0.860*		0.00495*	140*
1900		1.550*		0.00618*	112*
	25		1.230	0.00829	83.6
1925		1.907			
	25		1.310	0.0108	64.1
1950		2.497			
	10		1.200	0.01824	38.2
1960		2.996			
	5		1.110	0.0209	33.1
1965		3.297			
	5		1.110	0.0209	33.1
1970		3.655			
	5		1.116	0.0220	31.4
1975		4.080			
	5		1.117	0.0221	31.2
1980		4.562			
	5		1.116	0.0220	31.4
1985		5.096			
	5		1.114	0.0216	32.0
1990		5.687			
	5		1.103	0.0196	35.3
1995		6.278			
	5		1.100	0.0190	36.4
2000		6.919			

*From graph of data in Table 1.

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CHAPTER III

ENERGY FROM FOSSIL FUELS

Production Data and Coal Reserves

The historical background in the use of energy from the fossil fuels has already been given in outline form in Chapter II. From here on it will be more informative if we consider the rates of growth of energy consumption from these sources, with the data presented in graphical form.

World Production of Coal and Crude Oil

Production of Coal

World production statistics before 1860 are not available, but, as we noted in Chapter II, the principal production during the first few centuries was in Britain, where the production began in the twelfth century and increased steadily over the next seven centuries. The British production rate reached 2 million tons per year by 1660 and 7 million by 1750, and world production reached 134 million metric tons by 1860.

Statistical data on annual production are available from 1860 to 1960, and the rate of production as a function of time is shown graphically in Figure 4 for that period. At a glance it will be seen that the growth in the rate of production during this period falls into three distinct phases: (1) a period of steady growth extending from 1860 until 1913, during which the production rate increased from 134×10^6 to $1,257 \times 10^6$ metric tons per year, (2) a period of unsettled growth and oscillation extending from 1913 to 1954, during which the production rate increased from $1,257 \times 10^6$ to $1,631 \times 10^6$ metric tons, and, finally, (3) a period from 1954 to 1960 when the production rate assumed a spurt of renewed growth from $1,631 \times 10^6$ to $2,414 \times 10^6$ metric tons per year.

The nature of this growth is brought out more clearly in Figure 5 where the same data are plotted logarithmically against time. Here the growth from 1860 to 1913 is seen to plot as an essentially straight line. This indicates that during that period

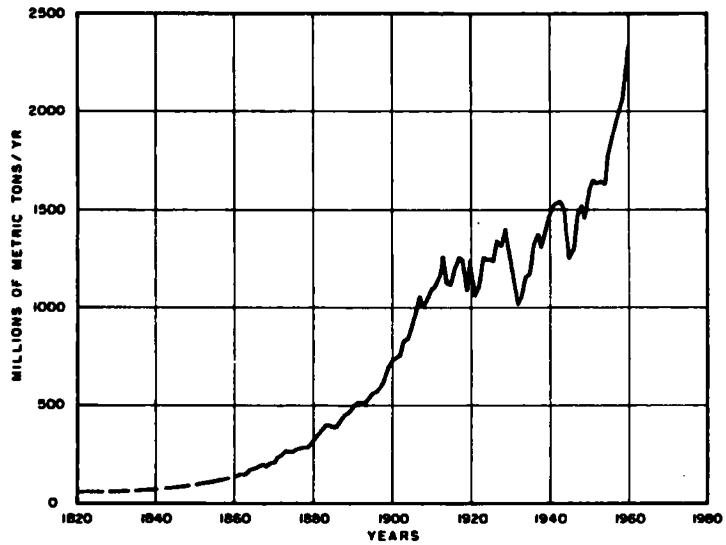

Figure 4. World Production of Coal

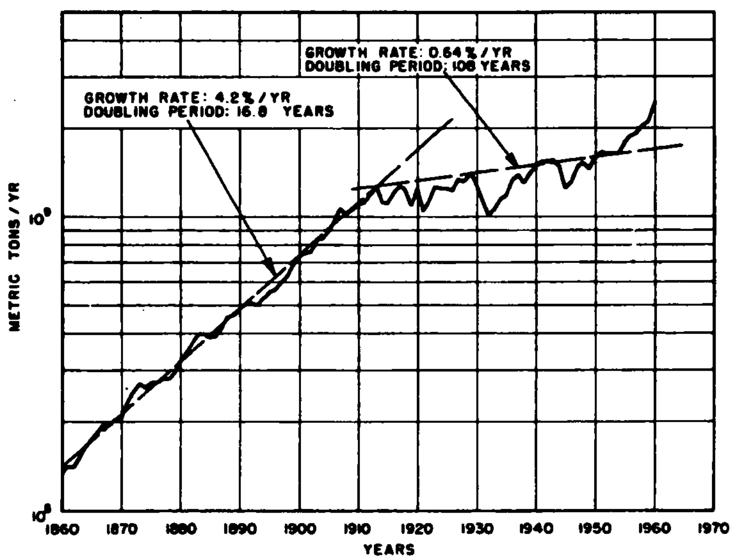

Figure 5. World Production of Coal (Logarithmic Scale)

the rate of coal production increased with time at an exponential, or compound-interest, rate of 4.2 per cent per year, or at such a rate of growth that the production rate doubled every 16.8 years.

During the intermediate period from 1913 to 1954 production increased much more slowly, averaging only about 0.64 per cent per year, while during the last period from 1954 to 1960 the rate of growth has been very nearly the same as for the earlier period—about 4.2 per cent per year.

Because Figures 4 and 5 present data for only the last century of the approximately 900 years during which coal has been mined, they do not properly convey an appreciation of the relative importance of coal mining during this period compared with that of earlier history. A better sense of this may be gained if we consider the cumulative production of coal during the total period. For the period prior to 1860, from the few production statistics and the knowledge that coal mining increased continually, it can be estimated that the total coal mined from the twelfth century until 1860 could only have been about 5.4 billion (5.4×10^9) metric tons. That mined during the 100 years from 1860 to 1960 amounted to 93.6×10^9 metric tons, giving a total of 99.0×10^9 metric tons for all coal mined from the beginning until 1960. However, the first half of this required the seven centuries up to 1927, whereas the second half required only the 33 years from 1927 to 1960. Only 20 per cent of the coal mined by 1960 was produced before 1900, and the remaining 80 per cent has been produced since that time.

Production of Crude Oil

Figures 6 and 7 show graphs of the world production of crude oil, in which the production rates are plotted arithmetically and logarithmically, respectively, against time. Production actually began in 1857, but the rates before 1885 were too small to plot on Figure 6. In this case, except for minor setbacks during the depression of the 1930's and during World War II, the production rate has been characterized by steady growth.

On the logarithmic scale of Figure 7 it will be seen that for the 50-year period from 1880 to 1930, the production rate increased linearly with time. Before 1880, although the production rate was very small, the rate of increase was even greater than that after 1880. Subsequent to 1880 the rate of increase has slackened. From 1880 to 1930 the production rate increased at an exponential rate of 7.4 per cent per year, with a doubling period of only 9.7 years.

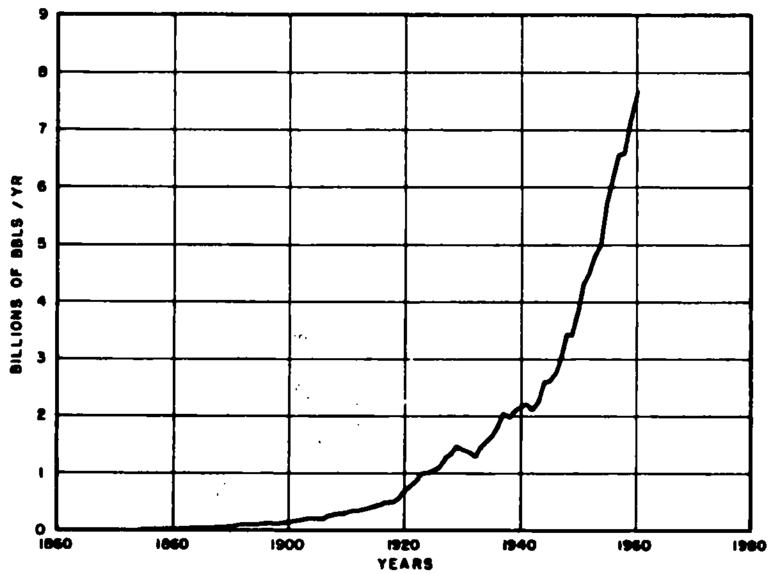

Figure 6. World Production of Crude Oil

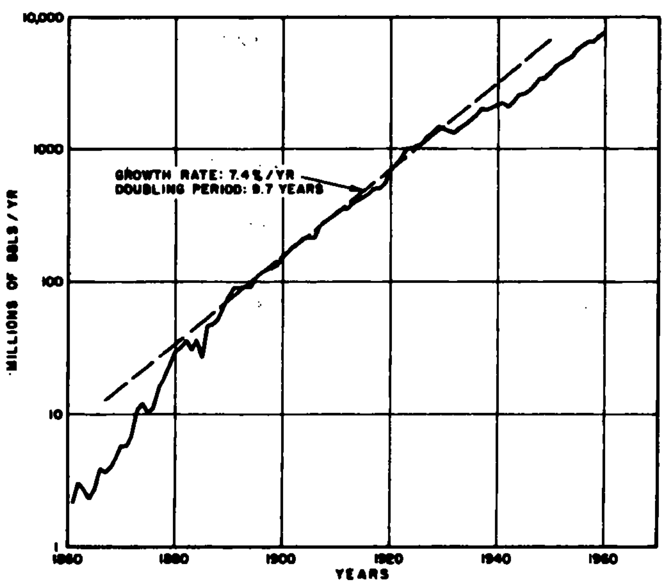

Figure 7. World Production of Crude Oil (Logarithmic Scale)

Energy from Coal and Crude Oil Combined

Finally, in Figure 8 there has been plotted on an arithmetic scale the production of energy from both coal and crude oil, in which the thermal energy of each fuel is expressed in the common unit, the kilowatt-hour of heat, obtained by combustion. Until

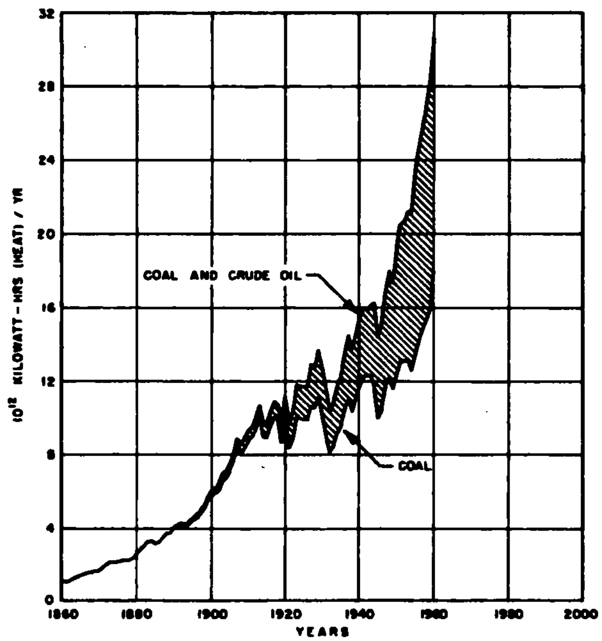

Figure 8. World Production of Energy from Coal and Crude Oil.

about 1900, it will be noted, crude oil contributed a negligible amount of the total energy. From that time on, the fraction contributed by crude oil has steadily increased until, by 1960, it amounted to almost one-half of the total.

United States Production of Energy from Coal, Oil and Natural Gas

Production of Coal

The production of coal in the United States started about 1820, when 14 tons are reported to have been mined. Since that time the production of coal increased steadily until about 1907, after which the rate has fluctuated between the extremes of about 400 and 700 million short tons per year, as shown in Figure 9.

In Figure 10 the same data are shown plotted on a logarithmic scale. Here again, after an initial more rapid rate, the

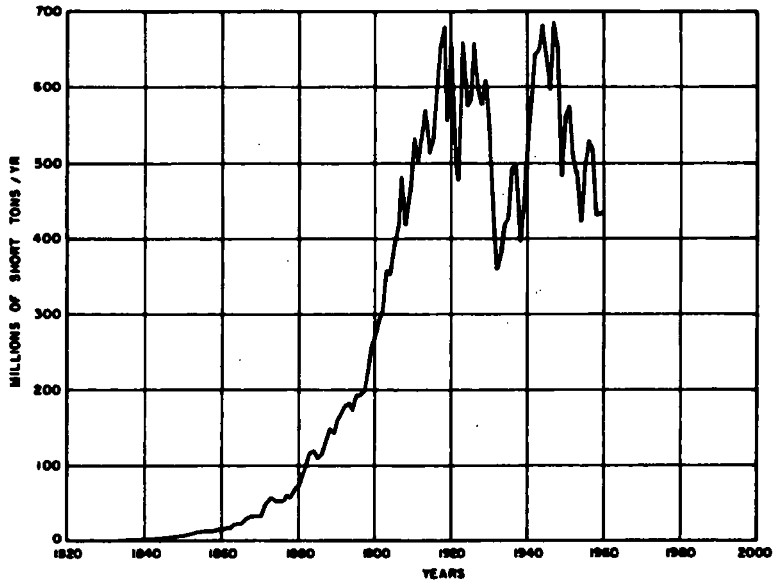

Figure 9. U.S. Production of Coal

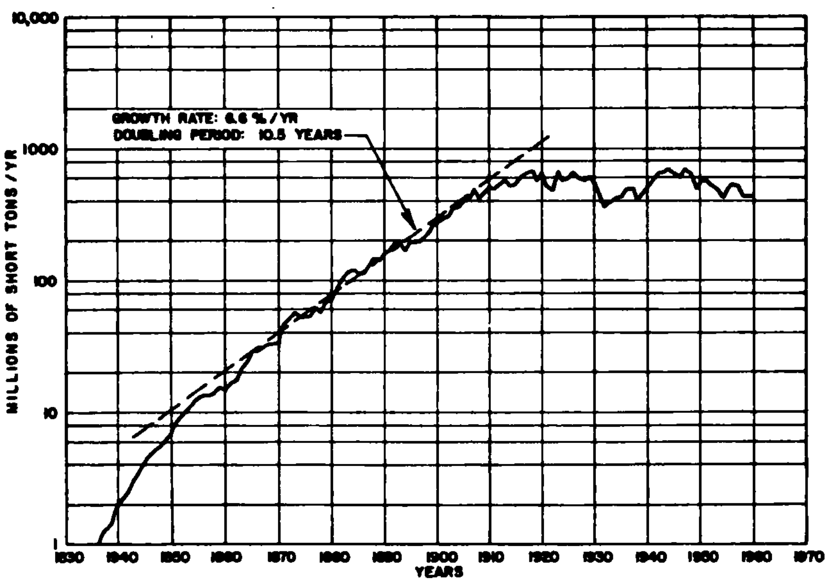

Figure 10. U.S. Production of Coal (Logarithmic Scale)

growth settled down to a linear plot on semilogarithmic paper indicating a steady exponential rate of increase. This persisted from about 1850 to 1907, during which period the production rate increased 6.6 per cent per year, with a doubling period of 10.5 years. After 1907 the growth practically ceased, due in large measure to the increasing displacement of coal by the complementary fuels, oil and gas.

Production of Crude Oil

The production of crude oil in the United States since 1860 is shown graphically on arithmetic and logarithmic scales, respectively, in Figures 11 and 12. Oil was first discovered in the United States by the Drake well drilled at Titusville, Pennsylvania, in 1859. Since that time, with only an occasional setback, the production rate has continually increased. On the semilogarithmic plotting of Figure 12, the production rate increased exponentially from about 1875 to 1929 at 7.9 per cent per year, doubling every 8.7 years. Since 1929 the growth has continued, but at a decreasing rate.

Production of Natural Gas

Figure 13 shows the U. S. production of marketed natural gas since about 1905. In the early days of the petroleum industry only a small amount of gas could be utilized, and the rest was

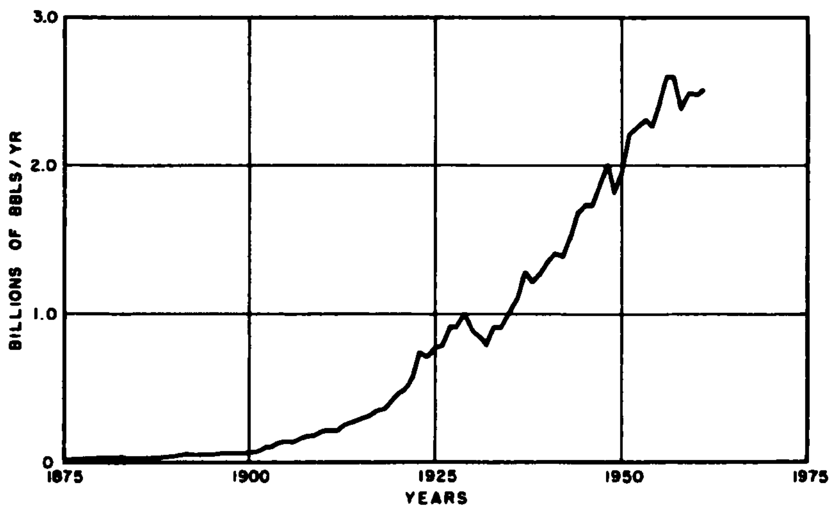

Figure 11. U. S. Production of Crude Oil

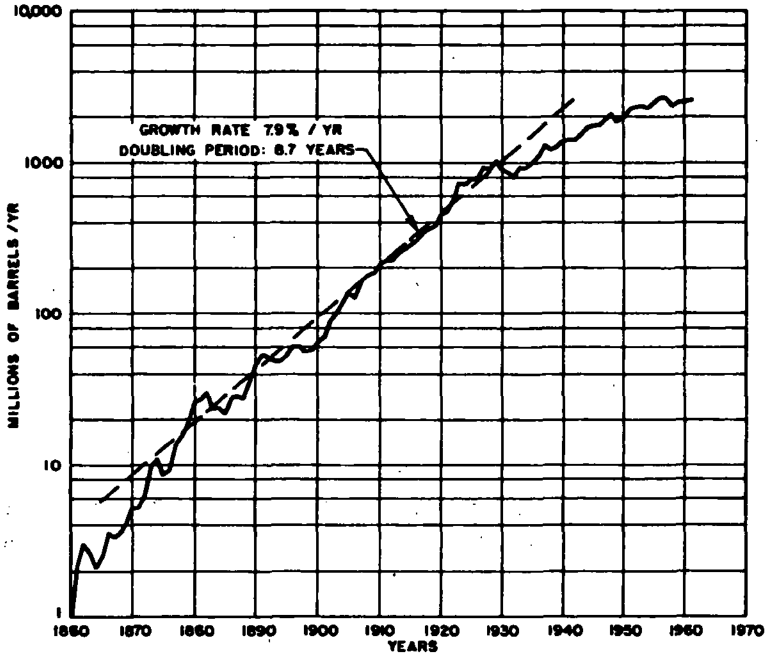

Figure 12. U.S. Production of Crude Oil (Logarithmic Scale)

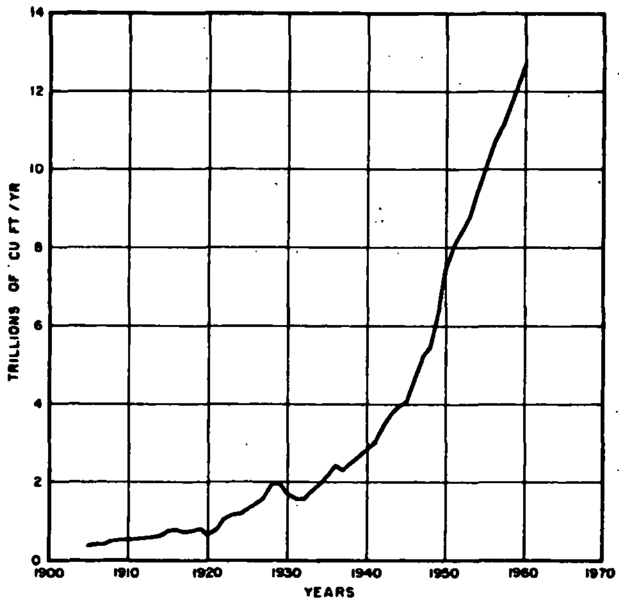

Figure 13. U.S. Marketed Production of Natural Gas

disposed of by flares. Gradually, however, gathering and distributing pipelines have been built, and facilities for using gas as fuel made available, so that very little gas is now wasted. As gas is genetically related to oil, the rate of growth of gas production and consumption is similar, except for a time delay, to that of oil.

Energy from Coal, Oil, Gas, and Water Power

Finally, the total energy produced in the United States from coal, oil, gas, and water power combined is shown in Figure 14 (Dept. of Commerce, 1949, p. 155; 1954, p. 22; 1961, p. 522) plotted on an arithmetic scale, and in Figure 15, plotted logarithmically. In the latter plot it will be seen that the straight-line section of the curve, or the period of exponential growth, persisted from 1845 until 1907, after which the growth rate abruptly dropped to a much smaller value. During the 60-year period of exponential growth the rate of increase was 7.4 per cent per year, with a doubling period of 9.7 years.

From 1907 to 1960 the consumption of energy from the fossil fuels and water power increased from 14.6×10^{15} B.t.u. per year to 44.9×10^{15}. The mean exponential rate of growth for the 53-year period dropped to only 2.04 per cent, and the mean doubling period increased to 34 years. The amounts of energy contributed from the separate sources for the period 1920-1960 are shown in Figure 16. During this period the percentage contribution by water power increased only from 3.1 to 3.9 per cent. The dramatic transition, however, has been the displacement of coal by oil and gas. In 1920, 89 per cent of the energy consumed was supplied by coal and only 8 per cent by oil and gas; by 1960 the contribution of coal had dropped to only 23 per cent, while that by oil and has had increased to 73 per cent, or about three-quarters of the total.

The importance of the information on the U.S. consumption of energy from coal, oil, gas, and water power, with respect to the industrial rate of growth can hardly be overemphasized, since, with the exception of energy derived from biologic sources, and a small amount of wind power, almost every wheel that turns, every industrial process that is in operation, and a predominant amount of space heating are made possible by the energy from these sources. Furthermore, it is this energy consumption which distinguishes the activities in the United States from those of other major areas of the world whose energy supplies are limited principally to biological sources. Hence, the curve of the consumption

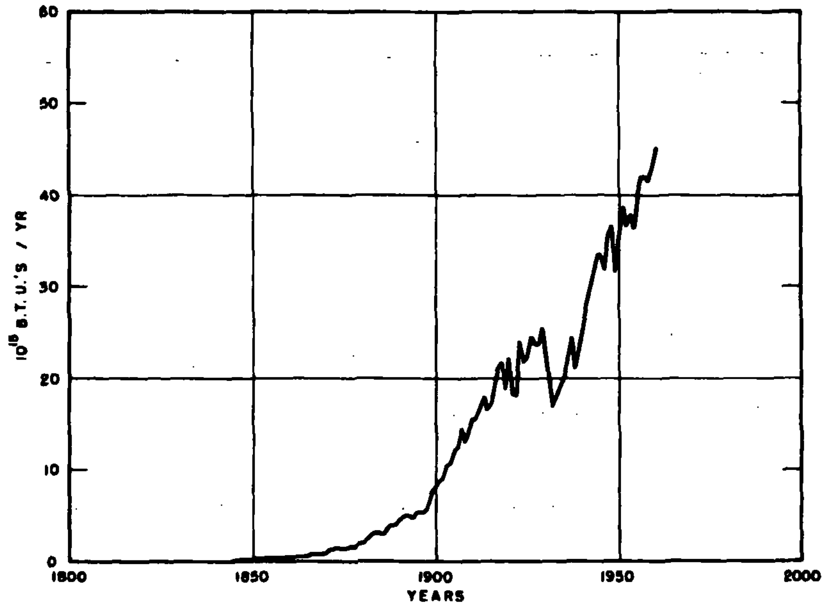

Figure 14. U.S. Consumption of Energy (Coal, Oil, Gas and Water Power)

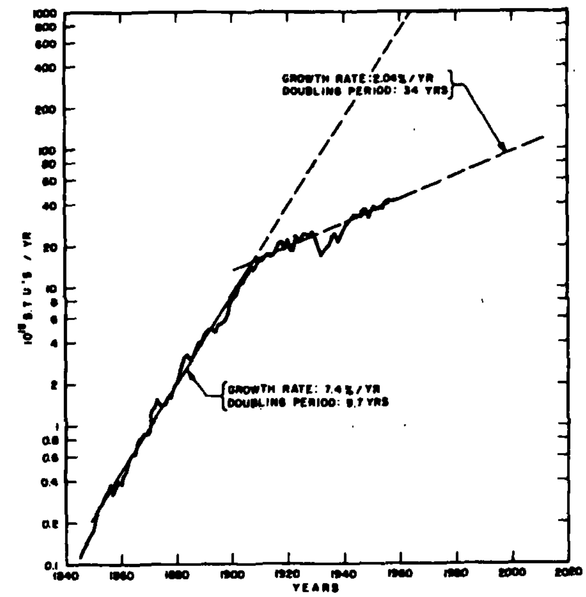

Figure 15. U. S. Consumption of Energy (Logarithmic Scale)

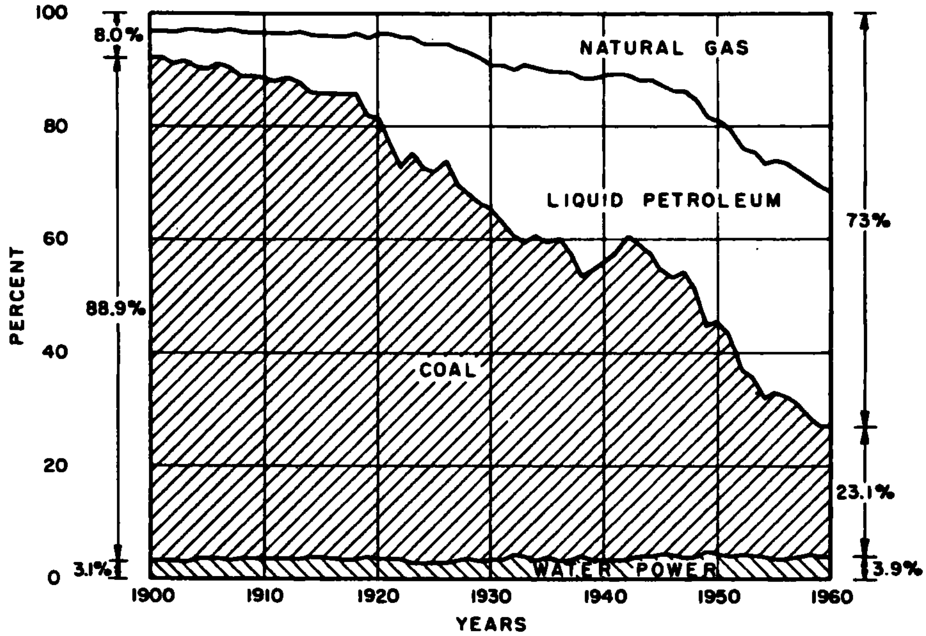

Figure 16. U.S. Consumption of Energy since 1900. Percentages Contributed by Coal, Oil, Gas and Water Power

of nonbiological energy in the United States is, in effect, a physical integration of all the industrial activity in the country.

While it is true that the industrial output per unit of energy consumed is also increasing with time, because of physical limitations this tends asymptotically to a maximum. Hence, if the total rate of energy consumption were to be maintained constant, the industrial output would continue to rise, but at a decreasing rate of growth, until it also leveled off to an essentially constant rate. The curves of Figures 14 and 15, therefore, may be considered to represent minimum rates of the industrial growth of the United States. During most of the nineteenth century the industrial rate of growth was somewhat greater than 7 per cent per year, and the rate of output doubled in somewhat less than 10 years. During most of the twentieth century there has been a drastic reduction in this rate of growth.

Future Production of Fossil Fuels

The history of the production and consumption of energy from the fossil fuels for both the world and the United States is graphically and accurately summarized in Figures 4 to 16. Beginning from zero, it is seen how the consumption of these fuels has gradually increased until during the last century the rates of consumption have reached magnitudes many times greater than the energy derived from all other sources in the industrialized areas of the world. Furthermore, as we have noted, most of this has occurred within the last 30 years.

It is difficult to contemplate these curves without wondering: How long can we keep this up?

That it cannot continue indefinitely can be seen very simply. The supply of fossil fuels initially in the ground before human exploitation began was some fixed finite amount. As was observed earlier, these fuels are the residues of organisms which became buried in the sedimentary muds and sands over a period of some 500 million years of geological history. Their energy content represents solar energy, stored by photosynthesis as chemical energy, from that same span of time. Geologically, this process is still continuing but probably at a rate not greatly different from that of the past. Hence, the new fossil fuels to be generated during the next million years will probably not differ greatly from 1/500th of that of the last 500 million years, and that for the next 1,000 years correspondingly less.

Hence, we may regard the initial supply of fossil fuels as constituting a nonrenewable resource which is exhaustible. When we burn oil or coal, as we observed, the energy content, after various degradations during use, degenerates to unusable heat at the lowest ambient temperature, and then leaves the earth as long-wavelength radiation. The material content is reduced to common inorganic chemicals such as H_2O and CO_2, and a residue of mineral ash.

This fact provides us with the most powerful means we have available for anticipating the future history of the consumption of these sources of energy. If we plot a curve of the production rate $\underline{P}$ against time $\underline{t}$ on arithmetic paper, as we have done in Figures 4, 6, 8, 9, 11, and 13, for any nonrenewable resource, this curve must have the following properties:

1. It must begin with $\underline{P} = 0$, and, after passing through one or more maxima, it must ultimately decline to zero. This last state would be due either to the exhaustion of the resource or to the abandonment of its production for other reasons.

2. The cumulative production $\underline{Q}$ up to any given time is given by the equation

$$Q = \int_0^t (dQ/dt)dt = \int_0^t P dt, \tag{1}$$

and this, on the graphical plot, is proportional to the area $\underline{A}$ between the rate-of-production curve and the time axis. This principle is illustrated in Figure 17, where the ultimate cumulative production $\underline{Q}_\infty$ at very large time is proportional to the total area under the curve.

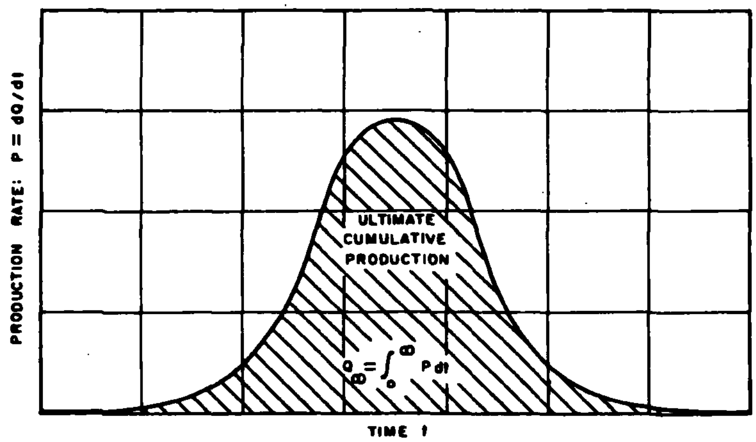

Figure 17. Production of an Exhaustible Resource

The fundamental fact with which we here must deal is this:

(Quantity ultimately produced) $\leq$ (Quantity initially present),

or

$$Q_\infty \leq Q_i. \tag{2}$$

Hence, if we can estimate $\underline{Q_i}$, the amount of the quantity initially present, the curve of production rate $\underline{P}$ versus time $\underline{t}$ must begin at zero and end at zero, and it must not encompass an area greater than that corresponding to $\underline{Q_i}$.

Application to Coal

The production of coal lends itself readily to this type of treatment because coal occurs in stratified deposits which frequently extend over large areas, or whole sedimentary basins, and hence are amenable to comparatively accurate estimates of their amount. Coal beds frequently crop out on the surface of the ground, and in the subsurface they can be mapped by comparatively few widely spaced drill holes.

The first world inventory of coal resources was made during the Twelfth International Geological Congress at Toronto in the year 1913. Any estimates that could be made at that time were necessarily very provisional. Nevertheless, the estimate of minable coal resources for the whole world amounted to about 8×10^{12} metric tons, which is only about 50 per cent higher than the present estimates.

Since that time, extensive and intensive geological exploration has been extended to all parts of the world. Also during the last decade the Fuels Branch of the United States Geological Survey has been engaged in a detailed re-examination of the coal resources of the United States, and also has maintained currently the estimates being made of the coal resources of the rest of the world.

The latest such world summary is that prepared by Paul Averitt (1961a) from the preliminary reports of the Geological Survey for presentation to the Federal Council. These estimates are given in detail in Table 3 and are shown graphically in an abbreviated form in Figure 18.

It is to be emphasized that these are the remaining coal reserves, and to obtain the initial reserves we shall have to add the quantity already produced, which for the world was about 99×10^9 metric tons by the end of 1960. That for the United States amounted to 32.0×10^9 metric tons. Then, from the data in Table 3 and the above figures on cumulative production, the estimates of initial minable coal reserves of the world as of 1961 are $2,419 \times 10^9$ metric tons; the corresponding figure for the United States is 785×10^9 metric tons.

The figures in Table 3 are of recoverable reserves defined as ".... reserves in the ground, as of the date of the estimate, that past experience suggests can actually be produced in the future"

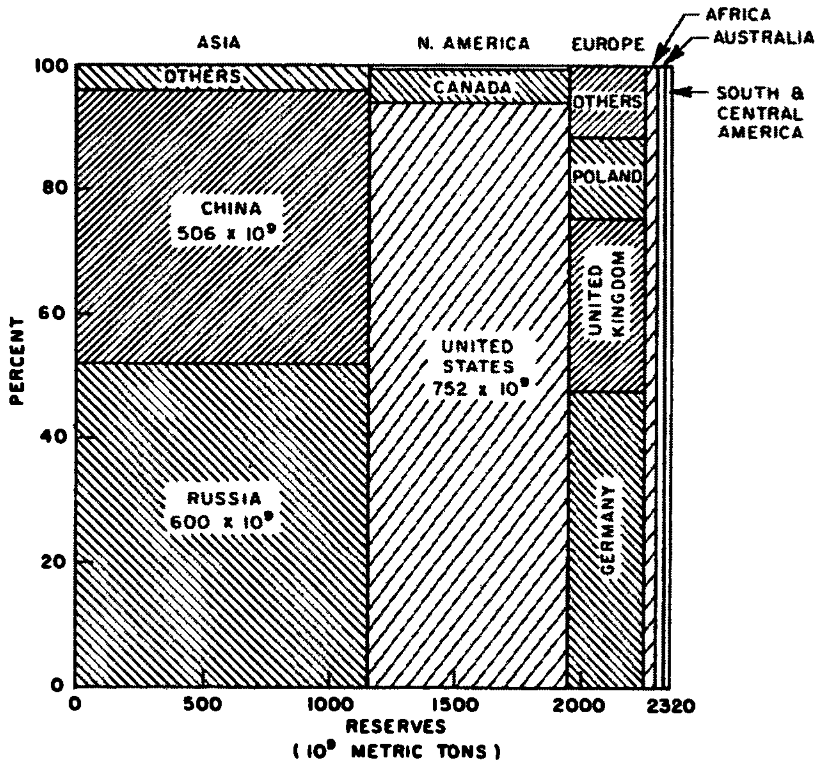

Figure 18. Recoverable World Coal Reserves

(Averitt, 1961b, p. 22), Elsewhere it is explained that these include all seams 14 inches or more thick, occurring at depths of 3,000 feet or less, with an allowance for nonrecovery of 50 per cent of the coal in place.

Before proceeding further it is worthy of note that the coal reserves of the world are far from equitably distributed among the world's people. The continent of Asia, for example, has 49.4 per cent, or almost exactly half, of the world's coal reserves, nearly all of which are in the U. S. S. R. and China. North America has 34.4 per cent, or about one-third; Europe has 13.0 per cent; and the remaining 3.2 per cent is divided between the three whole continents: Africa, South America, and Australia.

By countries, the United States has approximately one-third, Russia one-fourth, and China one-fifth of the world's coal

TABLE 3

Estimated Remaining Coal Reserves of the World by Region and Principal Coal-Producing Countries*

Region and Country	Producible Coal ($\times 10^9$ metric tons)	Percent of Regional Total	Percent of World Total
Asia:			
U.S.S.R.	600	52.3	25.8
China	506	44.1	21.8
India	32	2.8	1.4
Japan	5	0.4	0.2
Others	4	0.4	0.2
Total	1,147	100.0	49.4
North America:			
United States	753	94.4	32.5
Canada	43	5.4	1.8
Mexico	2	0.2	0.1
Total	798	100.0	34.4
Europe:			
Germany	143	47.5	6.2
United Kingdom	85	28.2	3.7
Poland	40	13.3	1.7
Czechoslovakia	10	3.3	0.4
France	6	2.0	0.3
Belgium	3	1.0	0.1
Netherlands	2	0.7	0.1
Others	12	4.0	0.5
Total	301	100.0	13.0
Africa:			
Union of South Africa	34	97.1	1.5
Others	1	2.9	-
Total	35	100.0	1.5
Australasia:			
Australia	29	99.0	1.3
Others	-	1.0	-
Total	29	100.0	1.3
South and Central America:			
Colombia	6	60.0	0.2
Venezuela	2	20.0	0.1
Others	2	20.0	0.1
Total	10	100.0	0.4
WORLD TOTAL	2,320	-	100.0

*From: Averitt, Paul, 1961, Coal Reserves of the United States and of the World, p. 5 in Domestic and World Resources of Fossil Fuels, Radioactive Minerals, and Geothermal Energy; Preliminary Reports Prepared by Members of the U. S. Geological Survey for the Natural Resources Subcommittee of the Federal Science Council.

reserves. Of the 13.0 per cent in Europe, Germany has about one-half, the United Kingdom one-fourth, and Poland one-eighth.

A fairly widespread delusion among the citizens of the United States is that this country owes its phenomenal industrial development, as contrasted with the lack of development of regions such as Africa, South and Central America, and India, to the superiority of American personal and institutional characteristics. It may be well to remind ourselves that, but for a fortuitous combination of a large fraction of the world's resources of coal and iron in the eastern United States, the growth of which we are justly proud could never have occurred.

Returning now to the problem of predicting the future of coal production, let us apply the technique illustrated in Figure 17. For the world the results are shown in Figure 19 and for the United States in Figure 20. In Figure 19 the world production of coal through 1960 is first plotted. From this point the graph must continue with time until it passes through one or more maxima, and then the production of coal must ultimately decline to zero. The area under the curve, however, must not exceed that corresponding to the estimated initial reserves, $2,400 \times 10^9$ metric tons.

A scale for the conversion of area to tons of coal is shown in the upper left-hand corner of the chart. Here one square in the coordinate grid is seen to have the dimensions

$$2 \times 10^9 \text{ metric tons/yr} \times 100 \text{ yrs},$$

and so represents 200×10^9 metric tons. Hence, the area under the production curve between the beginning of coal mining and its end cannot exceed 12 grid rectangles, representing $2,400 \times 10^9$ metric tons of coal.

The curve is drawn subject to these conditions. The shape of the curve, of course, is not known, but if the world should continue to be heavily dependent on coal, and if the peak of production should reach as much as 6×10^9 tons/yr—about three times the present production rate—this peak would occur about the year 2150, or 200 years hence. If the production rate went higher than this the peak would occur sooner; if less high the date of the peak would be postponed.

In Figure 20 the coal production of the United States is treated in a similar manner, except that the coal is measured in

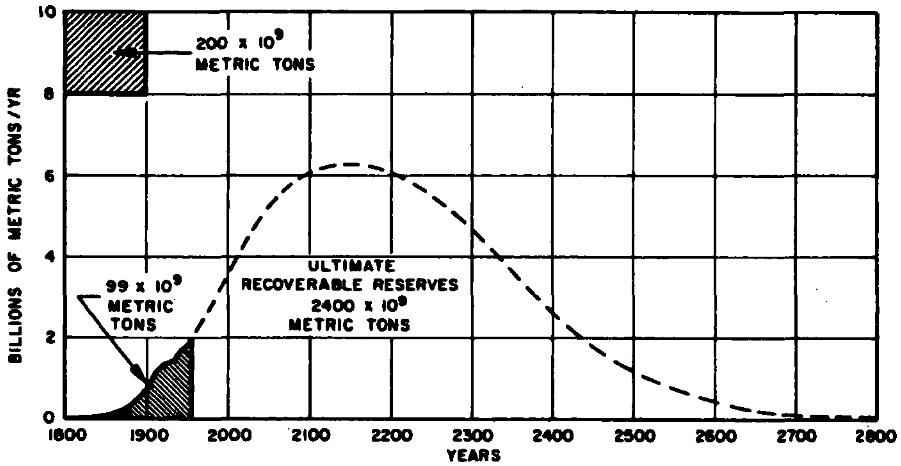

Figure 19. Ultimate World Coal Production

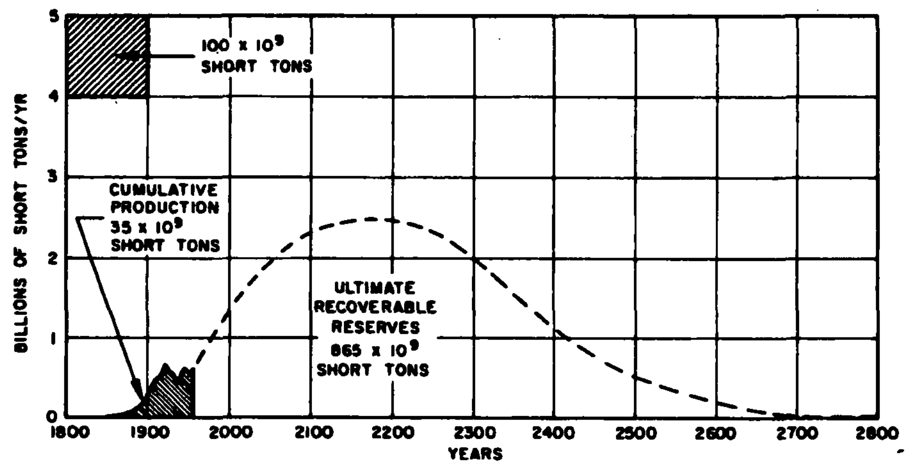

Figure 20. Ultimate U. S. Coal Production

short tons instead of metric tons. By January 1, 1961, the cumulative coal production of the United States amounted to 35.2 x 10^9 short tons. The remaining reserves by that date were 830 x 10^9 short tons. The initial reserves, which are the sum of these two figures, are thus 865 x 10^9 short tons.

The grid rectangle in Figure 20 represents 100 x 10^9 short tons, so the coal-production curve must be drawn in such a manner as to enclose 8.65 grid rectangles. Again, assuming that we continue to require coal, and assuming a production peak of 2.5 x 10^9

tons per year—two more doublings of the present rate—the peak again would occur about 200 years hence.

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CHAPTER IV

ENERGY FROM FOSSIL FUELS (continued)

Future Production of Petroleum and Natural Gas

Necessity for Extended Discussion

The technique described in Chapter III is also applicable to petroleum and natural gas, only in this case it is much more difficult to estimate the producible amounts of these fuels initially present. Because of this difficulty, as indicated by the wide disparity among recent estimates by different investigators, it will be necessary to consider petroleum and natural gas in much more detail than was the case for coal.

Such an extended examination not only is justified, but also is becoming increasingly urgent, in view of the fact that oil and gas are approaching equality with coal as a source of energy on a world scale, whereas, in the United States, the energy consumption from these fuels is already three times as large as that from coal. Yet, preliminary evidence indicates that the total energy reserves from oil and gas are much smaller than those from coal. Thus, because of the relative smallness of the reserves and their rapid rate of depletion, critical problems are due to arise with respect to supplies of oil and gas much sooner than with any other source of energy.

Petroleum Classification

Since a great deal of unnecessary confusion in discussing petroleum-reserve problems arises from the failure to distinguish between the different classes of petroleum fluids, let us first define what these classes are.

The first of these fluids is crude oil, which is the liquid petroleum obtainable from an oil reservoir after the gaseous constituents have been removed or have escaped. Next comes natural gas, consisting principally of methane (CH_4), the constituent of petroleum fluids which remains gaseous at standard conditions of temperature and pressure. Finally, there are the natural-gas liquids, which are the liquid constituents obtained from wells which otherwise produce natural gas.

The sum of the liquid phases, crude oil and natural-gas liquids, is frequently combined statistically and classed as petroleum liquids, or liquid hydrocarbons.

The extraction of natural-gas liquids became significant only after about 1920. Since that time its production rate has risen in the United States until by 1961 it represented about 15 per cent of the total production of liquid hydrocarbons. Thus, originally crude oil was the sole liquid hydrocarbon, but more recently natural-gas liquids have achieved a significant fraction of total production.

A great deal of confusion has been introduced into discussions of petroleum reserves by the failure to distinguish between crude oil and total petroleum liquids. In what follows this distinction will clearly be made. We shall first deal with crude oil, for which our data are the most complete, and then use the results obtained as a basis for estimating the reserves of natural gas and natural-gas liquids. Also, since the petroleum industry in the United States is more advanced in its evolution toward total depletion than that of any comparable area of the rest of the world, we shall use the data of the United States as a yardstick for estimating the reserves of other areas.

Estimation of the Crude Oil Reserves of the United States

Geological Background

Before proceeding with this problem in detail, let us first consider a few of the fundamental facts concerning the manner of occurrence of oil and gas underground. If a well is drilled deep enough at any place on the earth it will eventually encounter some form of dense, crystalline rock such as granite, or gneiss, or schist, of either igneous or metamorphic origin, whose grains are so tightly packed that the pore space is practically zero.

We shall refer to this system of crystalline rocks, which is continuous over the whole surface of the earth, as the basement or basement complex.

In many parts of the world, such as eastern Canada, Scandinavia, and a large part of Africa, the rocks of the basement complex occur at the surface of the ground. In other areas these rocks are covered with a veneer of unmetamorphosed rocks such as sandstones, shales, and limestones, which are sedimentary in origin. The thicknesses of these deposits of sedimentary rocks vary from zero to possibly 10 miles or more. The average thickness is probably not more than about a mile. The sediments having thicknesses of one to several miles occupy basin-like depressions in the upper surface of the basement complex.

These unmetamorphosed sediments comprise the habitat of the fossil fuels. They are the sands and muds in which the organic remains of the geologic past got buried and preserved. These rocks, or contiguous fractured basement rocks, are therefore the only rocks in which commercial quantities of fossil fuels have ever been found, or are ever expected to be found.

The unmetamorphosed sedimentary rocks are mostly porous, with the pore volume comprising about 20 per cent of the total volume. This pore space forms a three-dimensional interconnected network which normally is completely filled with water. Exceptionally, in very local regions of space whose horizontal dimensions may range from a few hundred feet to some tens of miles, oil and gas may have displaced the water in certain strata of the sedimentary deposit. These local concentrations of oil and gas in the sedimentary rocks are the sources of our commercial production of these fluids.

This knowledge provides us with a powerful geological basis against unbridled speculation as to the occurrence of oil and gas. The initial supply is finite; the rate of renewal is negligible; and the occurrences are limited to those areas of the earth where the basement rocks are covered by thick sedimentary deposits.

The geographical distribution of all of such basins on earth is reasonably well known. If we can estimate about how much oil and gas is contained per unit volume in the sediments in the better-known areas, such as the United States, then, by assuming comparable oil and gas contents in similar sedimentary basins in the rest of the world, an estimate in advance of extensive development can be made of the possible oil and gas that other areas may eventually produce.

This, in essence, is the geological basis for estimating the ultimate petroleum reserves. It is an essential method, but as we shall see, it has inherent limitations of accuracy. The sedimentary rocks of the United States and its continental shelves to a depth of two miles have a volume of about 3×10^6 cubic miles, or about 14×10^6 km^3. With an average porosity of 20 per cent the pore volume of these rocks would be about 2.8×10^6 km^3. Now suppose that these rocks contain 1,000 billion barrels of crude oil in commercially producible concentrations. The volume of this amount of oil would be 159 km^3, which would represent a fraction of 5.7×10^{-5} of the entire pore volume, or about 6 parts per 100,000.

There is no geological information in existence that will permit us to know whether this is a high figure or a low figure. We have no *a priori* way of knowing whether the average content of oil occurring in commercial quantities in sedimentary rocks should be a few parts in 100,000, or ten times or one-tenth this amount.

If the oil production of the United States is to be used as a primary standard for estimating the petroleum potentialities of the rest of the world, then the only possible way we have of determining how much oil the United States will produce is by pure empiricism, based on our actual experience in the exploration and production of petroleum. The United States experience can then be used to estimate what may be expected from other comparable regions.

Reserve Estimates

According to Wallace E. Pratt (1942, 1944, 1947), then Vice President for Exploration and Production of the Standard Oil Company of New Jersey, the world's largest oil company, one of the Jersey Standard Oil geologists, L. G. Weeks, had made an extensive world-wide study along the general lines sketched above. This report has never been published, but in 1948 Weeks (1948, p. 1094) published a summary of the results that had been obtained.

This consisted of estimates of the ultimate potential reserves of various areas, defined as the total amount of crude oil that could reasonably be expected to be produced by productive methods, and under economic conditions, prevailing in 1947. These estimates are reproduced here as Table 4. For our purposes the two principal results were:

Land area of the United States (excluding Alaska)	110×10^9 barrels
Land areas of entire world	610×10^9 barrels

Two years later, during a discussion on petroleum reserves at the United Nations Scientific Conference on the Conservation and Utilization of Resources, held at Lake Success, New York, Weeks (1950, p. 107-110) amplified his earlier estimate by adding about 400×10^9 barrels for the continental-shelf areas of the world, and arrived at a round estimate of $1,000 \times 10^9$ barrels for the whole world. This was in criticism of an estimate of $1,500 \times 10^9$ barrels by A. I. Levorsen (1950, p. 94-99).

Weeks gave his own appraisal of the reliability of these figures in the following words (Weeks, 1950. p. 109):

> I look upon my estimates for the United States as reasonable at this time. Furthermore, I now know of no good reason for considering that the incidence of oil occurrence in the United States should be much, if any, above that of the average for the world. As previously stated, I feel that the actual measure of oil recoverable by conventional methods and under present economies is more likely to be 50 per cent larger than 10 per cent smaller than my estimate of same. However, again I must warn that these are not proved reserves. The actual figure of ultimate reserves may very easily vary from my figure by considerably more than the percentages I have just cited.

It should be emphasized that the foregoing estimates were for crude oil only.

In March 1956 Hubbert (1956) added 20 billion barrels to Weeks' estimate for the land area of the United States (excluding Alaska) and 20 billion barrels for the U.S. offshore areas, and arrived at a figure of 150×10^9 barrels for the ultimate potential reserves of crude oil in the United States, and $1,250 \times 10^9$ barrels

TABLE 4

(Weeks' Table II.) Production and Reserve Summary

Country or Region	Cumulative January 1, 1948		1947 Daily Average		Proved Reserves		Ultimate Potential Reserves		Percentage of Ultimate Produced
	Millions Bbls.	%	Barrels	%	Millions Bbls.	%	Millions Bbls.	%	
United States	35,080.7	64.1	5,082,000	61.5	21,488[1]	31.6	110,000	18.0	32
Balance N.America	2,435.7	4.4	175,000	2.1	1,200	1.7	40,000	6.6	6
Total N. America	37,516.4	68.5	5,257,700	63.6	22,688	33.3	150,000	24.6	25
Venezuela	4,046.6	7.4	1,190,800	14.4	9,650	14.2	80,000	13.1	7
Balance S. America	1,549.8	2.8	226,865	2.8					
Total S. America	5,596.4	10.2	1,417,665	17.2	9,650	14.2	80,000	13.1	7
Total W. Hemisphere	43,112.8	78.7	6,675,365	80.8	32,338	47.5	230,000	37.7	14.4
Europe, excl. Russia	1,655.0	3.0	129,410	1.6	650	1.0	13,000	2.1	12.7
Middle East, incl. Egypt	2,541.5	4.6	864,000	10.5	28,800	42.3	155,000	25.4	1.6
Balance Asia, excl. Russia	429.9	0.8	11,400	0.1	100	.15	24,000	4.0	1.8
Indonesia	1,241.8	2.3	56,000	0.7	1,100[2]	1.6	30,000	4.9	4
Africa, excl. Egypt	0.6	0.01	–	–	50	.07	8,000	1.3	.01
Total E. Hem. excl. Russia	5,868.8	10.7	1,060,810	12.9	30,700	45.1	230,000	37.7	2.5
Russia	5,783.9	10.6	525,000	6.4	5,000	7.4	150,000	24.6	3.8
Total E. Hemisphere	11,652.7	21.3	1,585,810	19.2	35,700	52.5	380,000	62.3	3
Total World	54,765.5	100.0	8,261,175	100.0	68,038	100.0	610,000	100.0	9
Total Foreign	19,684.8	35.9	3,179,175	38.5	46,550	68.4	500,000	82.0	4

[1] A.P.I. [2] Oil and Gas Journal.

for the whole world. Almost simultaneously, Pratt (1956) published an estimate for the United States of 170×10^9 barrels of liquid hydrocarbons (which implies about 145×10^9 barrels of crude oil); and Pogue and Hill (1956) of the Chase Manhattan Bank published a figure of 165×10^9 barrels of crude oil for the ultimate potential reserves of the United States.

At the meeting of the American Association of Petroleum Geologists in Dallas in March 1959, G. Moses Knebel, Chief Geologist of the Standard Oil Company of New Jersey, stated that he and his staff had a few years previously made a comprehensive review of the oil potentialities of both North and South America, and that their estimates for the United States were in substantial agreement with the 150 billion-barrel figure of Hubbert, an estimate which was still regarded as valid. He later disclosed privately that their estimate for the United States was 203 billion barrels of liquid hydrocarbons. Of this, crude oil would comprise about 85 per cent, or about 173 billion barrels.

These figures are cited because they represent a very good cross-section of informed petroleum-industry opinion at that time. Pratt's estimate was based, in part, on twenty-two returns to a questionnaire he had sent to a selected group of well-informed people in the petroleum industry. The high figure in these returns was an estimate of 200×10^9 barrels of crude oil by the consulting firm DeGolyer and MacNaughton.

The only discordant figure of this series was an estimate of 300 billion barrels from an anonymous source in the Department of the Interior (1956).

Shortly after 1956, however, all consistency in the estimates of petroleum reserves vanished. Within a year after the Pogue and Hill estimate of 165 billion barrels, Hill, Hammar and Winger (1957), also of the Chase Manhattan Bank, raised the Pogue and Hill estimate to 250 billion barrels. In 1958, published estimates ranged from a low figure of 165 billion barrels by Davis (1958) of Gulf Oil Corporation to a high of about 372 billion barrels by Netschert (1958) of Resources for the Future.

In 1958 L. G. Weeks (p. 434) raised his earlier estimate of 110 billion barrels for the ultimate potential reserves of crude oil for the land area of the United States to 240 billion barrels of liquid petroleum for both the land and offshore areas. This quantity was said to represent ". . . . the ultimate potential liquid petroleum resources, recoverable by conventional primary methods in terms of current economics...." Of this, about 85 per cent, or 204 billion barrels, would be represented by crude oil.

What Weeks meant by "conventional primary methods" is not entirely clear since his 240 billion-barrel figure was stated to include both cumulative production and proved reserves, each of which is a composite of oil already produced, or producible, by both primary and secondary methods. He did mention, however, that a means might ultimately be found to recover by secondary methods an additional quantity as large as the one cited. A year later (Weeks, 1959, p. A-27) this ambiguity was resolved. In a new estimate Weeks raised the figure of 240 billion barrels of liquid petroleum recoverable by conventional primary methods to 270 billion and then added 190 billion barrels producible by "secondary recovery," giving a total of 460 billion barrels. Again, about 85 per cent of this, or about 391 billion barrels, would be represented by crude oil.

This last estimate was still adhered to by Weeks as recently as May 1961 (Weeks, 1961, p. 144).

The 1958 and 1959 estimates of Weeks were used by Paul Averitt (1961, p. 99-100) of the United States Geological Survey as the basis for his figure of 470 billion barrels of liquid petroleum (or 400 billion barrels of crude oil) for the United States exclusive of Alaska. However, what appears to be the "official" estimate of the U. S. G. S. is that prepared by A. D. Zapp (1961, Table 1) for presentation by V. E. McKelvey to the Natural Resources Subcommittee of the Federal Science Council, November 28, 1961. Zapp's estimate of the ultimate U. S. resources of crude oil (including past production) was 590 billion barrels. Concerning this estimate, V. E. McKelvey (1961, p. 12), in the same report, remarked:

> Those who have studied Zapp's method are much impressed with it and we in the Geological Survey have much confidence in his estimates.

A published exposition of Zapp's method (Zapp, 1962) has subsequently appeared in the U. S. Geological Survey Bulletin 1142-H, entitled "Future Petroleum Producing Capacity of the United States." In this, no estimate is given explicitly of the ultimate amount of crude oil the United States may be expected to produce, but such an estimate is implied in two statements on page H-24:

1. But this much is certain: it cannot be safely assumed that even the 20-percent mark has been reached in exploration for petroleum in the United States, excluding Alaska and excluding rocks deeper than 20,000 feet.

2. With the crude yardstick of at least 100 billion barrels of oil found so far, and a rough appraisal of the extent of exploration so far, an objective estimate of the approximate minimum ultimate "reserves" appears to be in sight.

As an aside, petroleum-exploration people are intimately familiar with the initial 20 per cent of the petroleum exploration postulated by Zapp, but many are at a loss as to how to proceed with respect to his postulated remaining 80 per cent.

The most recent estimate available is that of C. L. Moore (1962) of the U. S. Department of the Interior, Office of Oil and Gas. From a study of petroleum-industry statistics, Moore (pp. 8, 18) has arrived at an estimate of 364 billion barrels for the ultimate U. S. recovery of crude oil.

These various estimates are shown graphically in Figure 21. To review the often lengthy arguments whereby they were derived

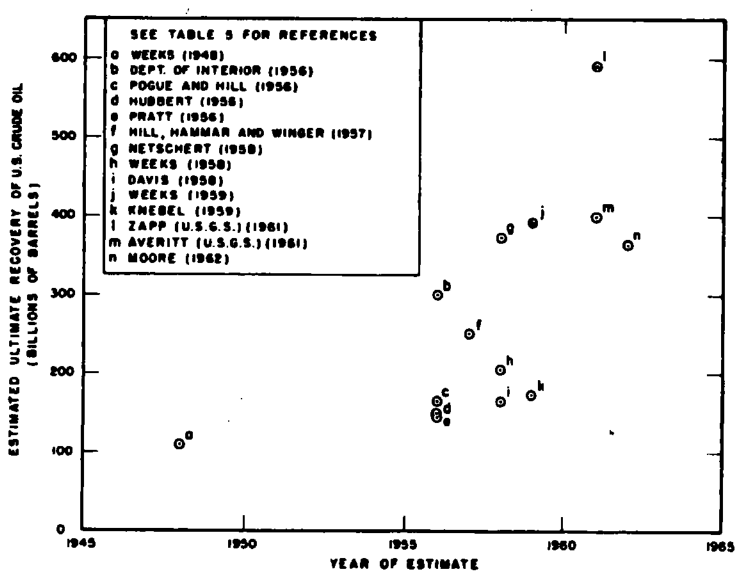

Figure 21. Estimates of Ultimate Recovery of Crude Oil

would be time-consuming and profitless, as the extent of their unreliability is attested by the range of disagreement exhibited among the estimates themselves. There exists some definite quantity of crude oil, Q_∞ (at the moment unknown) which will ultimately be produced in the United States. The estimates plotted in Figure 21 are each intended to represent this quantity. Suppose that the correct value happened to be 590 billion barrels, the highest figure cited. Then the lowest figure since 1955, 145 billion barrels, would be in error by 445 billion barrels; and the errors of the other estimates, except the correct one, would range between 190 and 445 billion barrels.

If the smallest figure happened to be the correct one, then all the others would be erroneously high, with the errors again ranging from 5 to 445 billion barrels.

If the correct figure happened to fall about mid-range, say at 370 billion barrels, then the errors on either side would range between zero and about 200 billion barrels.

It is thus demonstrable, without making any hypothesis whatever of what the true value of Q_∞ should be, that the preponderance of recent attempts to determine this quantity are grossly in error. This raises the question of whether the desired quantity is intrinsically indeterminate, except within these wide limits, or whether from data now available it should be possible to determine this quantity within a much narrower range of uncertainty. It is the thesis of the present report that such data do exist, and that from them a much more reliable estimate can be made.

New Method for Estimating the Ultimate Crude-Oil Production of the United States

Theory

The method we shall now employ makes explicit use only of two of the most reliable series of statistics of the petroleum industry: (1) the quantity of crude oil produced in the United States per year, for which data are available annually since 1860, and (2) the estimates of proved reserves of crude oil in the United States made annually since 1937 by the Committee on Petroleum Reserves of the American Petroleum Institute.

TABLE 5

Estimated Ultimate U. S. Crude-Oil Reserves

	Date	Author	Estimate (Barrels)
a	1948	Weeks	110×10^9
b	1956	Dept. of Interior	300×10^9
c	1956	Pogue and Hill	165×10^9
d	1956	Hubbert	150×10^9
e	1956	Pratt	145×10^9*
f	1957	Hill, Hammar and Winger	250×10^9
g	1958	Netschert	372×10^9*
h	1958	Weeks	204×10^9*
i	1958	Davis	165×10^9
j	1959	Weeks	391×10^9*
k	1959	Knebel	173×10^9*
l	1961	Zapp (U.S.G.S.)	590×10^9
m	1961	Averitt (U.S.G.S.)	400×10^9*
n	1962	Moore	364×10^9

*Calculated from author's estimate of total liquid hydrocarbons on the basis that crude oil equals 85% of liquid hydrocarbons.

a Weeks, L. G., 1948, Highlights on 1947 Developments in Foreign Petroleum Fields: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 1094.

b Interior, Dept. of, 1956, Impact of the Peaceful Uses of Atomic Energy on the Coal, Oil- and Natural-Gas Industries: Background Material for the Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy, v. 2, January, p. 82.

c Pogue, Joseph E., and Hill, Kenneth E., 1956, Future Growth and Financial Requirements of the World Petroleum Industry: New York, The Chase Manhattan Bank, Petroleum Dept., p. 24.

d Hubbert, M. King, 1956, Nuclear Energy and the Fossil Fuels: Drilling and Production Practice, Am. Petroleum Inst., p. 18.

e Pratt, Wallace E., 1956, The Impact of the Peaceful Uses of Atomic Energy on the Petroleum Industry: Background Material for the Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy, v. 2, January, p. 94.

f Hill, Kenneth E., Hammar, Harold D., and Winger, John G., 1957, Future Growth of the World Petroleum Industry: Paper for Presentation at the Spring Meeting of the API Division of Production, Rocky Mountain District, Casper, Wyoming, April 25 (preprint), p. 26.

g Netschert, Bruce C., 1958, The Future Supply of Oil and Gas: Baltimore, Resources for the Future, Inc., Johns Hopkins Press, p. 24, 55.

h Weeks, L. G., 1958, Fuel Reserves of the Future: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 434.

i Davis, Warren, 1958, A Study of the Future Productive Capacity and Probable Reserves of the U. S.: Oil and Gas Jour., v. 56, February 24, p. 114.

j Weeks, L. G., 1959, Where Will Energy Come from in 2059: The Petroleum Engineer, v. XXXI, August, Table 1, p. A-25.

k Knebel, G. Moses, 1959, personal communication.

l Zapp, A. D., 1961, World Petroleum Resources, Table 1 in Domestic and World Resources of Fossil Fuels, Radioactive Minerals, and Geothermal Energy: Preliminary Reports Prepared by Members of the U. S. Geological Survey for the Natural Resources Subcommittee of the Federal Science Council.

m Averitt, Paul, 1961, Coal Reserves of the United States—A Progress Report January 1, 1960: U. S. Geol. Survey Bull. 1136, p. 100.

n Moore, C. L., 1962, Method for Evaluating U. S. Crude Oil Resources and Projecting Domestic Crude Oil Availability: U.S. Dept. of Interior, Office of Oil and Gas, p. 8.

The data on the annual production of crude oil requires no comment. The meaning of the term "proved reserves," as defined by the Reserve Committee, however, needs to be clearly understood, because the Reserve Committee operates on the basis of this definition, and their reserve figures are not susceptible to any other interpretation. The following is a partial quotation from the definition of the term "proved reserves of crude oil" taken from the Report of Committee on Petroleum Reserves of the American Petroleum Institute of March 9, 1962, (p. 3):

> Proved Reserves of Crude Oil—Definition
>
> The reserves listed in this Report, as in all previous Annual Reports, refer solely to "proved" reserves. These are the volumes of crude oil which geological and engineering information indicate, beyond reasonable doubt, to be recoverable in the future from an oil reservoir under existing economic and operating conditions. They represent strictly technical judgments, and are not knowingly influenced by policies of conservatism or optimism. They are listed only by the definition of the term "proved." They do not include what are commonly referred to as "probable" or "possible" reserves.
>
> * * *
>
> Both drilled and undrilled acreage are considered in the estimates of the proved reserves. However, the undrilled proved reserves are limited to those drilling units immediately adjacent to the developed areas which are virtually certain of productive development, except where the geological information on the producing horizons insures continuity across the undrilled acreage.

The report adds that the estimates do not include oil that may become available by fluid injection or other methods from fields in which such operations have not yet been applied.

Each year's report presents data in each of the following classifications:

1. Estimate of proved reserves at the end of the preceding year.
2. Changes in proved reserves due to extensions and revisions during the subject year.

3. Proved reserves discovered in new fields and in new pools in old fields during the subject year.
4. Production during the subject year.
5. Proved reserves as of December 31 of the subject year. (Items 1 + 2 + 3 - 4)
6. Changes in reserves during the subject year. (Items 5 - 1)

Added reserves due to extensions and revisions (Item 2) each year are the order of 6 to 7 times the reserves due to new discoveries (Item 3).

The significance of the A. P. I. estimates of proved reserves can perhaps best be understood by considering a hypothetical field discovered in a given year. Suppose the field is destined, ultimately, to produce a total of 100 million barrels. Suppose that during the year of discovery only five wells were drilled. The proved reserve estimate would perhaps show:

Reserves added by extensions and revisions: None
Reserves due to new discovery: 150,000 barrels

For a number of years each successive year would then show sizeable reserve additions due to extensions and revisions, but none by new discoveries. Then, as the field approaches complete development, the changes due to extensions and revisions would diminish from one year to the next, ultimately to zero.

The sum of the reserves added, year by year, in this manner would ultimately equal the total amount of oil which the field will produce. This process mightcontinue, however, for thirty or forty years after the date of initial discovery. The reason is that, although the field may eventually produce 100 million barrels of oil, this amount of oil was not discovered at the date of discovery of the field; it was discovered only gradually as the field was developed.

The estimates of proved reserves for the whole United States have exactly the same significance. In fact, all the oil we can claim to have discovered in the United States up to the end of any given year is the total amount of oil already taken from the ground up to that date, the cumulative production, plus the proved reserves. We may call this quantity the "cumulative discoveries" up to that date; or, if one prefers, the "cumulative proved discoveries."

If we represent the cumulative production by the symbol Q_P, the cumulative proved discoveries by Q_D, and the proved reserves by Q_R, then for each year,

$$Q_D = Q_P + Q_R \tag{3}$$

The relation between rates of change of these quantities with time is obtained by taking the derivative with respect to time of equation (3), giving

$$\frac{dQ_D}{dt} = \frac{dQ_P}{dt} + \frac{dQ_R}{dt}, \tag{4}$$

in which dQ_D/dt is the rate of discovery, dQ_P/dt is the rate of production, and dQ_R/dt is the rate of increase of the proved reserves.

The manner in which the three quantities Q_D, Q_P, and Q_R must vary with time during the entire history of petroleum production from start to finish must be approximately as follows: The cumulative production Q_P, when plotted as a function of time, will increase slowly during the early stages of petroleum exploitation, increase more and more rapidly with time to about the halfway point, and then continue its ascent by rising more and more slowly, finally leveling off to the ultimate figure Q_∞ as production ceases.

The curve of proved reserves Q_R will start at zero, rise gradually until a maximum is reached at about the halfway point, and then gradually decline to zero.

As oil must be found before it can be produced, the curve of cumulative proved discoveries must closely resemble that of cumulative production, except that it must plot ahead of the production curve by some time interval Δt, which itself may vary during the cycle.

A plot of the family of the three curves Q_D, Q_P, and Q_R is shown in Figure 22 as they may be expected to appear in the case of cumulative production of crude oil in the United States. All present evidence indicates that the U. S. discovery and production is following a single growth cycle, rather than a multiple cycle like the State of Illinois which has two production peaks 30 years apart. One- and two-cycle growths are illustrated in Figure 23.

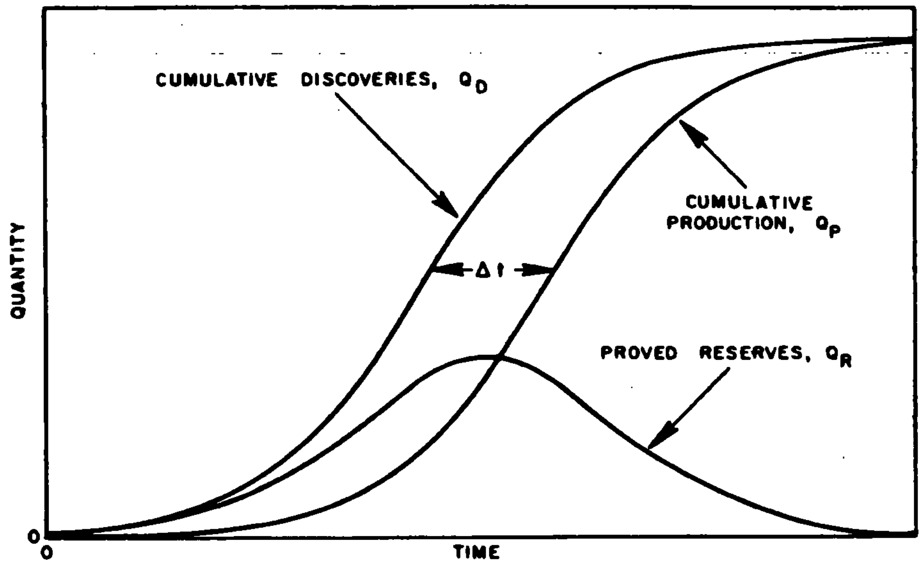

Figure 22. Cumulative Discoveries and Production and Proved Reserves

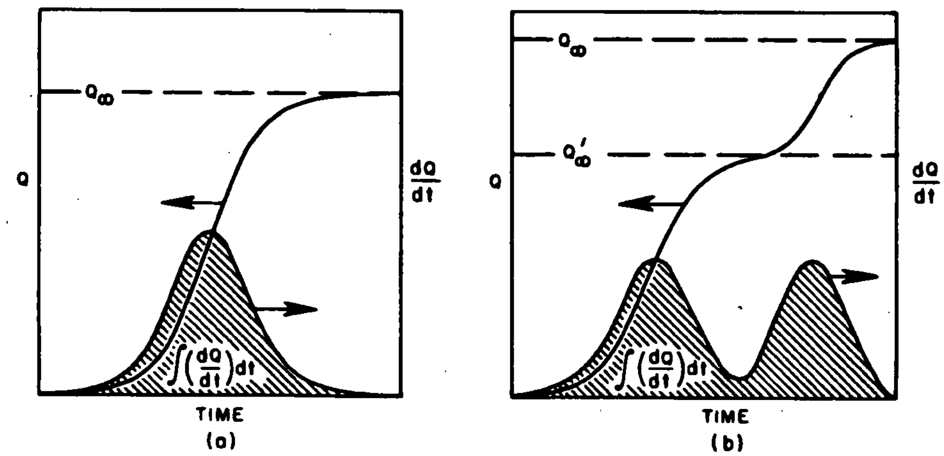

Figure 23. Growth Curves and Production Rates for Single- and Multiple-Cycle Developments

Because of the close similarity between the curve of cumulative proved discoveries and that of cumulative production, it follows that the study of the discovery curve must give one a preview of what production will do at a time of approximately $\Delta \underline{t}$ in the future.

Taking the time derivatives of the three curves shown in Figure 22 gives us the rate of discovery, rate of production, and rate of increase of proved reserves, which are plotted as a function of time in Figure 24. It will be noted that the rate of discovery will reach a peak at about mid-range and, thereafter, gradually

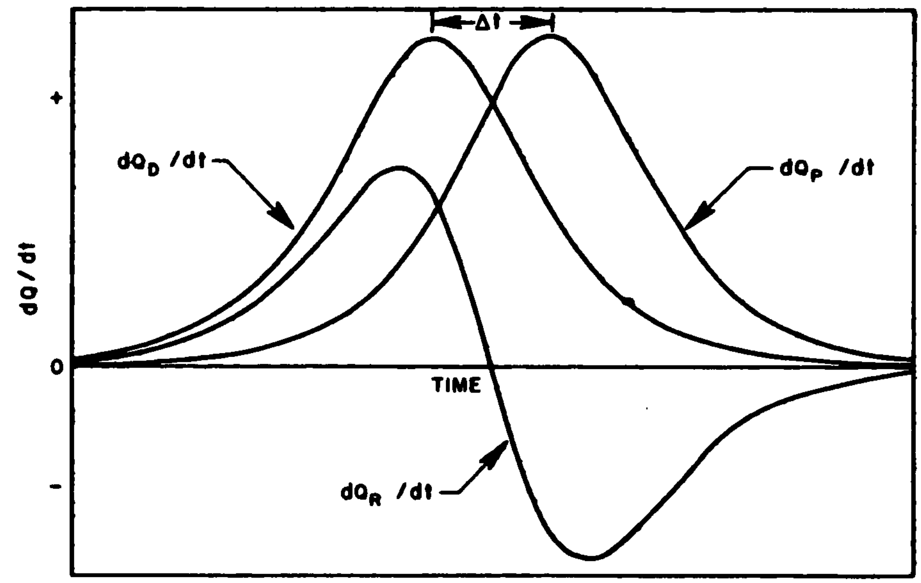

Figure 24. Rates of Discovery, Production and Change of Proved Reserves

decline to zero. The rate of production will reach a peak at a time about Δt after that of discovery, and the increase of proved reserves will change from positive to negative about halfway between the discovery and production peaks. The reserves themselves, Q_R, will reach a maximum at this same time.

The relations between the three curves at this mid-point can be seen by noting that when reserves reach their maximum value, their derivative

$$\frac{dQ_R}{dt} = 0 \qquad (5)$$

which, when inserted into equation (4), gives

$$\frac{dQ_D}{dt} = \frac{dQ_P}{dt} . \qquad (6)$$

This tells us that when reserves reach their maximum value the curves of discovery rate and production rate will cross, production going up and discovery going down. This is shown in Figure 24.

Observations

This is the theoretical framework in which we now propose to examine the crude-oil production data and proved-reserve data of the United States (excluding Alaska)*. Graphs of cumulative production Q_P, proved reserves Q_R, and cumulative proved discoveries Q_D for the United States are shown in Figure 25 (American Petroleum Institute, 1959, 1960, 1961, 1962). The curve for Q_D is the sum of the first two.

In order to obtain the approximate magnitude of Δt, we trace the Q_D curve on tracing paper and then translate it parallel to the time axis until the closest fit with Q_P is obtained. This is shown in Figure 26. Ten years is too small and 11 years is too large; the best fit is at about 10.5 years. Thus, since 1925 cumulative production in the United States has lagged discovery by the nearly constant interval of 10-11 years.

Growth phenomena such as those represented by the Q_D and Q_P curves, which start slowly, gradually accelerate, and finally level off to a maximum, are said to follow a logistic growth curve and are describable by an empirical equation of the form....

$$y = \frac{h}{1 + ae^{-bx}}, \tag{7}$$

in which h, a, and b are parameters whose magnitudes are to be determined by the data, and e the base of natural logarithms. Adapting this equation to the data of Figure 25, we have for the curve of cumulative proved discoveries

$$Q_D = \frac{Q_\infty}{1 + ae^{-bt}} \tag{8}$$

in which Q_∞ is the asymptotic value to which Q_D will tend as the time t becomes unlimitedly large.

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*In all subsequent discussions the petroleum data for the United States are to be understood to refer to the conterminous part of the United States, and to exclude Hawaii and Alaska, unless stated otherwise.

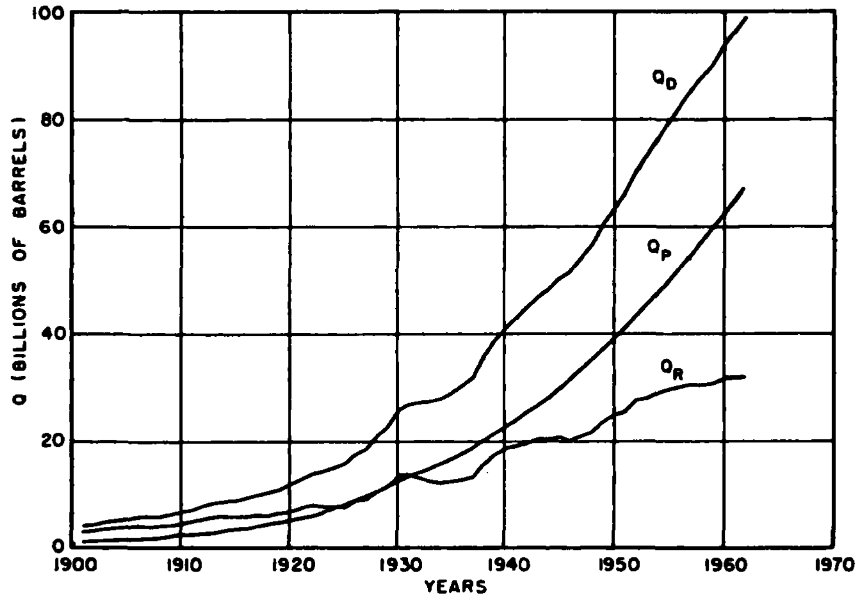

Figure 25. Cumulative Proved Discoveries and Production and Proved Reserves of U. S. Crude Oil

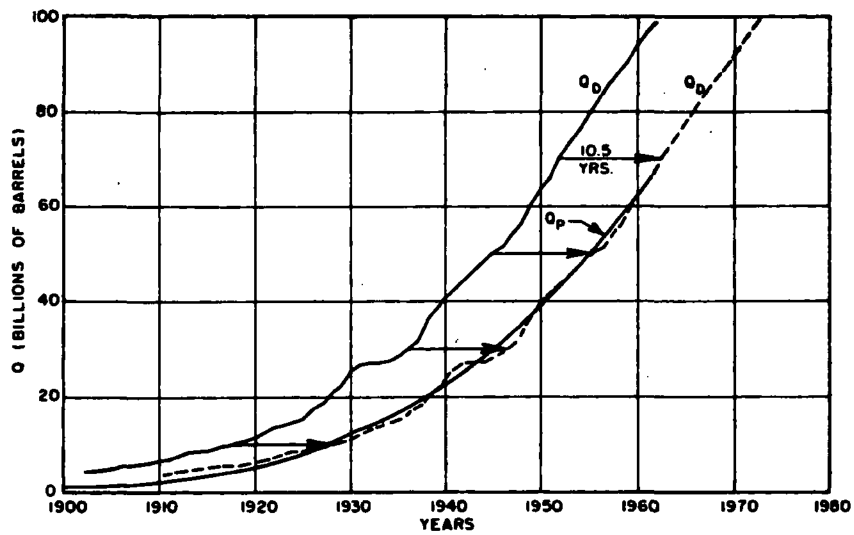

Figure 26. Time Lag Between Cumulative Proved Discoveries and Cumulative Production of U. S. Crude Oil

The best values of the parameters for the Q_D data can be determined by converting equation (8) to a linear form. By transposition

$$\frac{Q_\infty}{Q_D} - 1 = ae^{-bt}.$$

Then, by taking the logarithms of both sides, we obtain

$$\log [(Q_\infty/Q_D) - 1] = \log a - bt \log e, \qquad (9)$$

which is a linear equation between $\log [(Q_\infty/Q_D) - 1]$ and t.

The quantity $[Q_\infty/Q_D - 1]$ is then plotted as a function of time on semilogarithmic paper, using an assumed value of Q_∞. If the correct value is used for Q_∞, and if the data otherwise satisfy equation (8), the curve will be a straight line. By repeating this procedure, using several different values for Q_∞, it is possible to find the best value for this quantity. Then the other two parameters a and b can be obtained from the linear graph.

As determined in this manner, the increase of cumulative discoveries Q_D with time has been found to be approximated very closely by the equation

$$Q_D = \frac{170 \times 10^9 \text{ barrels}}{1 + 46.8\, e^{-0.0687 (t - 1900)}}; \qquad (10)$$

and cumulative production Q_P by

$$Q_P = \frac{170 \times 10^9 \text{ barrels}}{1 + 46.8\, e^{-0.0687 (t - 1910.5)}}. \qquad (11)$$

Analytically, the curve for Q_R is given by the difference between equations (10) and (11).

The results of these calculations and the closeness of the fit between the actual data for Q_D, Q_P and Q_R (shown in solid curves) and the computed curves (shown dashed) are presented graphically in Figure 27.

The discovery curve has plainly passed its inflection point at about 85 billion barrels, and this should be about the halfway point. This agrees with the asymptote of $Q_\infty = 170 \times 10^9$ barrels as given by the curves.

The significance of the cumulative production curve needs no particular discussion. It will simply level off to the maximum $\underline{Q}_{\infty}$ when production is finished. The discovery curve $\underline{Q}_D$, however, merits further attention, because this curve is the embodiment of the results of all the improvements which have been made

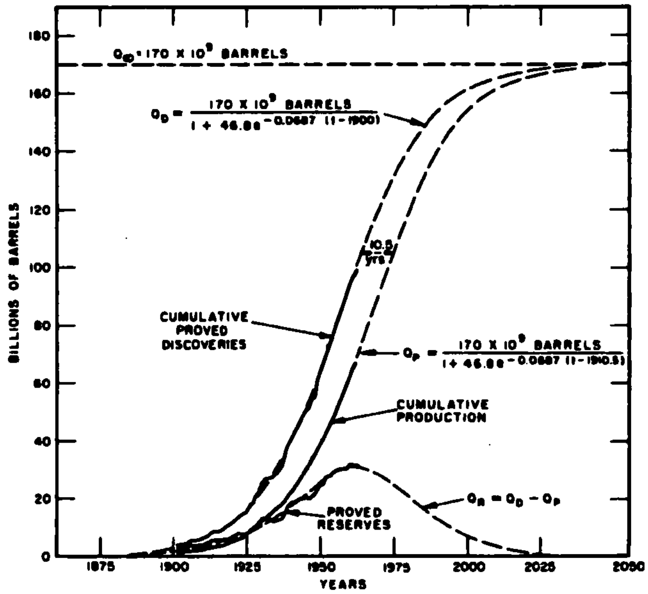

Figure 27. Cumulative Proved Discoveries and Production and Proved Reserves of U. S. Crude Oil

in discovery techniques, in drilling techniques, in recovery techniques, and all the oil added by geographical extensions within the United States and its offshore areas, since the beginning of the industry.

We thus do not have to worry about how much oil may be contained in known oil fields over and above the A. P. I. estimates of proved reserves, or how much improvement may be effected in the future in both exploration and productive techniques, for these will all be added in the future, as they have been in the past, by revisions and extensions in addition to new discoveries. And there is as yet no evidence of an impending departure in the future from the orderly progression which has characterized the evolution of the petroleum industry during the last hundred years.

In Figure 28 is shown the actual year-by-year plotting of the rates of discovery and of crude-oil production in the United States since 1900, on which have been superposed the analytically determined rates from equations (10) and (11). The rate of discovery, as is to be expected, oscillates rather widely from year to year, yet the data plainly indicate that the peak of the discovery rate occurred in the early or middle 1950's. The analytical-derivative

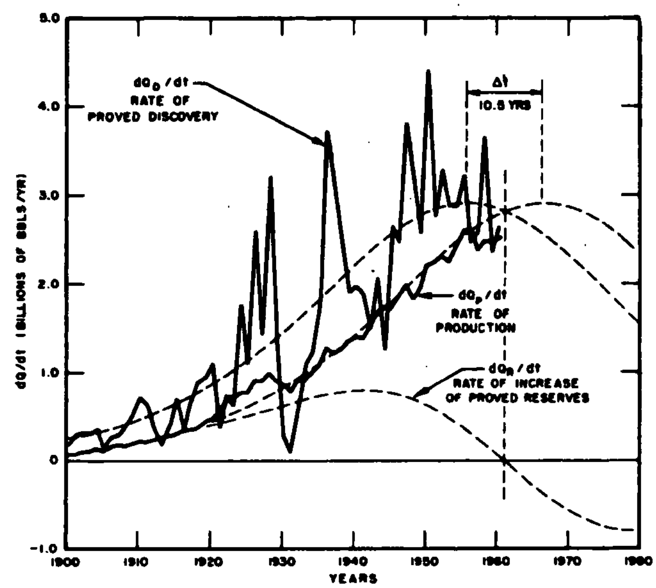

Figure 28. Rates of Discovery, Production and Increase of Proved Reserves of U. S. Crude Oil

curve places the date of this peak at 1956 and that for the production rate at about 1966-67. The analytical derivative of the curve of proved reserves crosses the zero point from increasing to decreasing reserves at about 1961-62, which should be the date of the peak of the proved reserves.

The rate of increase of proved reserves is shown in detail in Figure 29. Here, superposed on the actual data is the rate curve (shown dashed) as determined analytically. Here again, although the reserve additions oscillate widely from year to year, it will be seen that the analytical curve follows faithfully the trend of the actual data.

A composite view on a longer time scale of the rates of discovery and production and the increase of proved reserves is given

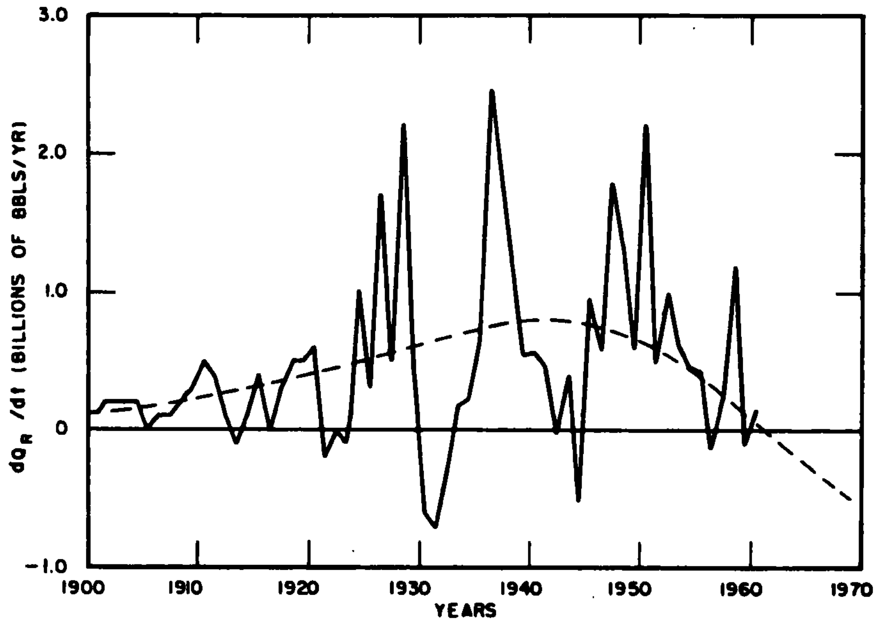

Figure 29. Rate of Increase of Proved Reserves of U.S. Crude Oil

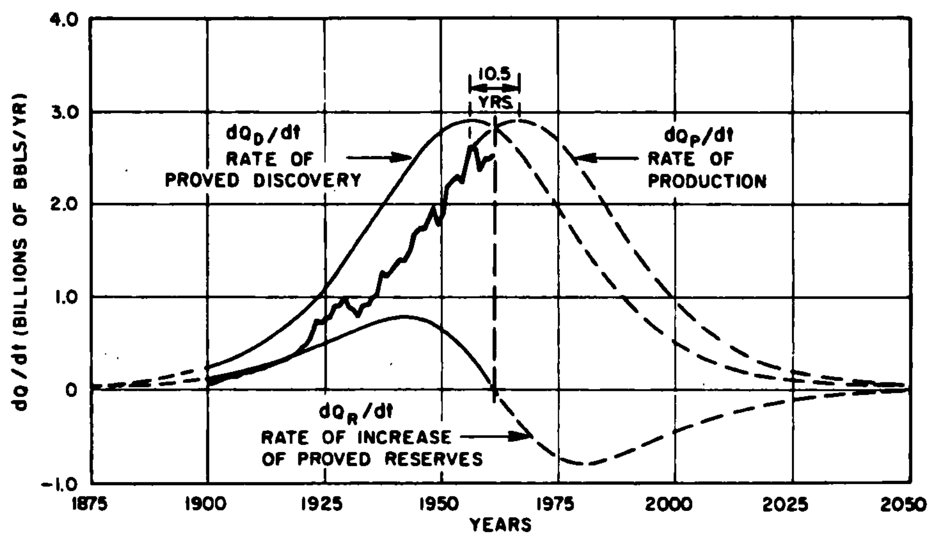

Figure 30. Rates of Discovery, Production and Increase of Proved Reserves of U.S. Crude Oil

in Figure 30. From the evolution which has occurred up to now it is difficult to escape the conclusion that the petroleum industry in the United States is somewhere near the halfway point in its exploration for and production of crude oil. By the end of 1961 the cumulative production of crude oil had reached 67. 37 billion barrels, and proved reserves were estimated at 31.76 billion barrels, from which the cumulative proved discoveries amounted to 99. 1 billion barrels.

However, the peak rate of discovery occurred about 6 to 7 years previously, at about 1956; proved reserves appear to be very nearly at their maximum in 1962; and the peak of production is expected to occur by about 1967 or earlier. Unless the evolution of the industry departs radically in the future from the orderly progression it has followed for the last hundred years, the most probable estimate that can now be derived from past experience for the ultimate cumulative production of crude oil is about 170 billion barrels.

With regard to the date of the peak of crude-oil production, mention should be made of a minor qualifying circumstance. Due in large measure to petroleum imports, which have been building up since World War II and now amount to approximately 20 per cent of domestic production, the present rate of production is somewhat less than full capacity. According to a recent report of the National Petroleum Council (1961, Table IV), the total crude-oil production capacity of the United States, excluding Elk Hills shut-in capacity, was 10.422 million barrels per day, or 3.8 billion barrels per year, in 1960. This figure for capacity assumes that all wells are operating at capacity, independently of whether pipelines and storage facilities could handle the production at this rate. Actual production for the year 1960 was 2.47 billion barrels.

This discrepancy between the actual rate of production and a hypothetical maximum productive capacity, therefore, allows some latitude in the exact year at which the peak of production could occur. Conceivably, if, for some reason comparable to the Suez Crisis, the production were to be at the maximum capacity for some given year, then in whatever year this may have occurred between 1962 and possibly 1975 the peak of production could occur. This possibility, however, is largely irrelevant with respect to the present analysis, in which only long-term secular changes, rather than the fluctuations which occur from year to year, are the subject of concern.

The real significance of the curtailment of U. S. production is that it conserves the domestic reserves of crude oil and thus tends to postpone the date of the production decline due to diminishing reserves of oil. Had there been no imports and had the domestic industry been operating at capacity ever since World War II, the oil that has been imported would have had to be replaced by oil from domestic reserves. This would have advanced the peak date of production with respect to that which is now anticipated.

Verification by Means of Data on Large and Small Fields

An independent check on whether Q_∞, the ultimate cumulative production of crude oil in the United States, is of the order of 170 billion barrels is afforded by a study of the large and small fields separately. Since 1943 the Oil and Gas Journal, in its Review-Forecast number which is issued annually about the last week in January, has been publishing statistics on the oil fields in the United States in which the large or so-called "giant" fields have been segregated for special attention. These are defined as those fields whose ultimate production is estimated to exceed 100 million barrels. All other fields are classed as small fields.

In the January 29, 1962 issue of this Journal, on page 135, the following data are given for all the oil fields in the United States:

Number of giant fields	240
Estimated ultimate production:	
All fields	103.26×10^9 barrels
Giant fields	59.22×10^9 barrels
Percent by giant fields	57.4

From this information, the average size of the large fields is found to be 0.247×10^9 barrels.

The number of small fields was not given, but a few years ago an independent estimate was made of the cumulative number of such fields which had been discovered by the end of 1957. This was about 12,000, and about 3,000 more have been discovered subsequently, giving a total by the end of 1961 of about 15,000

A table on the discovery rate of all fields up to 1959 is given by B. W. Blanpied (1959, p. 1130-1131). Of these, all but an insignificant fraction are small fields. These two results, the cumulative number of small fields discovered, and the number discovered per year, are shown graphically in Figure 31. The same data with longer time scale are shown in Figure 32. The peak in the discovery rate occurred in 1955, when the total number of smal' fields was 10,000. Assuming that this peak represents about the halfway point in small-field discovery, then the ultimate number of small fields is estimated to be about 20,000.

The ultimate liquid hydrocarbons credited by the Oil and Gas Journal to the then discovered small fields by the end of 1955 was 36.5 billion barrels (Oil and Gas Journal, January 30, 1956, p. 179), of which the crude-oil content would be about 85 per cent, or 31.0 x 10^9 billion barrels. Then assuming that this represents about half the ultimate for all the small fields we obtain an estimate of 62.0 billion barrels of crude oil as the ultimate production of all the small fields including those still to be discovered.

A corresponding ultimate figure for the large fields could be obtained if we could estimate how many big fields are likely ultimately to be discovered. This should be a particularly significant figure since, despite their small number, the large fields account for nearly 60 per cent of all the oil so far discovered in the United States. The ultimate number of large fields, $\underline{N}_{\infty}$, which can hardly be larger than a few hundred, is the quantity we now seek to determine.

The obvious way to do this is simply to enumerate the fields, giving them the serial numbers 1 to 240 in the order of their dates of discovery, and then plot the curve of the number $\underline{N}$ as a function of the dates of discovery, to see whether evidence of the approach to an ultimate number $\underline{N}_{\infty}$ can be detected. This has been done in Figure 33, and the curve for the fields listed in the January 1962 issue appears to be approaching an ultimate number of about 250.

That this is a false conclusion can be seen by the curve of analogous data as of December 31, 1951, also shown in Figure 33. This curve appears to have an asymptote, or limiting value, at a number of about 175 fields. Thus, it will be noted that these curves increase not only longitudinally as ordinary growth curves do, but they also skid sidewise.

While this may be unexpected, the reason for it is simple. For an ordinary growth curve, such as that of cumulative production, the data for each successive year are added to the curve

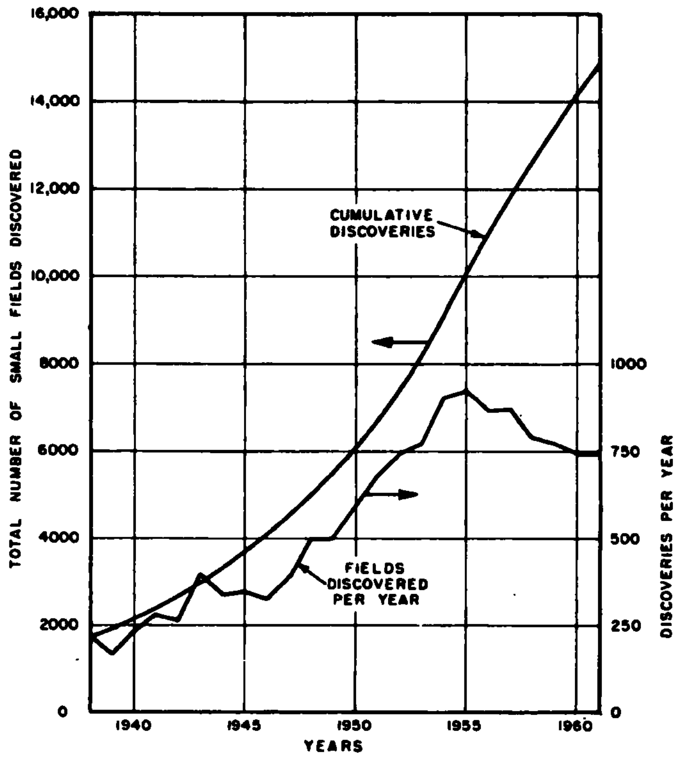

Figure 31. Cumulative Discoveries and Rate of Discovery of U. S. Small Fields, 1938-1961

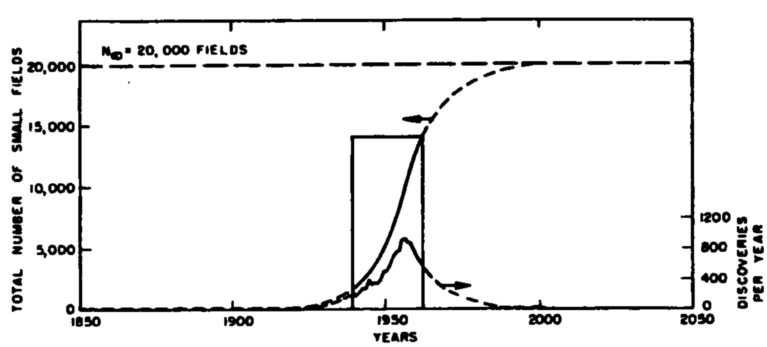

Figure 32. Long-Time Outlook for Discovery of Small Oil Fields in the U. S.

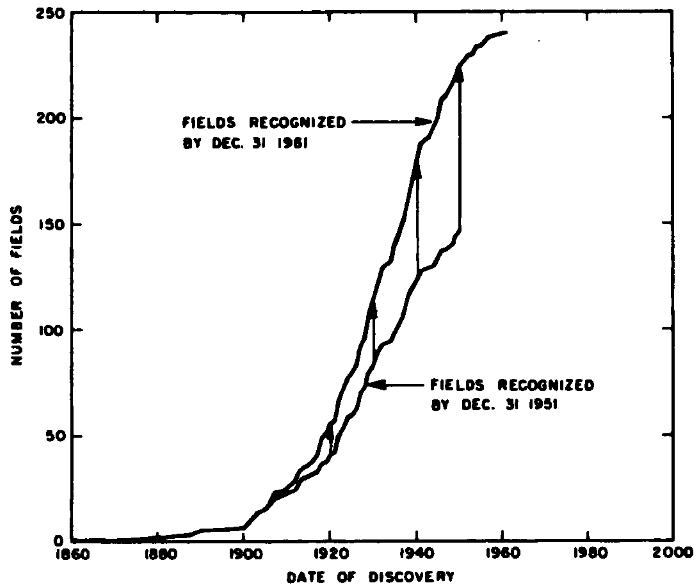

Figure 33. Large U.S. Oil Fields Recognized by December 31, 1951 and December 31, 1961

only at its extremity. For the large fields, however, each field has two separate dates, a date of discovery (when the field is classified as small) and a date of recognition as a large field. In other words every field which ultimately becomes a large field must go through an embryo, or incubation, stage as a small field before it ultimately hatches out as a large field. The first date is the date of discovery; the second is the date of recognition as a large field.

The fallacy involved in plotting the fields by dates of discovery lies in the fact that they cannot be plotted until after recognition, which may be years or decades after discovery. Thus, when a field discovered in 1945 is not recognized as a big field until 1961, then inserting it into the curve at 1945 displaces the whole curve up by 1 point from 1945 onward. The repetition of this process for each field added produces the behavior shown in Figure 33.

However, if the fields are plotted by dates of recognition only, as is shown in Figure 34, the curve behaves as any growth-curve should. The false asymptote is missing and the curve has the appearance of being about halfway to its true asymptote. The logistic equation for this curve is

$$N = \frac{460 \text{ fields}}{1 + 110\, e^{-0.078\,(t - 1900)}} \quad (12)$$

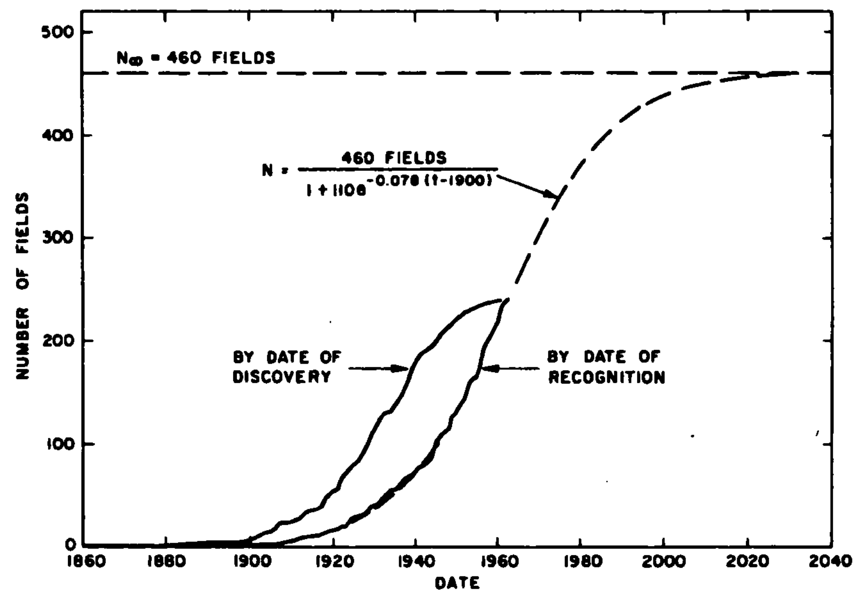

Figure 34. Large U.S. Oil Fields Plotted by Date of Discovery and by Date of Recognition

We may, accordingly, either limit our analysis to the curve of the number of large fields plotted by their dates of recognition, or we may attempt, in addition, to estimate the limiting position of the curve plotted by dates of discovery after all the large fields have been discovered and recognized.

This can be done approximately by investigating the statistical nature of the time delay, τ, defined as

$$\tau = t_r - t_d \quad (13)$$

where t_r is the time of recognition and t_d the time of discovery of a given large field. A curve of the number of fields plotted cumulatively against increase time-delay τ for a sample of 186 fields, excluding fields discovered after 1940, is shown in Figure 35. It is clearly seen that the cumulative number of fields as a function of τ is represented very closely by the equation

$$n = n_{\infty}(1 - e^{-0.046\,\tau}), \quad (14)$$

where $\underline{n}_\infty$ is the asymptotic number for the sample. Expressing the number of fields as a fraction of this asymptotic number we have

$$\frac{n}{n_\infty} = \frac{n}{206} = (1 - e^{-0.046\tau}), \qquad (15)$$

which is shown graphically in Figure 36. From this it will be seen that about half the large fields have time delays between discovery and recognition of more than 15 years.

The advantage of this time-delay curve is that it permits us to apply a correction to the number of fields discovered in any given year that have been recognized by some definite later date. For example, suppose that by December 1961 $\Delta \underline{N}$ fields discovered in 1946 have been recognized. As the time delay from 1946 to 1961 is 15 years, then according to Figure 36 only about half the fields discovered in 1946 should have been recognized by 1961. We therefore estimate that of all the large fields discovered in 1946 which will ultimately be recognized as large fields, only about half were recognized by 1961. We accordingly apply the correction

$$\Delta N' = 2\Delta N.$$

An analogous procedure is followed for each year prior to 1961 with τ equal successively to 1, 2, 3, ... $\underline{n}$ years. The $\Delta \underline{N}'$ are then integrated into a new curve which should represent, approximately, the cumulative number of large fields ultimately to be recognized, plotted by dates of discovery.

The results of such a computation applied to the data of December 31, 1961, are shown in Figure 37. The lower solid-line curve shows the fields already recognized by dates of discovery, and the upper solid-line curve shows the fields probably already discovered by the end of 1961 which will ultimately be recognized as large fields. The difference between the two curves represents the embryo large fields probably already discovered, but not yet recognized.

The logistic equation for the revised number of fields by dates of discovery shown in Figure 37 is

$$N = \frac{460 \text{ fields}}{1 + 5.0\, e^{-0.0856\,(t - 1920)}} . \qquad (16)$$

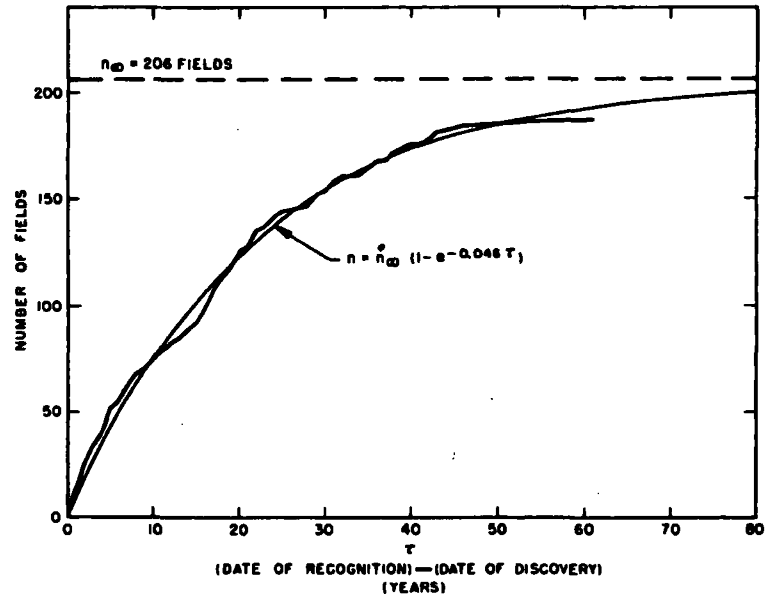

Figure 35. Time Lag Between Discovery and Recognition of U.S. Large Fields (Fields Discovered Since 1940 Excluded)

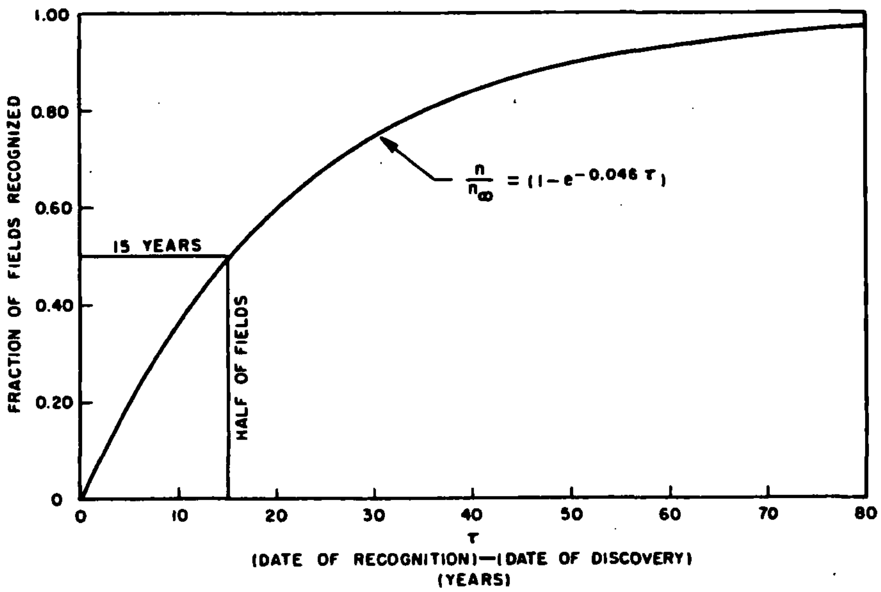

Figure 36. Fraction of U.S. Large Fields Recognized Within Time-Delay τ After Discovery

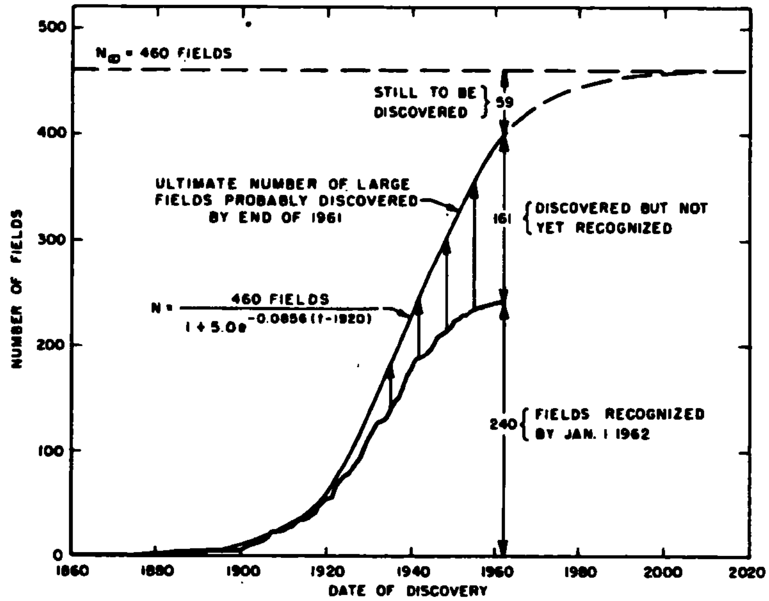

Figure 37. Cumulative Discoveries of Recognized and Probable U. S. Large Fields

It therefore appears from the data on both the number of large fields plotted by date of recognition, and the revised curve on the probable fields by date of discovery, that the ultimate number of large fields is about 460. Of these, as it will be seen from Figure 37, about 401 have probably already been discovered, leaving about 59 still to be discovered. Of the 401 fields already discovered 240 have already been recognized by the end of 1961, and about 161 are in the incubation stage as small fields which with further development will eventually become large fields.

Average Size of Large Fields

It has already been pointed out that according to the estimate of the Oil and Gas Journal the average size of the 240 large fields of December 31, 1961, is 0.247×10^9 barrels, or about one-quarter of a billion barrels.

Figure 38 shows the average size of successive groups of 25 large fields each in the order of discovery. This indicates that there is little ground to expect the average size of the large fields in the future to be very different from that of the past. Assuming,

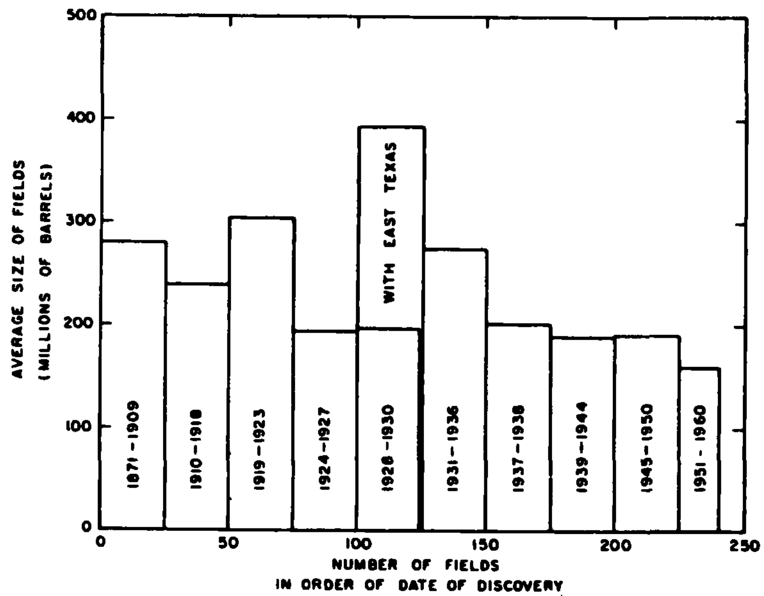

Figure 38. Average Size of Large Fields in the U. S. in Order of Dates of Discovery

then, a constant average size, the ultimate amount of crude oil expectable from 460 large fields should be about 113×10^9 barrels.

If we now add the 62×10^9 barrels for the small fields to the 113×10^9 barrels for the large fields, we obtain an estimate for the total ultimate production of crude oil in the United States of 175×10^9, or 175 billion, barrels.

The method of estimation based on the use of the Oil and Gas Journal data for the large and small fields is not considered to have as high a reliability as that using the growth curves. It is nevertheless considered to be valid as to order of magnitude, and to this extent it corroborates the estimate of 170 billion barrels obtained previously. As a contingency, however, we shall adapt the higher figure of 175 billion barrels as representing our present estimate of the ultimate potential reserve of crude oil in the United States. Of this, 67 billion barrels have already been produced, and 99 billion barrels (including that already produced) have already been discovered, leaving about 76 billion barrels still to be discovered.

If a contingency allowance were to be made of how much the actual figure of $\underline{Q}_\infty$ might exceed the present estimate of 175 billion barrels, a figure higher than an additional 50 billion would be hard to justify.

Should the future of 175 billion barrels be approximately correct, the future crude-oil production of the United States would have to follow a curve closely resembling that shown in Figure 39.

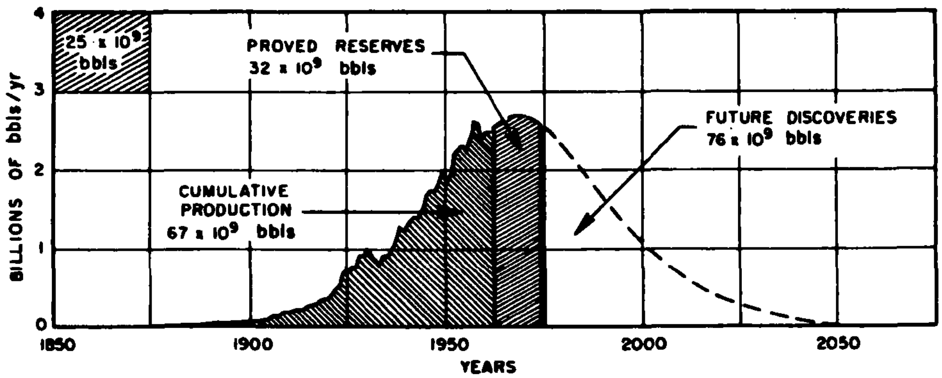

Figure 39. Estimate of Ultimate U. S. Production of Crude Oil

In this figure one grid rectangle represents 25 billion barrels of oil. The total area under the curve from start to finish could, therefore, comprise only 7 rectangles, and the culmination in the rate of production should occur in the late 1960's. If the figure of 225 billion barrels (including the 50 billion-barrel contingency allowance) should be more nearly correct, then the curve would encompass an area of 9 grid rectangles and the culmination would occur in the early 1970's.

Ultimate Potential Crude-Oil Reserves of the World

Using the United States estimate as a yardstick, we may now give an approximate estimate of the ultimate potential crude-oil reserves of the world. This is shown for the major geographical and political subdivisions of the world in Table 6. This is obtained by using Weeks' (1948) estimate as a base and then applying modifications which subsequent developments indicate to be necessary. The same data are shown graphically in Figure 40. The total world estimate comes to 1,250 billion barrels, of which 850 is for land areas and 400 is allowed for the offshore areas.

Of particular interest is the preponderance of the reserves of the Middle East and North Africa (300 billion barrels) over

TABLE 6

Estimated Ultimate World Crude-Oil Production

Area	Ultimate Recovery (× 10^9 bbls)	Percent of World Total
United States (including offshore)	175	14.0
Remainder of North America	45	3.6
South America	80	6.4
Europe (excluding U.S.S.R.)	13	1.1
U.S.S.R.	200	16.0
Middle East and North Africa	300	24.0
Indonesia	30	2.4
Australia	3	0.2
Remainder of Asia	24	1.9
Offshore areas (excluding U.S.)	380	30.4
World Total	1,250	100.0

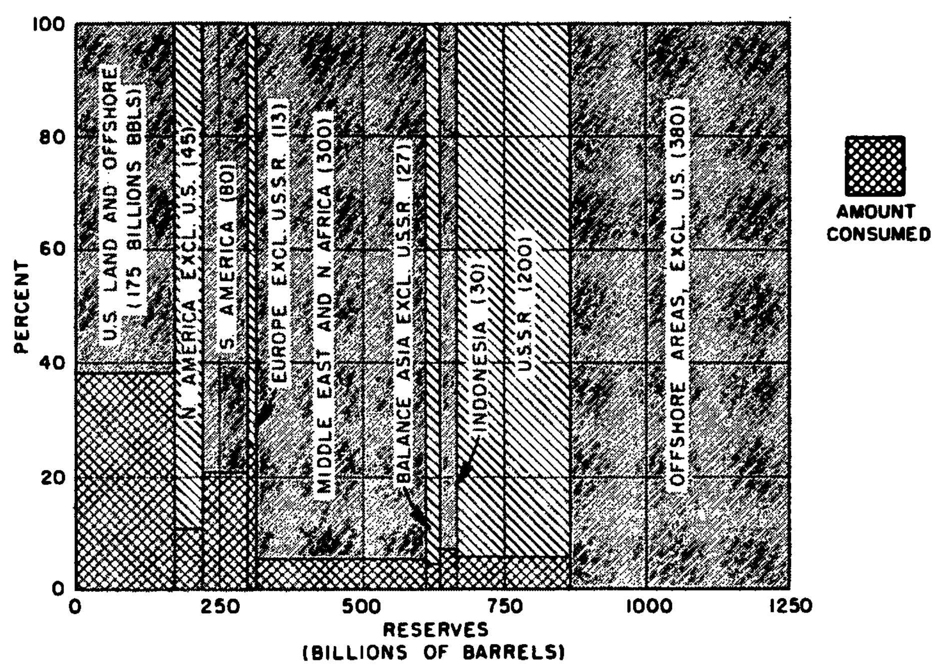

Figure 40. World Ultimate Potential Petroleum Reserves

those of any other geographical region of comparable area. Also, it is to be noted that because the United States was the world's largest producer of crude oil for nearly a century, it is also the farthest advanced toward ultimate depletion of any of the major oil-producing areas.

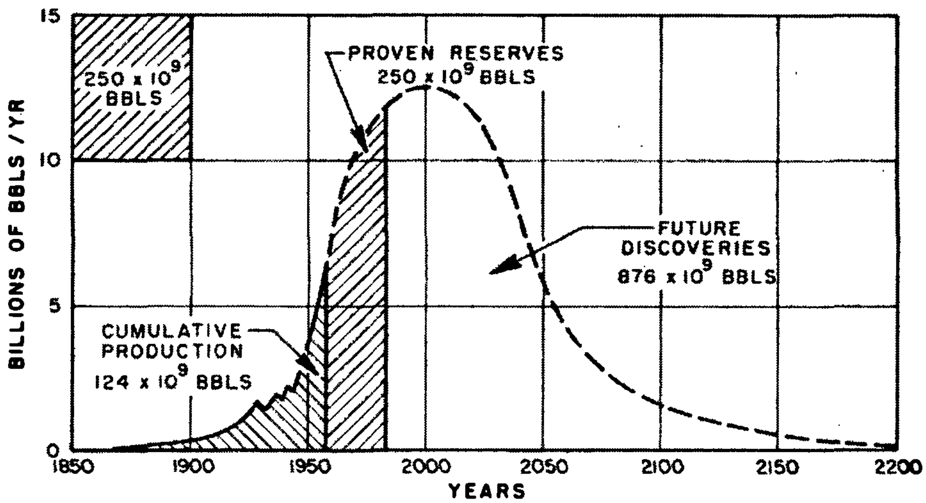

Figure 41. Ultimate World Production of Crude Oil

A curve of the ultimate world production is shown in Figure 41. Using 1,250 billion barrels as the ultimate potential reserve, and assuming a peak rate of production of 12.5 billion barrels per year—about twice the present production rate—the culmination of world production should occur about the year 2000 A. D.

United States Production and Ultimate Reserves of Natural Gas

The production rate of marketed natural gas in the United States has already been shown in Figure 13. Because pipelines for long-distance transmission of natural gas have only become available since World War II, the consumption of gas in the United States has reached a relatively less advanced state toward ultimate depletion than crude oil. It is, accordingly, not yet possible to estimate the ultimate asymptote of the curves of cumulative production and cumulative proved discoveries for natural gas, as was done for crude oil.

The next best procedure is to make use of the fact that natural gas and crude oil are genetically related, and then to base the estimate of the ultimate amount of natural gas on that of the ultimate amount of crude oil, using the observed ratio of gas to oil. It follows that the estimates of the ultimate potential reserves of gas obtained in this manner will vary, percentagewise, about as widely as the estimates of the reserves of crude oil. This is

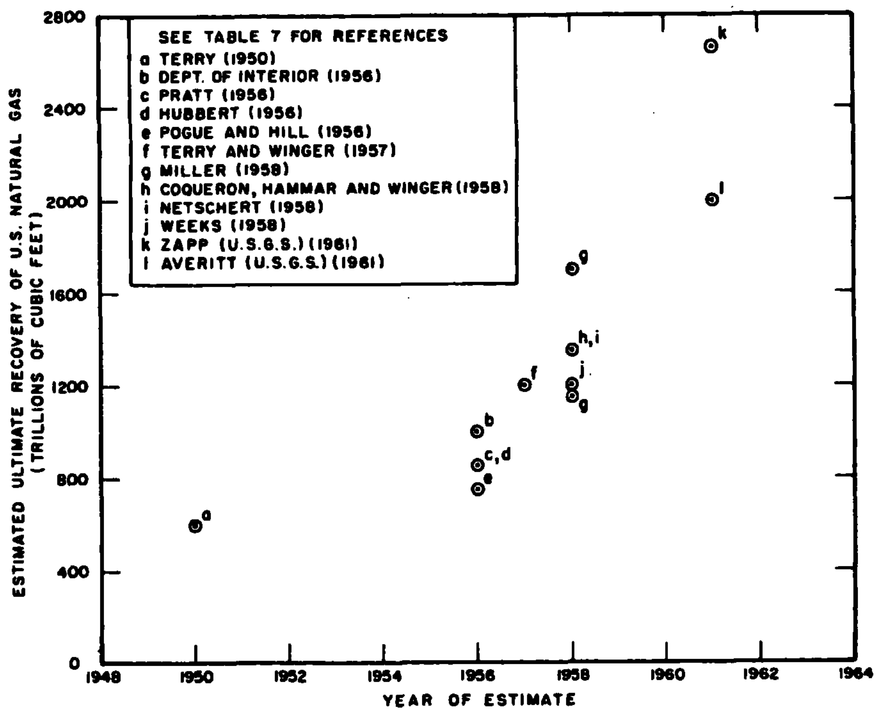

Figure 42. Estimates of Ultimate Recovery of U. S. Natural Gas

borne out by Figure 42 in which the principal published estimates since 1950 are presented. These estimates range from a low value of 600 trillion cubic feet by Terry (1950) to a high value of 2,650 trillion cubic feet by Zapp (1961) of the United States Geological Survey.

The remarks made earlier with regard to published estimates of the ultimate reserves of crude oil apply equally to those for natural gas. Regardless of what the correct value for the ultimate gas reserves may be, most of the published estimates are seriously erroneous.

TABLE 7

Estimated Ultimate U. S. Natural-Gas Reserves

	Date	Author	Estimate (Barrels)
a	1950	Terry	600×10^{12}
b	1956	Dept. of Interior	$1{,}000 \times 10^{12}$
c	1956	Pratt	850×10^{12}
d	1956	Hubbert	850×10^{12}
e	1956	Pogue and Hill	750×10^{12}
f	1957	Terry and Winger	$1{,}200 \times 10^{12}$
g	1958	Miller	$1{,}150 \times 10^{12}$ $-1{,}700 \times 10^{12}$
h	1958	Coqueron, Hammar and Winger	$1{,}350 \times 10^{12}$
i	1958	Netschert	$1{,}350 \times 10^{12}$
j	1958	Weeks	$1{,}200 \times 10^{12}$
k	1961	Zapp (U.S.G.S.)	$2{,}650 \times 10^{12}$
l	1961	Averitt (U.S.G.S.)	$2{,}004 \times 10^{12}$

a Terry, Lyon F., 1950, The Future Supply of Natural Gas Will Exceed 500 Trillion Cu. Ft.: Gas Age, October 26, p. 98.

b Interior, Dept. of, 1956, Impact of the Peaceful Uses of Atomic Energy on the Coal, Oil- and Natural-Gas Industries: Background Material for the Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy, v. 2, January, p. 83.

c Pratt, Wallace E., 1956, The Impact of the Peaceful Uses of Atomic Energy on the Petroleum Industry: Background Material for the Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy, v. 2, January, p. 94.

d Hubbert, M. King, 1956, Nuclear Energy and the Fossil Fuels: Drilling and Production Practice, Am. Petroleum Inst., p. 18.

e Pogue, Joseph E., and Hill, Kenneth E., 1956, Future Growth and Financial Requirements of the World Petroleum Industry: New York, The Chase Manhattan Bank, Petroleum Dept., p. 26.

f Terry, Lyon F., and Winger, John G., 1957, Sees 1,200 Trillion Cu. Ft. U. S. Recoverable Gas: Am. Gas Assoc. Monthly, July-August, p. 12.

g Miller, Ralph L., 1958, A New Look at Ultimate Natural Gas Reserves: World Oil, v. 147, October, p. 222.

h Coqueron, Frederick G., Hammar, Harold D., and Winger, John G., 1958, Future Growth of the World Petroleum Industry: New York, The Chase Manhattan Bank, Petroleum Dept., p. 34.

i Netschert, Bruce C., 1958, The Future Supply of Oil and Gas: Baltimore, Resources for the Future, Inc., Johns Hopkins Press, p. 93.

j Weeks, L. G., 1958, Fuel Reserves of the Future: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 436.

k Zapp, A. D., 1961, World Petroleum Resources, Table 1 <u>in</u> Domestic and World Resources of Fossil Fuels, Radioactive Minerals, and Geothermal Energy: Preliminary Reports Prepared by Members of the U. S. Geological Survey for the Natural Resources Subcommittee of the Federal Science Council.

l Averitt, Paul, 1961, Coal Reserves of the United States—A Progress Report January 1, 1960: U. S. Geol. Survey Bull. 1136, p. 101.

For our own estimate we shall take our figure of 175 billion barrels of crude oil as a base, and then apply the ratios of gas to oil obtained from petroleum-industry experience. One aspect of this experience is shown in Figure 43. Here a graph is shown of the ratio of cumulative proved discoveries of natural gas to the

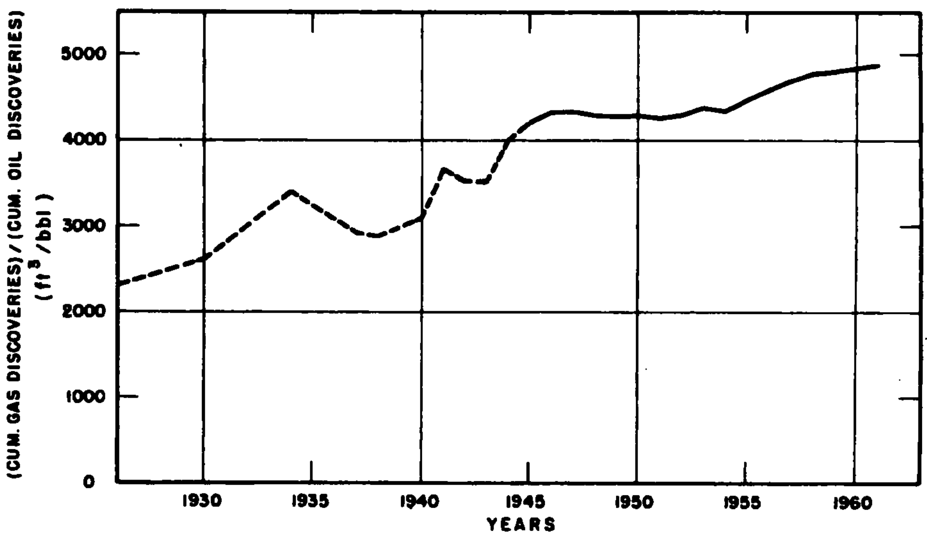

Figure 43. Gas-Oil Ratios for U. S. Based on Cumulative Discoveries of Oil and Gas

cumulative discoveries of crude oil in the United States for each year from 1925 to 1961. It will be seen that the gas-oil ratio gradually increased during this period from about 2,200 ft^3/bbl in 1925 to about 4,900 in 1961. Although this ratio is still increasing, it is probably too low, because of the large volumes of gas dissipated without any record during the history of the petroleum industry prior to World War II. A more reliable ratio should, therefore, be obtained from the gas and oil discovered during recent decades. In Figure 44 is shown a five-year running average of the ratio of the gas discovered per year to the oil discovered per year for each year from 1941 to 1961. The curve fluctuates between a low value of 4,000 ft^3/bbl and a high value of 10,000 ft^3/bbl, but without any pronounced secular trend. The average value for the 20-year period is 6,250 ft^3/bbl.

The figure of 6,250 ft^3/bbl represents the average gas-oil ratio for very large samples of gas and oil taken near the mid-range of the industry's history at a time when particular stress has been placed on exploration for gas. It does not appear likely, therefore, that this ratio will increase by a great deal in

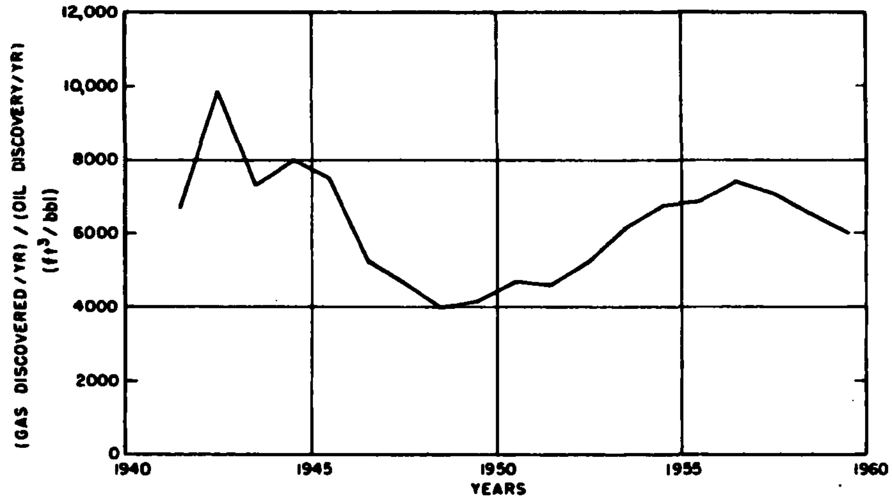

Figure 44. Gas-Oil Ratios for U.S. Based on Annual Discoveries (5-Year Running Average)

the future. However, as a contingency, let us assume that the ratio of gas to oil for future discoveries may be as high as 7,500 ft^3/bbl.

These two gas-oil ratios, a low of 6,250 ft^3/bbl and a high of 7,500 ft^3/bbl, will accordingly be used for a low and a high estimate of the ultimate reserves of natural gas in the United States.

Using these two ratios, and the estimate of the ultimate crude-oil production of 175 x 10^9 barrels, we obtain the corresponding estimates of the ultimate reserves of natural gas in the following manner:

Estimated ultimate production of crude oil	175.0×10^9 bbls
Cumulative discoveries of crude oil to 12-31-61	-99.1×10^9 bbls
Undiscovered reserves of crude oil, 12-31-61	75.9×10^9 bbls

Ultimate Reserves of Natural Gas

	Minimum Estimate	Maximum Estimate
Undiscovered crude oil	75.9×10^9 bbls	75.9×10^9 bbls
Gas-oil ratio	x 6,250 ft^3/bbl	x 7,500 ft^3/bbl
Undiscovered nat. gas	474×10^{12} ft^3	569×10^{12} ft^3
Cum. disc. nat. gas	$+ 484 \times 10^{12}$ ft^3	$+ 484 \times 10^{12}$ ft^3
Ultimate potential reserves nat. gas	958×10^{12} ft^3	$1,053 \times 10^{12}$ ft^3
Average	$\approx$ $1,000 \times 10^{12}$ ft^3	

We accordingly adapt the round figure of $1,000 \times 10^{12}$ ft^3, which is very nearly the arithmetical mean between our low and high estimates, as our present best estimate of the ultimate reserves of natural gas in the United States.

Using the asymptote of $1,000 \times 10^{12}$ ft^3 for the curves of cumulative proved discoveries and cumulative production of natural gas, we are then able to evaluate the logistic equations for these curves. The curve of cumulative production is obtained for the period from 1859 to 1917 from that of crude oil by assuming the production of 2,000 ft^3 of gas per barrel of oil. From 1917 to 1961 actual gas-production statistics are used (Dept. of Commerce, 1949, p. 146; 1954, p. 20; 1953-1961). Estimates of proved reserves of natural gas have been made annually by the Reserves Committee of the American Gas Association since 1945 (American Gas Association, 1945-1961). The addition of cumulative production and proved reserves from 1945 to 1961 then gives that portion of the curve of cumulative proved discoveries.

The logistic equations for cumulative discoveries and cumulative production, respectively, are then found to be

$$Q_D = \frac{1,000 \times 10^{12} \text{ ft}^3}{1 + 465 \, e^{-0.0793 (t - 1884)}}, \tag{17}$$

and

$$Q_P = \frac{1,000 \times 10^{12} \text{ ft}^3}{1 + 465 \, e^{-0.0793 (t - 1900)}}. \tag{18}$$

As heretofore, the equation for the proved reserves $\underline{Q_R}$ is the difference between those for $\underline{Q_D}$ and $\underline{Q_P}$.

This family of curves is shown in Figure 45. It will be noted that in this case the time lag $\underline{\Delta t}$ between the curve of cumulative discoveries and cumulative production is about 16 years as compared with the 10-11-year lag for crude oil. This is due principally to the fact that a large backlog of proved reserves of natural gas was being accumulated before the present large pipelines for gas distribution were put into operation.

The time derivatives of the family of curves in Figure 45 are shown in Figure 46. These represent, respectively, the rate

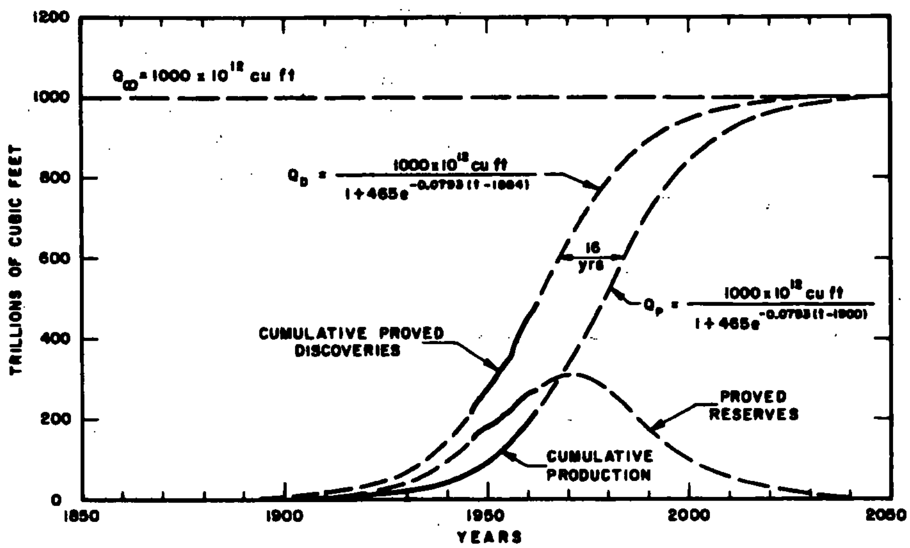

Figure 45. Cumulative Discovery and Production and Proved Reserves of U. S. Natural Gas

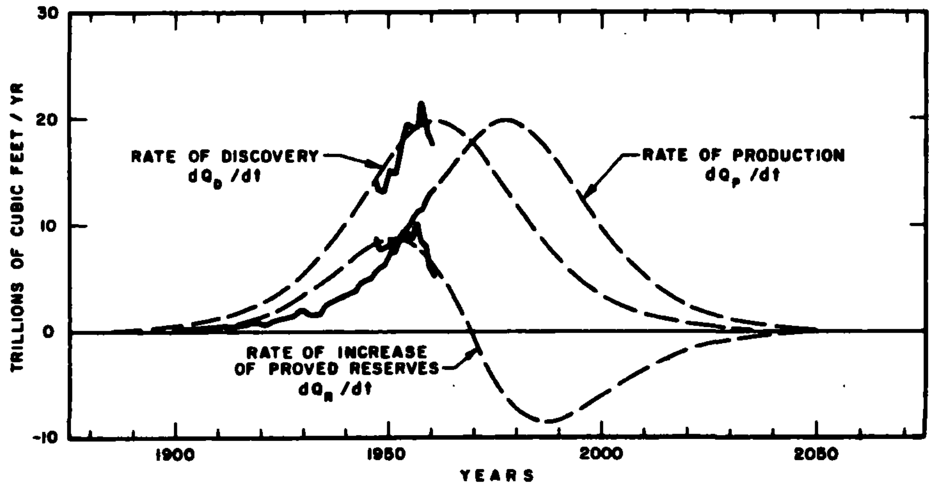

Figure 46. Rates of Discovery, Production and Increase of Proved Reserves of U. S. Natural Gas

of discovery, the rate of production, and the rate of increase of proved reserves. The date of the peak in the rate of discovery of natural gas should be about when the curve of cumulated proved discoveries reaches one-half the ultimate, Q_∞, or about 500 x x 10^{12} ft^3. To the end of 1961 cumulated proved discoveries amounted to 484 x 10^{12} ft^3, and the rate of discovery during recent years has been about 18 x 10^{12} ft^3/yr. Accordingly, the halfway point, or the inflection point of the curve, should be reached by about the end of 1962. This should also be about the date of the peak of natural-gas discoveries. The peak in production should occur about 16 years later, or about 1978, and the peak of proved reserves near the mid-point between these two dates, or about 1970.

Figure 47 shows the future production of natural gas as derived from the data of Figures 45 and 46, for both the low and the high estimates of ultimate reserves.

United States Production and Ultimate Reserves of Natural-Gas Liquids

The annual production of natural-gas liquids in the United States is shown graphically in Figure 48 (American Petroleum Institute, 1959, p. 80-81; American Gas Association, 1959-1962).

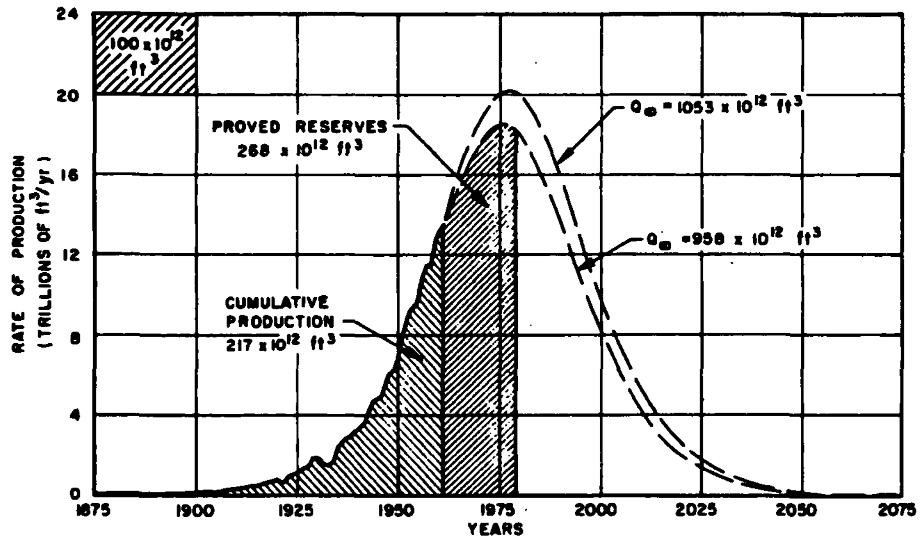

Figure 47. U. S. Production of Natural Gas for High and Low Estimates of Ultimate Reserves

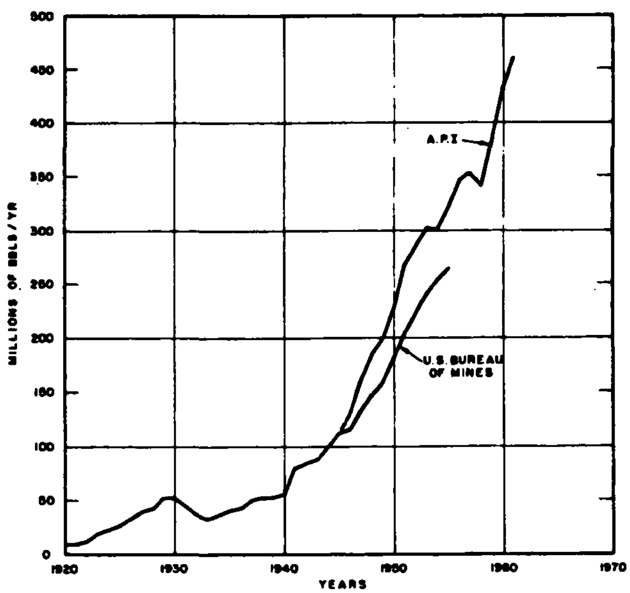

Figure 48. Rate of Production of U. S. Natural-Gas Liquids

Because natural-gas liquids are a by-product of the production of natural gas, an estimate of the ultimate potential reserves of natural-gas liquids may be made very simply from the estimate of the ultimate reserves of natural gas, and the ratio of natural gas to natural-gas liquids in past production experience.

From the statistics of the American Gas Association on production rates and proved reserves of both natural gas and natural-gas liquids (American Gas Association, 1948-1962), the cumulative proved discoveries of natural gas during the period 1947 to 1961, inclusive, increased by 250.2×10^{12} ft^3. During the same period the increase of the cumulative proved discoveries of natural-gas liquids increased by 8.45×10^9 bbls. The ratio of the gas to the natural-gas liquids discovered during this period amounts to 29.6×10^3 ft^3/bbl. If we assume that this ratio will remain approximately unchanged for the undiscovered gas reserves we can use it to estimate the undiscovered natural-gas liquids.

By December 31, 1961, the cumulative proved discoveries of natural gas amounted to 484×10^{12} ft^3. Subtracting this from the estimated ultimate natural-gas reserves of $1,000 \times 10^{12}$ ft^3 gives an estimate of 516×10^{12} ft^3 of natural gas still to be discovered. Then, by dividing the undiscovered gas by the ratio of gas to natural-gas liquids, we get

$$\frac{516 \times 10^{12} \text{ ft}^3}{29.6 \times 10^3 \text{ ft}^3/\text{bbl}} = 17.4 \times 10^9 \text{ bbls}$$

as the estimate of undiscovered natural-gas liquids. Adding to this the estimated cumulative discoveries of natural-gas liquids we obtain:

Cum. disc. nat.-gas liq. through 12-31-61	13.0×10^9 bbls
Nat.-gas liq. to be discovered as of 12-31-61	17.4×10^9 bbls
Est. ultimate potential res. nat.-gas liq.	30.4×10^9 bbls

as the estimated ultimate potential reserves of natural-gas liquids for the United States. Rounding this off to 30×10^9 bbls and adding it to the 175×10^9 bbls for crude oil, we then obtain 205×10^9 bbls as our present estimate of the ultimate potential reserves of liquid hydrocarbons of the United States.

The curves for cumulative proved discoveries, cumulative production, and proved reserves for natural-gas liquids are shown in Figure 49.

United States Production and Ultimate Reserves of Liquid Hydrocarbons

By combining the U. S. data for crude oil with those for natural-gas liquids, we obtain composite U. S. data for total liquid petroleum. These data for cumulative production, proved reserves, and cumulative proved discoveries are plotted graphically in Figure 50. The logistic curves for production and discovery, as obtained graphically from the data and independently of earlier

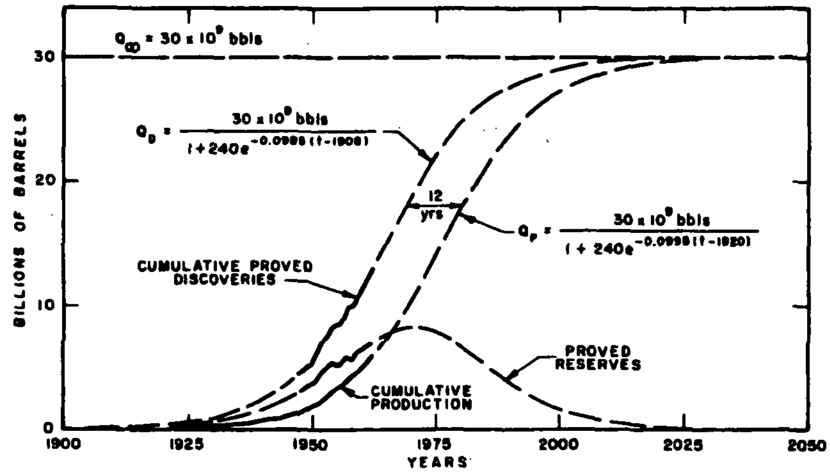

Figure 49. Cumulative Discoveries and Production and Proved Reserves of U. S. Natural-Gas Liquids

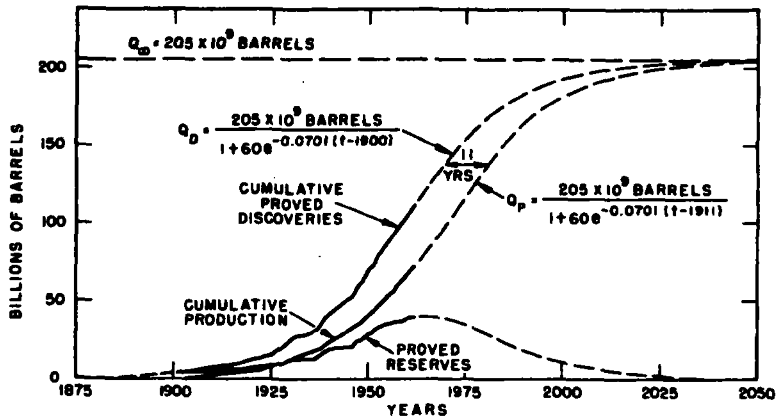

Figure 50. Cumulative Discovery and Production and Proved Reserves of U. S. Liquid Hydrocarbons

considerations, still give an asymptotic value of 205 billion barrels for $\underline{Q}_\infty$, the ultimate expectable cumulative production.

The time derivatives of the curves are shown in Figure 51.

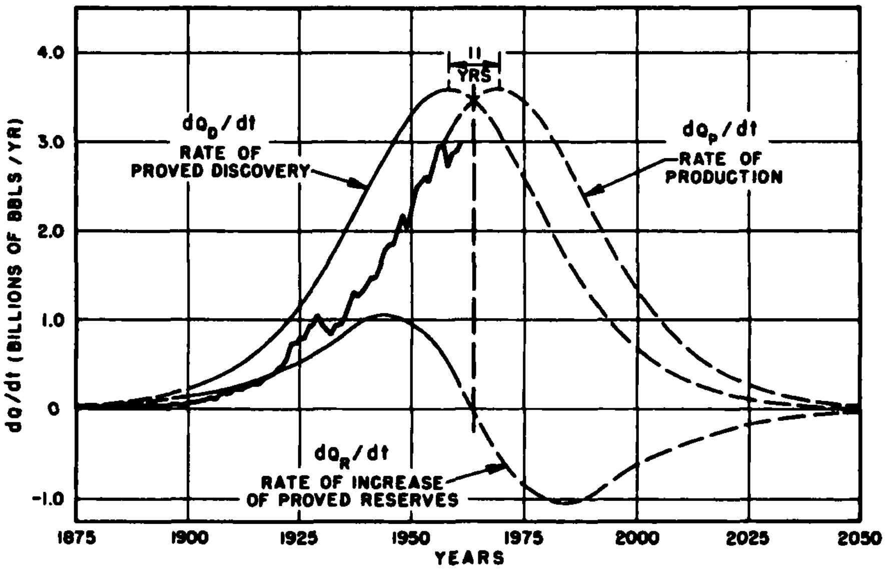

Figure 51. Rates of Proved Discovery, Production and Increase of Proved Reserves of U. S. Liquid Hydrocarbons

From the composite data on total petroleum liquids, the lead time, $\Delta \underline{t}$, of discovery with respect to production is about 11 years. The peak discovery rate appears to have occurred about 1958; the peak of proved reserves is expected to occur at about 1964, and that of the rate of production at about 1969.

Ultimate World Reserves of Natural Gas and Natural-Gas Liquids

Although markets do not as yet exist for the natural gas and natural-gas liquids of the oil and gas fields in the parts of the world remote from centers of industrialization, there is promise that such markets soon will exist. Recent developments in the transportation of natural gas in a liquified form by means of insulated and refrigerated tankers make it possible to transport natural gas from any region of production to remote centers of consumption.

Although statistical data do not exist for natural gas and natural-gas liquids on a world scale, the approximate amounts potentially available can be estimated from the estimated reserves of crude oil and the amount of natural gas and natural-gas liquids produced per bbl of crude oil in the United States. For a world estimate we assume 6,000 ft^3 of natural gas per bbl of crude oil, and that natural-gas liquids and crude oil comprise, respectively, 15 and 85 per cent of the total liquid hydrocarbons. This gives 0.1765 of a bbl of natural-gas liquids per bbl of crude oil.

Then, on the basis of our estimate of $1,250 \times 10^9$ bbls of crude oil as the ultimate reserves of the world, the ultimate reserves of natural gas and of natural-gas liquids will be $7,500 \times 10^{12}$ ft^3 and 220×10^9 bbls, respectively.

This would give a world estimate of $1,470 \times 10^9$, or roughly, $1,500 \times 10^9$ bbls for liquid hydrocarbons.

Oil Shales and Tar Sands

The world reserves of oil shales and tar sands are much less well known than those of the United States and Canada. The United States has the largest known reserve of oil shales in the world, and Canada the largest reserve of tar sands. The principal oil shale in the United States is the Green River shale in western Colorado, southwestern Wyoming, and eastern Utah. The tar sands of Canada occur in four known localities in Alberta, with reserves possibly as large as 600×10^9 bbls of crude-oil equivalent.

The reserves for the United States used here are those prepared by the United States Geological Survey and presented by V. E. McKelvey to the Natural Resources Subcommittee of the Federal Council, on November 28, 1961. According to this report, the estimates of the reserves of shale oil in the United States in the categories of known, potential, and known marginal reserves amount to 850×10^9 bbls. The reserves in the corresponding categories for oil in bituminous rocks, or tar sands, amount to only about 2.6×10^9 bbls.

The corresponding world figures in the same report are:

Shale oil	1,297 x 10^9 bbls
Oil in bituminous rocks	> 490 x 10^9 bbls

Potential marginal reserves in each of these categories could be much larger. The foregoing figures are those used here, although it is recognized that they are minimal figures.

Total Energy of the Fossil Fuels

Having reviewed the ultimate potential reserves of the various classes of the fossil fuels, we need now to compare them with respect to their total energy contents. For this purpose we adopt the heat of combustion expressed in the energy unit, the kilowatt-hour. A kilowatt-hour represents the work done at a rate of 10^3 joules/second during a time of 1 hour of 3,600 seconds. It, therefore, represents 3.60 x 10^6 joules. A kilowatt-hour of heat is the heat produced by a kilowatt-hour of work. For the world reserves of energy from the fossil fuels a convenient larger unit is 10^{15} kilowatt-hours.

Ultimate World Reserves

In Figure 52 are shown the present estimates of the ultimate reserves of energy for the different classes of fossil fuels, and the fraction of each which has been consumed already. The total ultimate energy for all the fossil fuels is approximately 27.4 x 10^{15} kilowatt-hours of heat. Of this 71.6 per cent is represented by coal, 17.3 per cent by petroleum and natural gas, and 11.1 per cent by tar sands and oil shale. The fraction consumed already is 4.1 per cent for coal, 10 per cent each for petroleum and natural gas, and zero for tar sands and oil shales.

United States Reserves

The corresponding data for the United States are given in Figure 53. The total ultimate reserves of energy from the fossil fuels in the United States is about 8.7 x 10^{15} kilowatt-hours, or about one-third of the world total. Of this, 78 per cent is represented by coal, 16 per cent by oil shale, and 3 per cent each by petroleum and natural gas. The amount consumed already is about 3 per cent for coal, 38 per cent for petroleum and 22 per cent for natural gas.

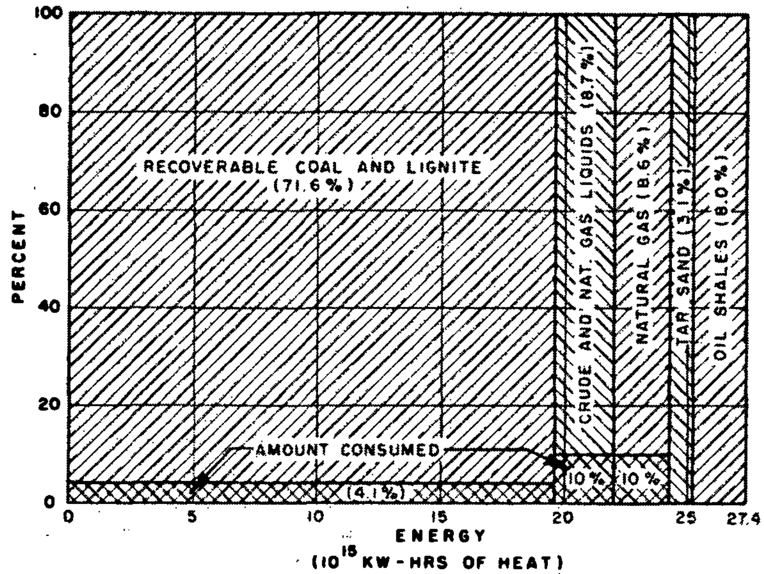

Figure 52. Total World Energy of Fossil Fuels

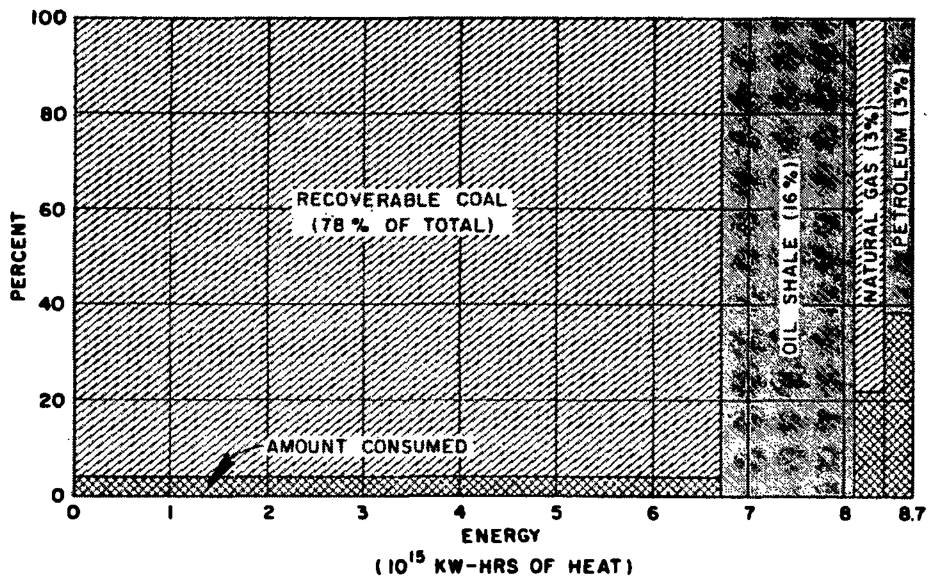

Figure 53. Total U. S. Energy of Fossil Fuels

Summary of Energy from the Fossil Fuels

To summarize the data that we have assembled on the energy supply from the fossil fuels, the world's total supply of energy from these sources, including that already consumed, amounts to about 27 x 10^{15} kilowatt-hours, of which about one-third occurs in the United States exclusive of Alaska. Of this energy supply, both for the world and for the United States, about three-quarters is represented by coal and one-quarter by petroleum, natural gas, oil shales, and tar sands.

The energy content of the fossil fuels consumed by the end of 1961 amounted to only about 4.7 per cent of the ultimate reserves for the world, and 5.0 per cent for the United States. However, the smallness of these figures tends to be deceptive and to lead to a false sense of security, because, as we have shown heretofore, with only a modest additional increase in the present rates of consumption, the peak in coal production for both the world and the United States will occur in about 200 years.

Since the reserves of petroleum and natural gas are much smaller than those of coal, and the ratio of their rates of consumption to their total reserves is much higher, it follows that these fuels will be much more short-lived than coal. In fact, the culmination in the world production of petroleum is expected to occur by about the end of the present century. In the United States the culmination in the production of crude oil is expected to occur before 1970, and that of natural gas before 1980.

This does not imply that the United States is soon to be destitute of liquid and gaseous fuels, because, as we have seen, there are still large reserves of oil shale and still larger reserves of coal from which such fuels can be produced, if necessary.

However, in keeping with the historical perspective with which we began this review, it is well to consider the exploitation of the fossil fuels in a span of history extending for some thousands of years before and after the present. On such a time scale the exploitation of the fossil fuels from the beginning to ultimate exhaustion, as is shown in Figure 54, will comprise but a brief episode.

The total length of time during which a fuel may be exploited to some trivial amount is not a significant figure; the significant time span is that during which the cumulative production increases

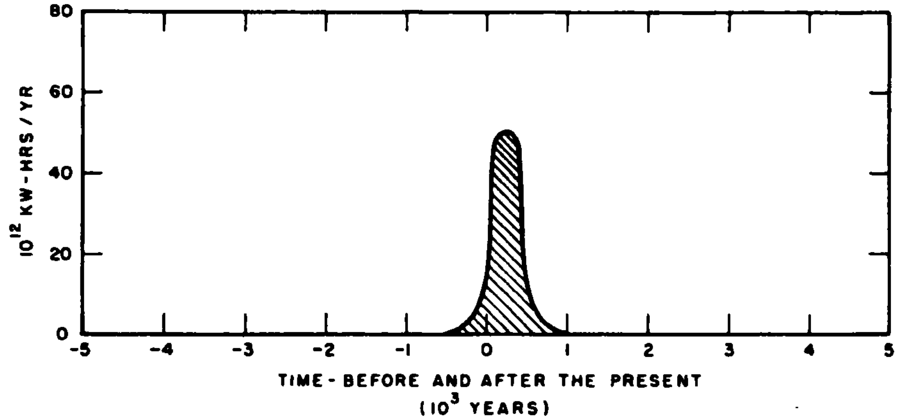

Figure 54. Total World Production of Fossil Fuels in Time Perspective

from, say, 10 per cent to 90 per cent of the ultimate reserves. For coal this figure promises to be only about 350 years. For the world's petroleum reserves, since only 10 per cent have been consumed up to now and the culmination is expected in about 40 years, it is estimated that an additional 40 per cent of the initial reserves will be produced between 1960 and the year 2000 and another 40 per cent between 2000 and 2040. Thus, about 80 per cent will be produced during the 80-year period between 1960 and 2040 A. D. The corresponding period during which 80 per cent of the petroleum and natural-gas reserves of the United States will be consumed will be somewhat shorter. The United States cumulative production of crude oil reached 17 x 10^9 bbls, or about 10 per cent, of the ultimate reserves by 1935. It is expected to reach 50 per cent by 1970 and 90 per cent by about 2005. The middle 80 per cent will accordingly be produced during the approximately 70-year period from 1935 to 2005. As compared with the production rate during this central period, that during the first and last 10 per cent of the ultimate reserves is relatively unimportant.

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CHAPTER V

CONTINUOUS SOURCES OF POWER

We now direct our attention to continuous sources of power, or sources which, if exhaustible, represent so great a reserve of energy that, for time periods of a few thousand years, they may be treated as if they were inexhaustible.

Solar Energy

The first of these is solar energy. As we have already pointed out in Chapter I, solar energy is intercepted by the earth at a mean rate of about 17.2×10^{16} watts, which is about a million times greater than the installed electrical-generating capacity of the United States in 1959.

At present only two channels of the flux of solar energy are available as large-scale sources of energy for human utilization. The first is the biological channel, beginning with photosynthesis; the second is the heat-engine channel, which produces the atmospheric and oceanic circulations and the hydrologic cycle, leading to wind power and water power.

Biologic Channel

At the Committee's conference on energy held in New York on July 19-20, 1961, the energy flux of the biologic channel was reviewed briefly by G. Evelyn Hutchinson of Yale University.

Professor Hutchinson pointed out that the rates of the photosynthetic process in terms of the fixation of carbon per year are presently estimated to be as follows:

	Grams/yr of fixed carbon
Forests	12×10^{15}
Agricultural lands	5.1×10^{15}
Grass lands	4.6×10^{15}
Total for land areas	21.7×10^{15}

The total amount of fixed carbon involved is about 1 to 3×10^{17} grams. The energetic efficiency of the process is only about 0.2 per cent.

Thus, while the biological efficiency in the capture of solar energy is low, the aggregate quantity is very large, the annual fixation of carbon on land by this process being about 7 times the fixed carbon in the fuels consumed per year.

The oceanic fixation of carbon per year is not accurately known, but could be as high as 35×10^{15} grams/year.

There is evidence that the greatly increasing use of the fossil fuels, whose material contents after combustion are principally H_2O and CO_2, is seriously contaminating the earth's atmosphere with CO_2. Analyses indicate that the CO_2 content of the atmosphere since 1900 has increased 10 per cent. Since CO_2 absorbs long-wavelength radiation, it is possible that this is already producing a secular climatic change in the direction of higher average temperatures. This could have profound effects both on the weather and on the ecological balances.

In view of the dangers of atmospheric contamination by both the waste gases of the fossil fuels and the radioactive contaminates from nuclear power plants, Professor Hutchinson urges serious consideration of the maximum utilization of solar energy.

Wind Power

The historical background on the development of power from both water and wind has been reviewed in Chapter II. Wind power is essentially limited to comparatively small units and is suitable for such special uses as pumping well water and charging batteries for local household electrical uses, but it does not offer much promise of competing with other prime movers in producing large-scale electric power. Even for the traditional uses such as the propulsion of sailing ships and the Dutch windmills for pumping water from the Dutch polders and for grinding grain, the use of power from the fossil fuels and water power has almost completely displaced wind power.

Water Power

The only channel of solar energy which lends itself to large-scale power production is water power, which is made possible only by the fact that natural streams are a means of concentrating very large amounts of power in small areas. Yet it was not possible to utilize power in such quantities at a single locality before the development of the means for generating power electrically and transmitting it over large areas for utilization. Thus, while water power is one of the oldest and most important sources of industrial power, individual water-power units rarely exceeded a few tens of kilowatts in size prior to the introduction of electrical generation and distribution. Now sites are being developed in which individual installations have power capacities measurable in hundreds of megawatts.

Unlike the fossil fuels, water power is a rate of production rather than a quantity of energy. The long-term history of the development of water power accordingly should be represented by a logistic type of growth. The installed capacity must start at a very low level, increase with time, at first slowly and then more rapidly, and finally level off to a maximum when all available water power is being utilized.

When all available power is thus being used, power can be generated at this maximum rate more or less indefinitely, provided the climate does not change significantly, and also provided that a steady-state method of desilting the reservoirs can be devised. At present rates of deposition of silt, most of the large reservoirs will require only the order of a few centuries to become filled with sediment. Unless this sediment eventually is removed from the reservoir at the same rate as it is added, the power capabilities of the reservoirs will be greatly diminished.

The significant quantities pertaining to water power in any given area are the maximum potential water power available and the amount of this that has been utilized up to any given time.

A summary of the developed and potential water power of the world has been compiled by Young (1955) of the United States Geological Survey. Using this as basic information, Francis L. Adams (1961) of the Federal Power Commission presented a comprehensive review of water power before the Committee's conference on energy in New York on July 19, 1961.

According to Adams the Federal Power Commission assumes a power capacity equal to 60 per cent of the U. S. Geological Survey's estimate of power at mean rate of flow at 100 per cent efficiency. Using this factor, Adams estimated the ultimate potential water-power capacity of the United States to be 148,000 megawatts, of which the amount already installed by the end of 1960 was 33,000 megawatts, or 23 per cent of the ultimate. A logistic curve of water-power development for the United States is shown in Figure 55.

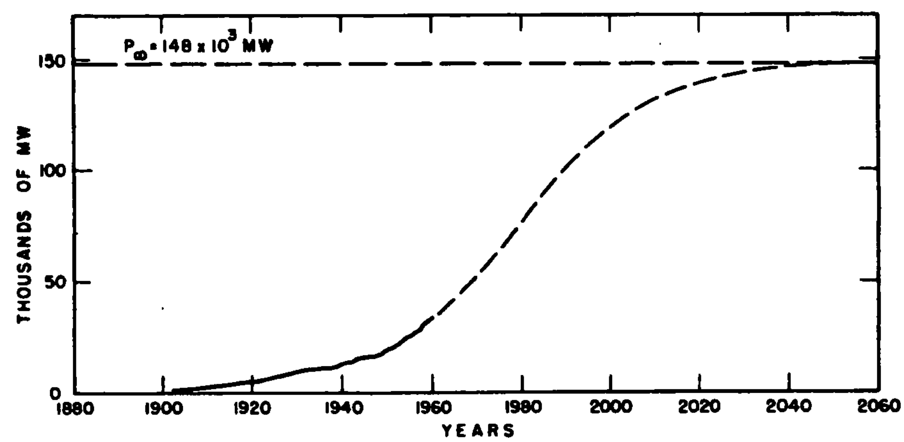

Figure 55. U. S. Installed and Ultimate Hydroelectric Power Capacity

Adams did not give data on the potential water power of the world in terms of megawatts of capacity, but rather in terms of the energy which could be produced per year expressed as kilowatt-hours per year. Using his ratio between installed power capacity and annual energy produced for the United States, it is possible to estimate the potential power capacity for the various areas of the world and the extent to which this has already been developed. The results of this calculation are shown in Table 8.

TABLE 8

World Water-Power Capacity

Region	Potential (10^3 Megawatts)	Per Cent of Total	Development (10^3 Megawatts)	Per Cent Developed
North America	313	11	59	19
South America	577	20	5	
Western Europe	158	6	47	30
Africa	780	27	2	
Middle East	21	1	—	
Southeast Asia	455	16	2	
Far East	42	1	19	
Australasia	45	2	2	
U.S.S.R., China and Satellites	466	16	16	3
Total	2,857	100	152	

Computed from data given by Adams, Francis, L., 1961, Statement on Water Power: At Conference on Energy Resources, Committee on Natural Resources, National Academy of Sciences, Rockefeller Institute, New York, N. Y., July 19, Chart I.

It will be noted that, whereas the United States has an ultimate potential water-power capacity of 148 x 10^3 megawatts, of which 23 per cent is already developed, the world has a potential capacity of 2.86 x 10^6 megawatts, of which only 152 x 10^3 megawatts, or 5.3 per cent, has been developed.

Also, it is interesting to note that Africa, with a potential water-power capacity of 780,000 megawatts, has the largest water-power resources of any continent; and South America is second.

To obtain some idea of how large the potential water-power resources are in comparison with other energy sources, the total installed electricity-generating capacity in the United States in 1959 was 174,000 megawatts (Dept. of Commerce, 1961, p. 525) and the electrical energy produced was 795 x 10^9 kilowatt-hours, which, had it been generated by coal, would have required 1.53 x 10^9 short tons. The world in 1959 produced 2.096 x 10^{12} kilowatt-hours of electric power, which required an equivalent of 4.37 x 10^9 short tons of coal (Dept. of Commerce, 1961, p. 931).

If the water power of the world were fully developed, the electrical energy produced per year would be about 12.0×10^{12} kilowatt-hours (Adams, 1961), which would be about 6 times the electrical-power production of the world in 1959. The coal required to produce this amount of power would be about 25×10^9 short tons per year, or about 10 times the world's coal production in 1959.

Direct Conversion of Solar Energy

The fact that a large fraction of the total solar power occurs as direct solar radiation in desert and semidesert areas in tropical to middle latitudes makes an intriguing problem of somehow capturing this energy for human uses. At the Committee's conference on energy resources in New York on July 19-20, 1961, Farrington Daniels, Director of the Solar Radiation Laboratory of the University of Wisconsin, reviewed the work and prospects of the direct utilization of solar energy.

Later, an all-day conference on this same subject was held at the National Academy of Sciences in Washington on May 25, 1962. This meeting, under the chairmanship of Roger Revelle, was attended by representatives of the principal industrial corporations doing research in this field, as well as by Professor Farrington Daniels from the University of Wisconsin and Professor Eric A. Farber who is in charge of an extensive research program on solar-energy utilization at the University of Florida.

At these conferences attention has been devoted principally to small, specialized uses of solar energy such as cooking, water heating, heating and cooling of domestic residences, electrical generation for rural telephone circuits, and use for space craft.

The outstanding exception was an account given by Frank Edlin of the Du Pont Corporation, Wilmington, Delaware, of a pilot-plant experiment designed to produce electrical power on a much larger scale. In this experiment the energy-capturing device was a 5-layer transparent plastic cover over an artificial pond. It was expected that 45-50 per cent of the incident solar radiation would be captured, heating the pond to 200° F. This pond would serve both as a collector and a storer of energy, the storage capacity being large enough to operate a heat engine continuously without a serious drop in temperature. A steam engine would be driven on a Rankine Cycle with an efficiency of 12-14 per cent, operating between the high temperature of the pond and the low temperature of sea water. The expected overall efficiency was about 6 per cent.

The experiment was not a complete failure, but not up to expectations either. Only a 70° F. temperature increase was obtained; sunlight capture was only 17 per cent, which would give an efficiency of converting sunlight into work of only 2 per cent. Even under these conditions, however, it appeared that the production of electrical power at a cost of 6 cents per kilowatt-hour may be within range. A minimum size for the pond for a pilot plant would be about 5,000 ft^2. Experiments of this type were said to be very expensive.

This experiment is here singled out as being particularly significant because it tended to avoid the principal difficulty inherent in solar-energy collection. The radiation density of solar energy is small, so that collection must be accomplished over large areas if large amounts of power are to be developed. Most systems of collection are prohibitively expensive, so that, if extended over large areas, they would involve capital costs many times that for power generation from conventional sources.

An extension of the type of collection described by Mr. Edlin to really large areas might have possibilities, especially in areas deficient in power from other sources. Unless large-area, inexpensive collecting devices can be developed, the direct use of solar energy appears to be destined to be restricted to comparatively small special-purpose uses. These may still be widely developed, however, as in domestic water heating in Florida and Japan and refrigeration and residential heating and air conditioning.

Tidal Power

In Chapter I it was pointed out that the total tidal power dissipated by the earth is about 1.4×10^{12} watts, of which about 1.1×10^{12} watts is accounted for by tidal friction in bays and estuaries around the world. It is the latter fraction which is susceptible to capture and conversion to electric power by suitable water-power devices.

A summary of data pertaining to actual and potential tidal power sites was presented by Francis L. Adams (1961, Chart XII), given here as Table 9. These comprise nine Bay of Fundy sites in Maine, Nova Scotia and New Brunswick, and four additional sites in France, England, and Argentina.

TABLE 9

(Adams' Chart XII) Tidal Power Data for the Bay of Fundy and Other Potential Developments

Bay or Basin	Tidal Ranges—Feet Springs	Neaps	Mean H	Area Sq.Mi. A	Proposed Development Scheme	Installed 10^3kw	Annual 10^6kwh
Bay of Fundy Sites							
Passamaquoddy	27	12	18	101	2-Pool	—	—
Cobscook	27	12	18	41	1-PH	300	1,843
Annapolis	33	14	21	32	1-Pool	37	79
Minas-Cobequid	54	24	35	300	—	2,000	—
Amherst Point	54	24	35	4	2-Pool	39	275
Shepody	50	22	32	45	2-Pool	—	—
Cumberland	51	23	33	28	2-PH	450	2,140
Petitcodiac	54	24	35	12	2-Pool	—	—
Memramcook	54	24	35	9	1-PH	201	1,310
						3,027	5,647
Other Sites							
San Jose (Argentina)	27	15	19	300	—	1,050	4,500
Severn (England)	47	22	32	30	1-Pool	800	2,300
La Rance (France)	38	11	23	8	1-Pool	324	890
Mont St. Michel (France)	41	12	25	200	2-Pool	3,000	25,000
						5,174	32,690
Total						8,201	38,337

Adams, Francis, L., 1961, Statement on Water Power: At Conference on Energy Resources, Committee on Natural Resources, National Academy of Sciences, Rockefeller Institute, New York, N. Y., July 19, Chart XII.

The largest of the Bay of Fundy sites would have an installed power capacity of 2,000 megawatts, the Argentina site 1,050 megawatts, and the French site at Mont St. Michel 3,000 megawatts. The remaining sites range between 37 and 800 megawatts. The total potential capacity of the Bay of Fundy is 3,027 megawatts, with an estimated annual energy output of 5.6×10^9 kilowatt-hours. The total potential capacity of all the sites is 8,201 megawatts, with an estimated annual output of 38.3×10^9 kilowatt-hours.

A comparison of these figures with the energy production from water power in the United States can be made by noting that in 1959 the energy produced from water power was 172×10^9 kilowatt-hours (Adams, 1961, p. 3).

Geothermal Energy

As was pointed out in Chapter I, the temperature in the earth increases with depth, in consequence of which heat is conducted from the earth's interior to its surface. An additional amount of heat is convected to the earth's surface by the gases and lavas of volcanos, and by hot springs in regions which have been heated above normal by volcanic activity.

The mean rate of increase of temperature with depth in areas remote from volcanic disturbances is about 1^{o} C. per 30 meters, or about 33^{o} C. per kilometer of depth. Hence, within drillable depths of 5 to 8 kilometers, temperatures as high as 150^{o} - 200^{o} C. above surface temperatures may be expected.

Superficially, it would appear that with such temperatures at drillable depths, earth heat sufficient for significant power generation could be obtained anywhere. Actually this is not the case. Rocks are very poor conductors of heat; thus the heat that could be obtained in this manner is negligible. The only situations in which earth heat can be used on a large scale are those at which hot volcanic rocks are comparatively near the surface and either volcanic, or circulating, ground waters act as heat collectors from large volumes of rocks. Since these hot rocks are finite in quantity and have finite contents of heat, it follows that the amount of energy extractable from such a source must also be limited.

A review of the present developments in the production of power was given by Earl F. English (1959), Consulting Engineer and Vice President, Thermal Power Company. According to this review, major drilling operations which have resulted in usable quantities of steam for power production have been conducted in only three principal localities. These are: Lardarello in Italy, Wairakei and Kawerau in New Zealand, and The Geysers in Sonoma County, California.

Electric power has been produced at Lardarello for 40 years, and the capacity is now 400 megawatts. Wells are now being drilled in New Zealand, and a power plant is under construction and partly in operation. The steam capacity is estimated to be in excess of 400 megawatts.

The Geysers in California produce enough steam for 25 megawatts of electric power. Pacific Gas and Electric Company has built one plant with a capacity of 12.5 megawatts, and this capacity is soon to be doubled.

A more comprehensive approach to the power potentials of thermal areas is made by determining the total heat output from such areas. Data of this kind have recently been compiled by Donald E. White of the U. S. Geological Survey in two papers not yet formally published. According to White (1961a) the thermal outputs in ten localities in New Zealand range from a low value of 59 megawatts to a high value of 1,260 megawatts. In the four localities in the western United States the thermal outputs are the following:

Steamboat Springs, Nevada	27×10^6 watts
Yellowstone Park:	
Norris Basin	33×10^6 watts
Upper Basin	380×10^6 watts
Mammoth and Hot River	140×10^6 watts

White (1961b) also points out that at Steamboat Springs, Nevada, the quantity of excess heat stored in a volume of rock 5 square kilometers in area by 3 kilometers deep amounts to 1.6×10^{18} calories, which is equal to 1.9×10^{12} kilowatt-hours. This is equivalent to the heat of combustion of about 235 million tons of coal, and at the present rate of flow would require 7,000 years to dissipate.

Further information on the world distribution of potential power sites utilizing volcanic heat has just been received from the Italian volcanologists, Francesco Penta and Giorgio Bartolucci (1962). These authors, in a paper entitled "Sullo stato delle 'ricerche' e dell'utilizzazione industriale (termoelettrica) del vapore acqueo sotterraneo nei vari paesi del mondo" ["On the state of the 'researches' and the industrial (thermoelectric) utilization of the underground steam in the various countries of the world"]. As the title implies, this is a review of the known localities in the world. It is accompanied by a bibliography of 98 references to pertinent technical literature.

This review is in agreement with the data cited above on volcanic steam power developments in Italy, the United States, and New Zealand. Altogether about 46 separate localities are cited as having potentialities for power production of industrial magnitudes. From the data given, it would appear that a few thousand megawatts is the expectable order of magnitude for the world power capacity from geothermal sources.

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CHAPTER VI

NUCLEAR ENERGY

We come now to the most recent source of energy to become available for human use—the atomic nucleus. Nuclear energy results from each of two contrasting processes, the fissioning of a few of the isotopes of heavy elements in the atomic scale, producing lighter elements; and the fusing of light elements near the lower end of the scale of atomic numbers to produce heavier elements. In each instance the mass of the reaction products is slightly less than that of the reactants and the lost mass is converted into energy in accordance with the Einstein equation relating mass to energy,

$$E = \Delta m c^2, \qquad (19)$$

where E is the energy released, Δm the reduction in mass, and c the velocity of light.

Since the velocity of light is 3.00×10^8 m/sec, then, if Δm is 1 gram,

$$E = 10^{-3} \text{ kg} \times 9.00 \times 10^{16} \text{ m}^2/\text{sec}^2$$

$$= 9.00 \times 10^{13} \text{ joules.}$$

Energy from the Fissioning of Heavy Isotopes

The only isotope naturally capable of fissioning is uranium-235, which comprises 0.7 per cent of whole uranium. The remainder of natural uranium is the isotope U-238.

It was found by J. Chadwick in England in 1932 (Smyth, 1945, p. 9-10) that in certain nuclear experiments a strange particle having approximately the mass of the hydrogen atom, or the proton, but zero electric charge, was emitted. This was known later as the neutron. Further experiments during the 1930's showed that normally nonradioactive elements, when bombarded with neutrons, can be made artifically radioactive. Finally, in January 1939, O. Hahn and F. Strassmann in Germany (Smyth, 1945, p. 24) reported obtaining barium from the neutron bombardment of uranium. Since barium is an element remote from uranium in the atomic scale, it could not have been produced by any simple radioactive transformation. This led to the surmise that the barium plus a complementary atomic particle must have been produced by the fissioning of uranium. This surmise was verified within the next few weeks in several different laboratories in the United States.

Subsequent studies showed that the fissionable uranium isotope was the comparatively rare U-235, and that the products from numerous fissionings comprise a wide scatter of isotopes, many highly radioactive, in the mid-range of the table of atomic numbers. The energy released per fission was found to have an average value of 200 million electron volts, or 8.90×10^{-18} kilowatt-hours. From Avogadro's Number, there are

$$\frac{6.02 \times 10^{23}}{235} = 2.56 \times 10^{21}$$

U-235 atoms per gram. From this it follows that the energy released upon the fissioning of 1 gram of U-235 must be

$$2.56 \times 10^{21} \times 8.90 \times 10^{-18} = 2.28 \times 10^{4} \text{ kw-hr}$$

$$= 8.21 \times 10^{10} \text{ joules.}$$

This is equal approximately to the heat of combustion of 3 tons of coal or or 13 barrels of crude oil.

The reduction in mass of 1 gram of U-235 upon being fissioned is then obtained from the Einstein equation

$$\Delta m = \frac{E}{c^2} = \frac{8.21 \times 10^{10}}{9.00 \times 10^{16}} = 0.913 \times 10^{-6} \text{ kg}$$

$$= 0.913 \times 10^{-3} \text{ gm,}$$

which is very nearly 1 part per 1,000. Hence, the fissioning of 1 gram of U-235 produces 0.999 grams of fission products and loses approximately 1 milligram of mass which is converted into 2.28×10^4 kilowatt-hours of heat.

In addition to radioactive isotopes, the fission products of U-235 also include neutrons. No sooner had the fissioning of uranium been demonstrated than intensive investigations were begun in the United States in an attempt to obtain a sustained fission chain reaction. This would be a reaction in which, if a single fissioning occurred from a stray neutron, then the neutrons produced would cause still other fissionings to occur and so be able to sustain the reaction.

Such a reaction was first achieved by E. Fermi and associates (Smyth, 1945, p. 98) in Chicago on December 2, 1942, using a "pile" with a graphite matrix in which lumps of common uranium or its oxide were placed in a three-dimensional lattice. When the pile had been built up with about 6 tons of uranium, it reached the critical stage and a sustained chain reaction was achieved.

At just beyond the critical level the reaction could be controlled by the insertion or removal of neutron-absorbing cadmium strips, making it possible to start, stop, increase, or retard the reaction at will.

The object of the wartime experiment was to produce nuclear bombs. Our present interest is limited to the fact that, by means of variations of the original Chicago experiment, it is possible to produce and control sustained fission reactions, and that the heat released can be used to operate conventional steam-power plants.

A schematic flow diagram of the fissioning of U-235 in a chain reaction is shown in Figure 56. The material products produced by the fissioning of a single atom are two other atoms plus neutrons, whose combined weights are a little less than that of the U-235 atom. The fission product of a large number of separate fissions comprises a scatter of atoms in the mid-range of the table of atomic numbers. Many of these fission products are extremely radioactive, some with half-lives of approximately 30 years.

The difficulty posed by the use of U-235 for power generation is its comparative scarcity. However, it has been found that the two much more abundant isotopes, U-238 and Th-232

FISSION POWER REACTION

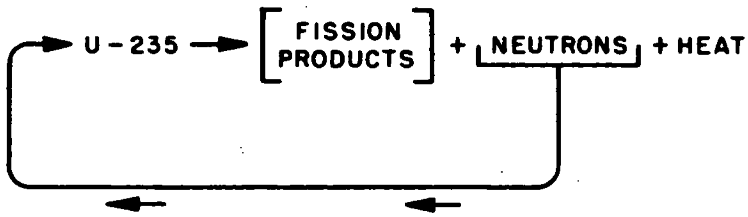

Figure 56. Schematic Representation of Nuclear-Power Reaction Involving the Fissioning of U-235

(which is essentially the whole of natural thorium), can be converted into fissionable isotopes by being placed in a nuclear pile powered initially by U-235. By this process, omitting intermediate details,

$$\text{U-238} \rightarrow \text{Pu-239},$$

and

$$\text{Th-232} \rightarrow \text{U-233};$$

and both plutonium-239 and uranium-233 are fissionable.

BREEDER REACTION
(SCHEMATIC)

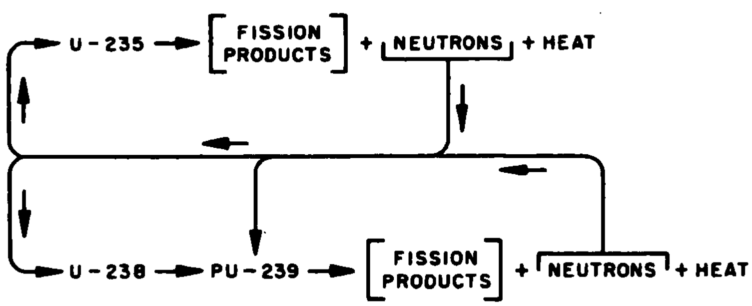

Figure 57. Schematic Representation of Breeder Reaction for U-238

The nonfissionable isotopes, U-238 and Th-232, from which the fissionable isotopes, Pu-239 and U-233, are made, are known as fertile materials. The process of converting fertile isotopes to fissile isotopes is known as breeding. The process of breeding is illustrated for U-235 and U-238 in Figure 57. The same diagram would apply were Th-232 and U-233 substituted for U-238 and Pu-239.

By the breeding process, in principle all of uranium and all of thorium are potentially usable as nuclear fuels, instead of only the much scarcer isotope U-235. Since U-238 is 140 times as abundant as U-235 and thorium is geochemically about 3 times as abundant as U-238, it is evident that the available fuel is increased by a factor of about 400 if breeder reactors are developed. This, however, according to Alvin M. Weinberg, Director of Oak Ridge National Laboratory, is only a minimum of the gain potentially obtainable. The development of complete or nearly complete breeding changes the cost of the operation in such a manner as to make it economical to utilize rocks with low uranium or thorium contents. The fuel added in this manner is millions of times greater than that available when only U-235 can be used. Hence the energy gain contingent upon the development of breeder reactors is a very large factor.

The development of large-scale power by means of the fissioning of uranium and thorium and their derived isotopes reduces to three fundamental problems:

1. the development of breeder reactors,

2. an adequate supply of uranium and thorium, and

3. proper disposal of the extremely dangerous fission products.

Breeder Reactors

An extensive experimental program for the development of breeder reactors is underway by the Atomic Energy Commission, but its details will not be reviewed at this time.

The Supply of Uranium and Thorium

Uranium and thorium are of widespread occurrence in the rocks of the earth's crust, but in very small amounts. The granites which are the principal parent rocks of the continents contain thorium and uranium in the approximate average amounts of 12 parts per million of thorium and 4 parts per million of uranium. Since the sediments are principally derived from granitic rocks, and since the ocean waters contain essentially no thorium, it is expectable that the ratio of thorium to uranium in sediments should also be about 3 to 1. So far, however, nothing like this amount of thorium has been found. Uranium in sediments is fairly widespread, so we are led to suspect that some large concentrations of thorium in sediments, as yet undiscovered, will eventually be found.

Figure 58 is a map of the United States showing the locations and amounts of the principal known uranium and thorium deposits of the United States. The figures shown are supplemented by the data of Tables 10 and 11 from McKelvey, Butler, Olson and Gottfried (1961) of the U. S. Geological Survey. In addition, the data on the Conway granite in New Hampshire is from a recent and as yet unpublished paper by Adams, Kline, Richardson and Rogers (1962).

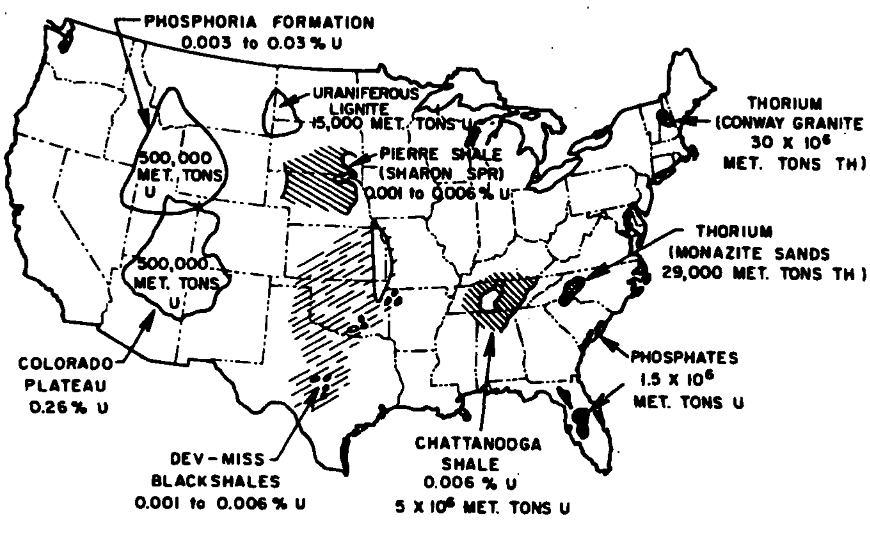

Figure 58. Major Uranium and Thorium Deposits in the U. S.

TABLE 10

Potential Uranium Reserves and Resources of the United States Comparable in Quality to Ore Mined from 1948 to 1960[1]

(Table 2 of McKelvey, Butler, Olson, and Gottfried)

Estimates of tonnage correspond to the sum of past production, known reserves, and undiscovered resources. Uranium content of ore in the districts listed averages 0.17 to 0.30 percent and costs $8 to $10 per pound to recover. All estimates and totals are rounded.

GENERAL AREA AND GEOLOGIC UNIT	Uranium[2] (metric tons)
Colorado Plateau	
Triassic rocks	200,000 – 700,000
Morrison formation outside San Juan Basin	40,000 – 80,000
Morrison and Todilto formations, San Juan Basin, New Mexico	280,000 – 1,300,000
Subtotal, Colorado Plateau	500,000 – 2,000,000
Other western sandstone and lignite ores	
Eastern N. Mex., Western Okla., NW Texas, Permian and Triassic Rocks	18,000 – 30,000
Black Hills, S. Dak., and Wyo. — Inyan Kara Group	9,000 – 20,000
Wyoming and NW Colo. — Wasatch, Wind River, and Browns Park formation	80,000 – 200,000
Gulf Coast, Texas, mainly Jackson and Goliad formations	30,000 – 60,000
Lignite, N. and S. Dak.	15,000 – 30,000
Subtotal, areas outside Colo. Plateau	150,000 – 350,000
Other kinds of deposits and areas	
Tertiary clastic, mixed volcanic and sedimentary rocks, Western U. S.	8,000 – 20,000
Veins, Western U. S.	9,000 – 20,000
Appalachian Region, all types	1,500 – 15,000
Subtotal, all others	20,000 – 55,000
Total	700,000 – 2,300,000
Coal equivalent (metric tons)	2100×10^9 – 6900×10^9

[1]Indicated and inferred reserves of uranium in the United States are about 185,000 metric tons (R. D. Nininger, 1960, U.S.A.E.C. TID-8207).

[2]The minimum figure represents uranium in ore that is believed to occur in known geologic horizons, at depths comparable to deposits mined now, and in the vicinity of known districts. The maximum is based on projected occurrence of ore further from known districts, (generally also at depths greater than those in which uranium mining is being undertaken now) and makes moderate allowance for the existence of ore in horizons not now known to be mineralized. The minimum compares with an estimate of about 500,000 tons made for similar material by Nininger (idem). The deeper ores included in the maximum figures very likely would cost more than $8-10 per pound to recover.

McKelvey, V. E., Butler, A. P., Olson, J. C., and Gottfried, David, 1961, Uranium and Thorium Resources in the United States and World, Table 2 in Domestic and World Resources of Fossil Fuels, Radioactive Minerals, and Geothermal Energy: Preliminary Reports Prepared by Members of the U. S. Geological Survey for the Natural Resources Subcommittee of the Federal Science Council.

TABLE 11

Potential World Uranium Reserves and Resources Comparable in Quality to Those Mined from 1948 to 1960

(Table 3 of McKelvey, Butler, Olson, and Gottfried)

Area	Uranium[1] (metric tons)
United States	700,000 – 3,000,000
Canada	450,000 – 3,000,000
Europe and Asia	480,000 – 18,000,000
Africa	300,000 – 10,000,000
Latin America	2,000 – 8,000,000
Australia	8,000 – 3,000,000
Total	1,840,000 – 45,000,000
Coal equivalent (metric tons)	5×10^{12} 1×10^{14}

[1]The minimum figure for the United States are those of A. P. Butler, 1961 (see table 2). Those for Canada, Africa, Latin America and Australia are the combined "reasonably assured reserves" and "Geologic estimates of possible future discoveries" of table 2 of R. D. Nininger, 1960, U.S.A.E.C. TID-8207. The minimum estimate for Europe and Asia includes about 110,000 tons estimated by Nininger as combined assured and possible for non-Communist Europe, and 370,000 tons estimated by the staff of the Joint Committee on Atomic Energy as the maximum resources of the U.S.S.R., European Satellites, and China (see Robert McKinney, 1960, Background material for the review of the international atomic policies and programs of the United States, 86th Congress, p. 1613-1618). All of the maximum estimates are based on the assumption that U. S. reserves are at least equal to the crustal abundance of uranium in percent (0.00026) time 10^{10}, and that reserves elsewhere are proportionate (see figure 1 and table 1).

McKelvey, V. E., Butler, A. P., Olson J. C., and Gottfried, David, 1961, Uranium and Thorium Resources in the United States and World, Table 3 in Domestic and World Resources of Fossil Fuels, Radioactive Minerals, and Geothermal Energy: Preliminary Reports Prepared by Members of the U. S. Geological Survey for the National Resources Subcommittee of the Federal Science Council.

The significant fact in these tables is that the United States is estimated to have potential reserves from 700,000 to 2,300,000 metric tons of uranium in ores of comparable quality to those mined during the period 1948 to 1960. These ores have uranium contents ranging from 0.17 to 0.30 per cent, or contents ranging from 1,700 to 3,000 grams per metric ton.

Data are not given on the reserves of much smaller concentrations in the range of 50 to 100 grams per ton, but the quantities in this range in various black shales and phosphate rocks are very much larger.

According to the paper by Adams and associates (1962), the Conway granite in New Hampshire has an average thorium content of about 56 grams per metric ton. This rock crops out over an area of 300 square miles and has a thorium content of about 3×10^6 metric tons per hundred feet of depth.

From these data it is evident that the amount of uranium and thorium in concentrations of 50 grams or more per metric ton of rock at minable depths in the United States must be of the order of tens if not hundreds of millions of metric tons.

The significance of this will be apparent when the energy content of these nuclear fuels is compared with that of the world reserves of the fossil fuels. Assuming complete breeding, 1 gram of uranium or thorium upon fissioning will release 2.28×10^4 kilowatt-hours of heat.

The ultimate energy reserve of all the fossil fuels is about 28×10^{15} kilowatt-hours. The amount of uranium or thorium required to produce this much heat would accordingly be

$$\text{Mass of U or Th} = \frac{28 \times 10^{15}}{2.28 \times 10^4}$$

$$= 12.3 \times 10^{11} \text{ grams}$$

$$= 1.23 \times 10^6 \text{ metric tons.}$$

Hence, the uranium and thorium reserves in the United States occurring in rocks having a content of 50 or more grams per metric ton must be of the order of hundreds to thousands of times greater than the world's initial supply of fossil fuels. Also, a rock having a uranium or thorium content of 50 grams per ton is energetically equivalent to about 150 tons of coal or 650 barrels of crude oil per ton of rock.

It is clear, therefore, that if breeding becomes the established practice, we shall have achieved almost unlimited supplies of energy from the fissionable and fertile isotopes of uranium and thorium.

Waste Disposal of Fission Products

The principal remaining problem is the development of means for economical and safe disposal of the fission products. Mention has already been made of the fact that when 1 gram of U-235 is fissioned 0.999 grams of fission products are formed, consisting of a wide spectrum of isotopes in the mid-range of the table of atomic weights. According to F. L. Culler, Jr. (1955), Director, Chemical Technology Division, Oak Ridge National Laboratory, the fission products produced by 1,000 grams of U-235 with 30 per cent burnup, consist, after 100 days of cooling, of 230.00 grams of inactive isotopes, 15.93 grams of short-lived radioactive isotopes, and 16.61 grams of long-lived radioactive isotopes. The short-lived isotopes comprise fifteen different species with half-life periods ranging from seconds to 290 days. The long-lived isotopes consist of four species of which the two longest and most dangerous are ceasium-137 and strontium-90 with half-lives of 33 and 25 years, respectively. These occur in amounts of 7.05 and 4.63 grams, respectively, and represent about two-thirds, by mass, of the long-lived isotopes.

All of these radioactive fission products are extremely dangerous until they have decayed to the very low levels of tolerance prescribed for biological safety. A rule of thumb that has been used as an order of magnitude among the members of the Atomic Energy Commission's health physics division is that none of these materials can be considered to be safe for biologic exposure until a period of at least 20 half-lives has elapsed. For the short-lived fission products, this would be a period of the order of 20 years; for the long-lived isotopes the corresponding period would be at least 660 years, and possibly even 1,000 years.

On February 28, 1955, at the request of the Atomic Energy Commission, an Advisory Committee on Waste Disposal of the Division of Earth Sciences was established by the National Academy of Sciences—National Research Council. After a number of conferences with A. E. C. personnel and visits to Oak Ridge National Laboratory, the Committee issued a report dated April, 1957, in which, on page 3, the following basic principle was stated:

> Unlike the disposal of any other type of waste, the hazard related to radioactive waste is so great that no element of doubt should be allowed to exist

regarding safety. Stringent rules must be set up and a system of inspection and monitoring instituted. Safe disposal means that the waste shall not come in contact with any living thing. Considering half-lives of the isotopes in waste this means for 600 years if Cs^{137} and Sr^{90} are present or for about one-tenth as many years if these two isotopes are removed.

At one of the earlier conferences, held in Washington, D. C., on November 15, 1954, the views on radio-active waste disposal of the Atomic Energy Commission were presented by Arthur E. Gorman. He pointed out that from the point of view of the A. E. C. the problem of where and how to dispose of high-level wastes is quite serious. Yet, at that time all such wastes were being held in underground storage tanks (stainless steel)--a practice which could only be regarded as a temporary expedient, since the period of activity of the long-lived wastes is much longer than the potential life of the tanks. In effect, they were buying time until a satisfactory ultimate disposal method could be worked out (Gorman, 1955, p. 2-3).

After the preliminary conferences mentioned above, the Committee concluded that the rate of generation of radioactive wastes at present is very small as compared with magnitudes which will be produced when the generation of power by nuclear fission begins its eventual exponential rate of growth. However, policies and practices initiated now should be of such a nature as still to be valid when the rate of production of wastes should be many times larger than it is at present. The total quantity of wastes was found not to be large, since if all the electric power produced in the United States at the present time were generated by nuclear-fission power plants, the fuel consumed and fission products produced per year would be only of the order of 100 metric tons.

With this in view the Committee reviewed the likely means of waste disposal, of which two were regarded with special favor: (1) in the salt mines or domes, preferably in solid form, and (2) in the form of heavy liquids in permeable sedimentary rocks in the bottoms of synclinal basins. It was pointed out, however, that none of the existing A. E. C. installations, and few of the proposed power plants, had been located at suitable waste-disposal sites, and it was suggested that eventually consideration should be given to locating power plants and waste-processing plants at suitable waste-disposal sites with either a regrouping of power distribution with respect to these sites, or else developing means for long-distance transmission of power to centers of consumption.

After five years, the Committee summarized its observations and recommendations in the following letter addressed to John A. McCone, Chairman of the Atomic Energy Commission:

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

DIVISION OF EARTH SCIENCES
2101 CONSTITUTION AVENUE, WASHINGTON 25, D.C.

June 21, 1960

Mr. John A. McCone, Chairman
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Mr. McCone:

On February 28, 1955, arrangements were formalized between the Atomic Energy Commission and the National Academy of Sciences-National Research Council to provide advisory services on geological and geophysical problems related to the disposal of radioactive wastes on continental areas. Your Academy-Research Council Committee on Waste Disposal has been active for some 5 years, has held an important conference attended by about 75 scientists and engineers, has closely followed the results of research on disposal problems, and has held numerous meetings, both at AEC installations and elsewhere.

Early in its deliberations, the Committee reached the conclusion which was later stated on page 3 of the report of April 1957 that no system of waste disposal can be considered safe in which the wastes are not completely isolated from all living things for the period during which they are dangerous. This period for high-level wastes containing the long-lived isotopes of Cs^{137} and Sr^{90} is at least 600 years. After an extensive review of possible disposal methods which would satisfy the stringent conditions of safety set forth above, your Committee, in light of the technology then existing, favored the following:

1. Disposal within chambers excavated or dissolved in rock salt.
2. Deep disposal in sands or other porous and permeable rocks near the lowest parts of synclinal basins.

While it is possible that other safe disposal methods may be developed, your Committee still regards these as the most promising methods, and feels that no worthwhile advantage will be gained by further delay in stating its appraisal of the present situation, namely:

> No existing AEC installation which generates either high-level or intermediate-level wastes appears to have a satisfactory geological location for the safe local disposal of such waste products; neither does any of the present waste-disposal practices that have come to the attention of the Committee satisfy its criterion for safe disposal of such wastes.

The Committee's recommendations are as follows:

1. The Committee regards it as urgent that action be taken for the establishment of waste-disposal facilities at suitable geological sites where the accumulated wastes of the existing installations can be processed and safely disposed of.
2. Your Committee further recommends that approved plans for the safe disposal of radioactive wastes be made a prerequisite for the approval of the site of any future installation by the AEC or under its jurisdiction.
3. In particular, your Committee recommends that the Commission consider concentrating its chemical processing activities at a minimum number of sites located at satisfactory places for the disposal of radioactive wastes.

Sincerely yours,

H. H. Hess
Chairman

Committee Members

John N. Adkins
William E. Benson
John C. Frye
William B. Heroy
M. King Hubbert
Richard J. Russell
Charles V. Theis
William Thurston,
Secretary

This was prompted by the fact that the Committee did not feel that the budget for waste disposal was commensurate with the magnitude of the problem. The investigations were further hindered by a hope on the part of A. E. C. personnel that a suitable waste-disposal site could be found at or near each present installation.

It is here recommended that a much broader view of this problem be adopted, and that a budgetary increase for this purpose, amounting possibly to several fold, be allowed.

Energy from Fusion

Energy is obtained from fusion when hydrogen, or its heavy isotope deuterium, is combined into helium. The process is illustrated in Figure 59, showing three deuterium atoms combined to form one atom of Helium-4 plus one proton and one neutron with a release of energy of 9.61×10^{-19} kilowatt-hours of energy in the form of heat. Since the ratio of deuterium atoms to hydrogen atoms in water is about 1/6500, and the deuterium can be separated at an energy cost which is a fraction of 1 per cent of the energy potentially obtainable from fusion, we may estimate about how much energy could be obtained from various amounts of sea water. This has been done in Table 12.

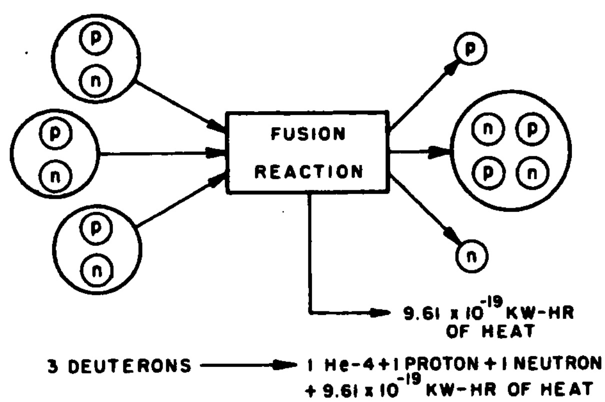

Figure 59. Possible Method of Producing Power by Fusion

The energy obtainable from 1 gram of water is about 3. 30 kilowatt-hours of heat, or a little less than the heat of combustion of a pound of coal. The energy from 1 cubic meter of water is equivalent to that of 1,870 barrels of crude oil, and that from

TABLE 12

Energy Obtainable From Sea Water By Fusion

Volume of Water	Energy (kw-hrs heat)	Equivalent Coal or Oil
1 cm^3	3.30	0.9 lb coal
1 m^3	3.30×10^6	433 tons of coal or 1870 bbls of oil
1 km^3	3.30×10^{15}	4.33×10^{11} tons of coal or 1870×10^9 bbls of oil
0.67 km^3	2.20×10^{15}	1250×10^9 bbls of oil (estimated initial world oil reserves)
8.2 km^3	27×10^{15}	Total World Supply of Fossil Fuels

1 cubic kilometer to 1,870 x 10^9 barrels of crude oil, or to 1-1/2 times the crude-oil reserves of the world.

These circumstances, including the abundance of water on the earth, and the fact that the end-product is common helium which is nonradioactive, make the achievement of controlled fusion potentially one of the most important goals in the history of mankind.

This problem was reviewed at the conference on energy by James L. Tuck of the Los Alamos Laboratory. His report was one of tempered optimism. A great deal of essential fundamental knowledge is being acquired which, within a decade or two if not earlier, may permit solution of the problem of controlled fusion.

One point on which Mr. Tuck made a very strong plea was the prevention of present wastage of helium. Helium is absolutely essential in the cryogenic work to produce strong magnetic fields by means of superconductivity, and such fields appear to be indispensable as a container for fusion reactions.

A much more complete review of the problem of obtaining controlled fusion is given under the heading, "The Goals and the Problems," on pages 228-243 of "Research on Power from Fusion and Other Major Activities in the A. E. C. Programs," A. E. C. Semi-Annual Report, January-June, 1958.

It may be well to stress that in the reaction shown in Figure 59, one neutron is produced with each atom of Helium-4. Since neutrons not only produce fissioning in fissile isotopes, but render many other elements artifically radioactive, a fusion power plant may be difficult to operate on that account. Certainly very heavy shielding will be required, and to accomplish this it might prove desirable to locate such plants at a considerable depth underground.

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CHAPTER VII

OUTLOOK AND RECOMMENDATIONS

Recapitulation

From the review which we have just made it should be clear that our modern industrial civilization is distinguished from all prior civilizations, and from all contemporary civilizations in the so-called underdeveloped areas of the world, in its dependence upon enormous quantities of energy obtained from sources other than the contemporary biologic channel, and upon correspondingly large quantities of other mineral products, particularly the ores of the industrial metals. We have also seen that, although this development has had its beginning in the remote prehistoric past, most of it has taken place within the last two centuries, and principally since the year 1900.

Rates of Growth

We have seen how the progressive manipulation of the world's energy flux by the human species and, more recently, the tapping of the large stores of energy contained in the fossil fuels have continuously upset the plant and animal ecological equilibria, and almost always in the direction of increase of the human population. Consequently, during the last century or two—the period of history with which we are most familiar--the pattern of change which we have observed, and in which we have participated, has been of almost continual growth—growth of the world population at an increasing rate which has now reached 2 per cent per year, growth of the United States population from the first census in 1790 until 1860 at 3 per cent per year, growth in the world rate of industrial energy consumption for nearly a century at 4 per cent per year, and of United States consumption at 7 per cent per year.

Yet when reviewed in historical perspective, we have seen that these recent developments have had no precedents in human history, and that the rates of growth we have been witnessing, instead of being the "normal" order of things, are in fact the most abnormal in human history—the usual, or normal, state of affairs being one in which the magnitudes of various human activities have been subject to an almost imperceptible rate of change.

That such rates of growth are essentially ephemeral, and cannot be continued into the future indefinitely, can be seen by noting that the earth on which we live is finite in magnitude; whereas no physical quantity, whether the human population, the rate of energy consumption, or the rate of production of a material resource such as a metal, can continue to increase at a fixed exponential rate without soon exceeding all physical bounds.

For example, during most of the nineteenth century the rate of production of pig iron in the United States increased at 6.4 per cent per year. At such a rate of growth the production rate doubled in 11 years and increased 10-fold in 36 years. By 1900 the production rate had reached 15.4 million metric tons of pig iron per year. With eight more 10-fold increases the rate of pig iron production would be increased by 100 millionfold, or to 15.4×10^{14} metric tons of pig iron per year. At a steady rate of increase of 6.4 per cent per year this would take place during eight 36-year periods, or in 288 years.

The figure of 15.4×10^{14} metric tons is approximately the estimated total iron content (at 4.7 per cent average iron content by weight) of the rocks of the United States to a depth of 2,000 meters, or 1.2 miles. It is manifestly a physical impossibility to continue the nineteenth-century rate of growth until production rates anywhere near this magnitude have been reached. The growth rates not only must decline, but in all instances where exhaustible resources are concerned they must eventually become zero and then negative, as is shown in Figure 17.

For a renewable resource, such as water power, instead of the quantity of energy involved having some definite amount, it is the power which is finite. The growth curve with which we are then concerned is the amount of this power that is brought under control and converted to human uses as a function of time. Such a curve would be that of installed water-power capacity. This must start at zero; and then, after a period of growth, it must eventually level off asymptotic to some maximum amount, which may approach but cannot exceed the water power naturally available in a given area. This is the type of growth represented by the logistic growth curve of Figure 55.

Then we have the growth curves of biologic populations, of which that of the human population is only a particular example. Since the normal ecologic state is one in which biologic populations are nearly constant, or else oscillate with nearly constant amplitudes, as is the case with annual plants and insects, it follows that any rapid departure from this state must be due to some major disturbance.

It is well known, and has been shown experimentally in detail by Raymond Pearl (1925), that when a population sample of any biologic species is isolated from its ecological system and placed in a favorable artificial environment, this population will increase spontaneously at an exponential, or geometrical, rate. However, because of the finite size of the space in which this experiment must be performed, the geometrical rate of increase can continue only for a limited number of doublings before the rate of increase begins to slacken, and decreases ultimately to zero. The population itself increases in the manner of the S-shaped logistic growth curves shown in Figures 22 and 23, a type of growth which is described analytically by equation (7). In fact, the name "logistic curve" was first given to this type of curve, and its basic theory derived by the Belgian mathematician, P.-F. Verhulst (1838; 1845; 1847), in a series of celebrated memoirs on the law of population increase.

In case the food supply, rather than space, is a limiting factor, the population may reach a maximum and then decline and stabilize at some lower level. Or, of course, if the food supply fails it can decline to zero.

In a natural ecological environment (Lotka, 1925), conditions are much more complex. In a near-equilibrium state populations tend to remain nearly constant or to change very slowly with time. However, in response to some major disturbance <u>all</u> populations of the complex undergo rapid change (Figure 60). Some increase by a positive logistic growth to some higher number than before; others decrease and level off at some lower number; some may even become extinct.

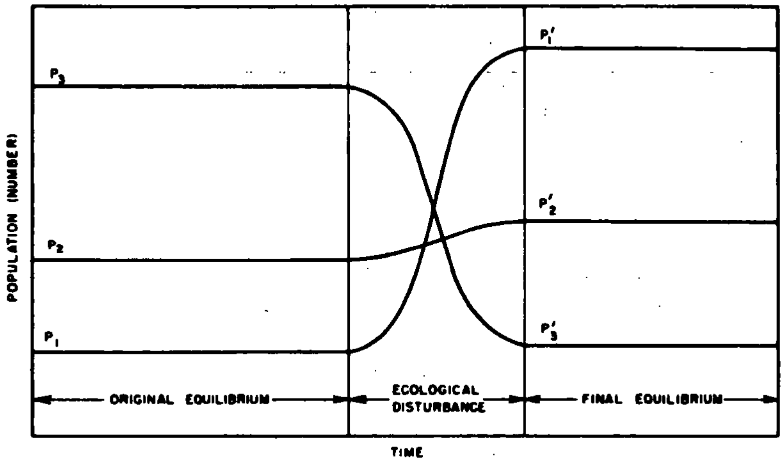

Figure 60. Population Changes Due to Ecological Disturbance

The significance of this to our present inquiry is that the whole biologic complex of the earth is at present in the midst of one of the greatest ecological upheavals known in geological history. The various biological populations are about mid-range in their transitions from their earlier near-equilibrium states to new equilibria at markedly different levels. In this transition some populations, notably that of man, are increasing; others, including most of the familiar wild animals and most native plants, are decreasing; some have already become extinct.

Because the earth is of finite magnitude, it is unavoidable that the present abnormal rate of increase of the human population must eventually slow down and ultimately become zero or even negative. The population itself may level off asymptotic to some maximum number, or it may overshoot and stabilize at a lower, more nearly optimum figure. Or, in the event of a general cultural degeneration, it may be forced back to some level that could be sustained by the industry of a more primitive culture.

The alternatives faced by the human population at the time of the inevitable cessation of growth, as was pointed out by Frank Notestein during an informal panel discussion at Northwestern University on the occasion of its Centennial Celebration in 1951, are the following:

When the population growth ceases, the birth rate and the death rate (number of births per thousand per year, and number of deaths per thousand per year) must become equal. From the point of view of one who has to be a member of the population at that time, the question might be asked: What would be a desirable condition under which to live? Notestein suggested that a high standard of public health might be a major attribute of a desirable condition for existence.

However, a high standard of public health implies a long expectancy of life, which in the United States and Western Europe at present is about 70 years. With a life expectancy of 70 years, and an equilibrium birth rate and death rate, 1/70th of the population would have to be replaced per year, which, on a per-thousand basis, would be 1000/70, or a death rate and birth rate of about 14 per thousand per year.

In case this low birth rate should be unacceptable to the population, and its members insisted upon breeding at the biological rate of 40-50 per thousand per year, then the death rate would have to rise to the same figure. As a result the life expectancy would be reduced to 20-25 years, characteristic of a very low state of the public health. Hence, such a population could choose to have either a high standard of public health or a high birth rate, but it could not have both.

Nonfuel Mineral Resources

We have discussed in detail in the present report the nature of the supplies of the fossil fuels, and have shown that they can be expected to serve as principal sources of industrial energy only for a period of about 300-400 years. During this period petroleum and natural gas will be the earliest of the fossil fuels to approach depletion, with their span of greatest usefulness lasting less than a century. We have not made a corresponding review of mineral resources other than energy, since this is the subject of a companion report by Dean F. Frasché (1962). Nevertheless, since our modern industrial complex depends upon large supplies of both energy and nonfuel minerals, mention of the latter needs to be made in our appraisal of our present position and possible future evolution.

Like the fuels, the nonfuel mineral resources are distributed over the earth in a highly inequitable manner. The principal industrial minerals until now have been coal and iron ores, and the world's regions of industrialization have been limited to the areas of the northern hemisphere, where large quantities of coal and iron ores have occurred in proximity to one another. In countries like Brazil, which has large reserves of iron ore but almost no coal, significant industrialization has so far been impossible. Brazilian iron ores have been transported to the United States and other industrial centers where coal is available.

The mining of metallic ores customarily proceeds from deposits of highest grade, and, as these are exhausted, either mining must cease or else ores of progressively lower grades must be produced. In the United States the high-grade iron ores (50 per cent iron content or better) of the Lake Superior region have already been largely exhausted and mining of the lower-grade (30 per cent iron content) taconite ores is proceeding. The average grade of the copper ores mined in the United States has been declining for some decades, and today ores with a copper content as low as 17 pounds per ton, or 0.8 per cent, are being mined. A century ago most copper producers required ores with an average copper content of not less than 10 per cent; today the world average is 1.5 per cent (Pehrson, 1962, p. 25).

The mine production of lead in the United States reached a peak rate of 684,000 short tons per year in 1925 and 1926, and by 1960 this rate had declined to 244,000 tons, or to 36 per cent of the peak rate. Similarly, the United States production of zinc reached two peaks of about 775,000 short tons per year each, the first in 1926 and the second in 1942 during the war. By 1960 the production rate had dropped to 432,000 tons per year, or to 56 per cent of the peak rate.

The approximate world situation as of 1956 for six of the principal industrial metals—aluminum, iron, zinc, copper, lead and tin—is shown in Table 13. This is taken from a table by Elmer Walter Pehrson (1959, p. 3) of the United States Bureau of Mines, but is based on work by the German mineral economist, Ferdinand Friedensburg. In the first two columns the average percentage content and the total content of each metal in the upper 2,000 meters of the lithosphere are shown. In the following columns data for each metal are given on: (1) the estimated exploitable reserves by present methods, (2) the ratio of exploitable reserves to the total amount of the metal in the ground, (3) the 1956 rate of production, and (4) the number of years supply of exploitable reserves at the 1956 rate of production.

TABLE 13

Quantitative Comparisons of Theoretical Resources and Exploitable Reserves In The Earth's Crust With 1956 World Production, For Selected Metals[a]

(Pehrson's Table 1)

Element	Theoretical Availability[b]		Estimated Exploitable Reserve, billion (10^9) metric tons	Ratio, Exploitable to Theoretical, One to:	1956 World Production, metric tons	Years of Supply in Exploitable Reserve[c]
	Average Content, per cent	Total Resource, billion (10^9) metric tons				
Aluminum	7.48	58,366,000	2.0	29,000,000	3,500,000	570
Iron	4.7	36,674,000	50.0	700,000	200,000,000	250
Zinc	0.017	133,000	0.07	2,000,000	3,100,000	23
Copper	0.01	78,000	0.10	800,000	3,500,000	29
Lead	0.003	23,000	0.04	600,000	2,100,000	19
Tin	0.0005	4,000	0.007	600,000	200,000	35

[a]Based largely on the study by Ferdinand Friedensburg, "The Future Supply of Metals," Zeitschrift für Erzbergbau und Metallhüttenwesen, Dec. 1957, pp. 573-576.

[b]Content of lithosphere to a depth of 2,000 meters; estimated gross weight 780 × 10^{15} metric tons.

[c]At 1956 rate of production.

It is significant that for only two of the metals, aluminum and iron, is the number of years supply of estimated exploitable reserves larger than 100 years. The years of supply of the other four metals range from 19 to 35 years. The ratios of the total content of each metal to the estimated exploitable reserves range, however, from 600,000 to 29 million.

These data emphasize two basic facts of the mineral industry:

1. The estimated world supply of metallic ores of grades now capable of utilization for most minerals is measurable at present rates of production in decades rather than in centuries.

2. The total amount of each metal occurring within minable depths is, on the average, the order of a million times larger than the amount of metal contained in currently exploitable grades of ore.

In principle, it is possible to mine and extract the metals from rocks having much lower metallic contents than present ores, but to do so would require much higher expenditures of energy per unit produced than is required at present, and would also require a much more sophisticated technology, particularly in the direction of large-scale industrial chemistry.

Mineral Requirements to Industrialize Undeveloped Areas.

A problem closely related to that of the mineral and energy requirements of the presently industrialized areas of the world is the question of how much larger these requirements would be if the world were to be industrialized to the extent that has now been reached in the United States. An approximate answer can be given to this question by noting that the United States, with 6 per cent of the world's present population, consumes approximately 30 per cent of the world's total current production of minerals. Let M_1 be the present rate of mineral production, and M_2 the rate that would be required to give the total world population the same per capita mineral consumption as that in the United States. Let P be the world population, and C the United States per capita consumption.

Then the per capita consumption for both the United States and the world would be

$$C = \frac{0.3\ M_1}{0.06\ P} = \frac{M_2}{P}.$$

Solving this for $\underline{M_2}$ then gives

$$M_2 = 5\ M_1\ .$$

In other words, if the whole world were industrialized to the same level as is the United States, the annual drain on the world's mineral resources would be about five times what it now is.

This neglects the fact, however, that before any area can reach the per capita energy and mineral consumption rate of the United States, it must first build up its industry to that level. Were the whole world to have done this, the minerals and energy required would have been about five times the present cumulative production of the world. At such a world rate of consumption the middle 80 per cent of the world's supply of crude oil and natural gas would be consumed during a period of about 15-20 years, and the corresponding period for coal would be reduced from about 350 years to less than a century. Moreover, the presently estimated world supply of the ores of most industrial metals, producible by present technology, would have been exhausted well before such a level of industrialization could have been reached.

Hence, so long as the world depends on the fossil fuels as its principal source of industrial energy, there appears to be little ground for the humanitarian hope of significantly improving the standard of living by industrialization of the underdeveloped areas of the world. For the same reason, there is not very much promise that the activities of the highly industrialized areas can be maintained at anything like present levels for more than a few centuries, and there are possibilities that shortages may develop before the end of the present century.

Necessity of Nuclear Energy.

If a world-wide industrial collapse due to the exhaustion of the fossil fuels and the high-grade ores of metals within the next few centuries is to be forestalled, there appears to be no possible way of accomplishing this except by a newer and larger supply of energy suitable to the requirements of large-scale industrial operations. We have already observed that, while solar power is of this magnitude, it does not offer much promise of concentration such as to provide the power for large electric-power networks. Water power is of a lesser magnitude, but still large and capable of providing power in the hundreds-of-megawatts range in many parts of the world. It still, however, is not large enough, and besides it requires prior industrialization before it can be developed and used.

The only remaining source of energy that does have the proper magnitude and does lend itself to large industrial uses is nuclear. We have already seen that the supplies of uranium and thorium in the United States alone, occurring in concentration of 50 grams or more per metric ton of rock within a depth of 2,000 meters, have an energy content at least hundreds of times, and possibly thousands of times, greater than that of all the fossil fuels in the world. We have noted further that the energy content of 1 metric ton of such rock is equal to that of 150 tons of coal or 650 barrels of oil. Therefore, even if the extraction of this uranium or thorium should require energy equal to a few tons of coal or barrels of oil per ton of rock, the net amount of energy obtainable per ton of rock should still be many times greater than that from an equivalent mass of any fossil fuel.

The resources of fission energy, uranium and thorium, and of fusion energy, deuterium or heavy hydrogen, are quite as exhaustible as the fossil fuels, but the quantities are so large that it is doubtful if any significant diminution of the total reserves could be effected by industrial uses within the next thousand years. Hence, for all present purposes, nuclear energy may be regarded as being essentially inexhaustible in terms of human usage.

With such quantities of energy available, it then would become both possible and practical to work the lower and lower grades of metallic ores, and in so doing to begin to realize a part of the potential million-fold increase in reserves indicated in Table 13, thus forestalling the otherwise imminent shortages of many of the industrial metals. With a source of energy of this magnitude, and the additional quantities of metals which would thus become available, the dream of improving the standards of living of all the races of man no longer appears so visionary.

Time Perspective

The present state of human affairs can perhaps more clearly be seen in terms of a time perspective, minus and plus, of some thousands of years with respect to the present, as depicted in Figure 61. On such a scale the phenomena of present interest—the growth in the rate of consumption of energy, the growth of the human population, and the rise in the standard of living as indicated by the increase in the per capita rate in energy consumption—are all seen to be represented by curves which are near zero and rising almost imperceptibly until the last few centuries. Then, after an initial gradual increase, each curve, as the present is approached, rises almost vertically to magnitudes many times greater than ever before.

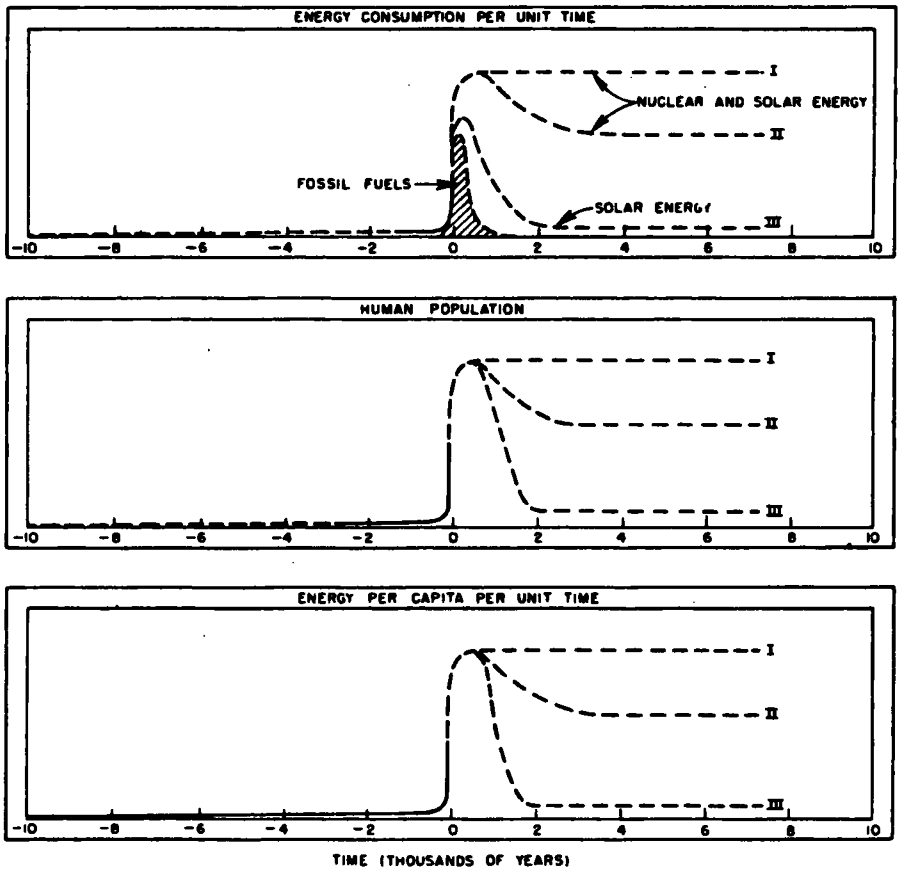

Figure 61. Human Affairs in Time Perspective

On this time scale the consumption of fossil fuels is seen to rise sharply from zero and almost as sharply to descend, with the total duration of the period of consumption representing but a brief interval of the total period of human history.

As to the future, if we disallow imminent annihilation by nuclear warfare, three distinct possibilities appear to exist. These are represented on the graphs as Courses I, II and III. One possibility, shown as Course I, is that we may be able to maintain our present scientific and technological culture, using the fossil fuels as an essential intermediate step in the transition to ultimate dependence upon the large-scale use of nuclear energy. Should this be successfully accomplished there appear to be no physical reasons why we should not be able to level our activities off asymptotically to some maximum level which could be maintained for many centuries.

There is also a possibility, indicated as Course II, that we may not succeed in overcoming the cultural lag between our inherited folkways and our present requirements in time to prevent a serious overshooting of the world population above a manageable magnitude. After a temporary state of chaos we might still be able to stabilize our population and the magnitude of our industrial activities at some lower and more nearly optimum level which could be maintained for a long period of time.

Finally, there is the possibility, indicated as Course III, that we could go into a state of confusion and chaos, including nuclear warfare, from which we might never be able to recover. In that case we could suffer a cultural decline and return to our former agrarian and handicraft level of culture. At what level the population would become stabilized in this event it is not possible to state with any assurance, but since modern medicines and techniques of public health are a by-product of our present culture, and not otherwise possible, it appears doubtful whether a population nearly as large as that of the present could be sustained.

Which of these three possibilities may be the one actually realized depends largely upon the foresight that can be exercised with respect to the guidance of human affairs, and in large measure on whether the cultural lag can be sufficiently reduced between the inhibitory sacred-cow behavior patterns which we have inherited from our recent past and the action requirements which are necessitated by the socio-industrial complex with which we have to deal. If such impediments can be overcome it is entirely possible that, with only minor extensions of our present knowledge of the physics, chemistry, biology and geology of the world in which we live, we shall be able to make the transition to a stabilized industrial civilization with a decent standard of living and a high standard of health for all the world's human inhabitants. If we are unable to make this transition, and if we do permit ourselves to go into a cultural decline, then, as Brown, Bonner, and Weir (1957, p. 151) have pointed out, it is doubtful whether we shall ever be able to arise again.

Recommendations

If our future evolution is to follow one of the more desirable paths—one characterized by a high per capita utilization of energy, a general state of individual well-being, and a high standard of public health—then it is clear that a number of essential steps must be taken, some sequentially and others in parallel. Among the more important of these are the following:

I. The growth of the world's population must be brought under control.

While this is a problem of formidable magnitude, it is not intrinsically more difficult than the control of disease, in which the medical profession has already achieved marked success. The present flare-up of the world population is in fact the consequence of this success. Until comparatively recently, as we have noted, the world population was almost stationary. The birth rate and death rate were nearly equal but also near the biological maximum of 40-50 per thousand per year, with a life expectancy of 20-25 years.

During the last few centuries, and particularly during the last few decades, the death rate, world-wide, has been dropped spectacularly to a present average value of about 20 per thousand, while the birth rates of most of the world's population have been but little reduced. The difference between the birth rate and the death rate is a direct measure of the rate of population growth.

If the desirable objectives mentioned above are to be achieved, it is essential that the death rate and birth rate must be equalized at a low level compatible with a high standard of public health (about 15 per thousand). If this is not done, assuredly they will eventually become equalized at a level corresponding to a low standard of public health.

This is partly a problem in physiological and medical research and partly a problem in applied sociology and anthropology. As a measure of what can be accomplished when the problem is faced forthrightly, we have the recent experience of the Japanese (Cook, 1959). Here, we have a nation with a population half that of the United States which has deliberately dropped its birth rate during the ten-year period 1947-1957 from 34. 3 to 19. 2 per thousand, the most rapid decrease known in history.

II. New sources of energy must be developed.

As sources of energy for the world's future needs, the fossil fuels are exhaustible, solar power cannot practicably be concentrated, and water power, though large, is inadequate. This leaves us ultimately with only nuclear energy as a source which is both adaptable to large-scale power generation and of sufficient magnitude to meet the world's potential requirements.

Fossil Fuels. Since the fossil fuels are adequate to meet the limited needs of the presently industrialized areas of the world for the next few centuries, there is obviously no immediate emergency as to energy supplies for these areas. Neither, however, are there grounds for complacency, because most of the areas of the world are not industrialized and, so long as we depend upon the fossil fuels, are not likely to become so.

Among the fossil fuels themselves, because petroleum and natural gas are the least abundant and coal the most abundant, it is evident that in the comparatively near future a transition must be begun from crude oil and natural gas to the more abundant reserves of oil shale and tar sand, and ultimately to coal, for our supplies of liquid and gaseous fuels. This transition, utilizing the large research establishments of the petroleum industry, will probably be made in an orderly manner as rapidly as new sources of liquid and gaseous fuels are required, and no additional research effort in this field appears to be needed.

In the coal industry proper, however, there is need for increased integrated research in all phases of production, processing, and transportation. Research of this kind would particularly benefit by a reorientation in which coal is regarded as an energy and organic-chemical raw material rather than as just a fuel, much as crude oil is regarded by the petroleum industry.

Although coal represents nearly 80 per cent of the energy reserves of the fossil fuels in the United States, it has been a depressed industry, largely because of a displacement by oil and gas, since World War I. One of the largest bottlenecks in present coal utilization arises from the prohibitive costs of railroad transportation. Promise of eliminating this bottleneck is now afforded by the recent successful developments in the transportation of coal in the form of a coal-water slurry by pipeline at a greatly reduced cost. The present impediment to this form of transportation is the lack of the right of eminent domain for coal pipelines. The granting of this right by means of the legislation proposed by President John F. Kennedy in his letter of March 20, 1962, to both houses of Congress, is highly recommended.

A needed restriction in the uses of coal should also be mentioned. Of all the coal reserves in the United States only a small fraction is suitable for the manufacture of metallurgical coke, which is particularly essential for the smelting of iron ore. Much of the coking coal has already been indiscriminately mined and burned as fuel. A control is needed whereby only noncoking coals are burned as fuels, reserving the more valuable coking coals for the metallurgical industry.

Nuclear Energy. The eventual dependence upon nuclear energy as the principal source of industrial power in areas which now have abundant fossil fuels, and the immediate needs in other areas, makes it essential that research and development in this field should be vigorously pursued. With regard to fission energy, there are two very important problems. The first is the development of power reactors based upon complete or nearly complete breeding. This will permit the utilization not only of common uranium-238 but also of thorium-232. More importantly, it will make it economical to consider rocks with uranium and thorium contents as low as 50 grams per metric ton as practically utilizable ores, and so will enormously enhance the magnitude of the reserves of nuclear fuels.

The second problem associated with fission reactors is that of safe disposal of the highly dangerous radioactive fission-product wastes. These wastes, some of which are dangerous for the order of a thousand years, must be completely isolated from the biological environment for their periods of danger. Up to the present, the work in this field has not been pursued with a vigor commensurate with its importance. It is recommended that the budgetary support for such work be increased considerably—possibly several fold—over the average of the last few years.

The control of the fusion reaction—deuterium to helium—possibly represents the greatest energy goal now known. The problem is one of very great difficulty and may never be solved. Nevertheless, what is most needed at this stage of development is systematic, long-range, fundamental research of the type now being pursued, rather than some kind of a crash program. Continuation of this research at about the present level is recommended.

Synthesis of Chemical Fuels. Automotive vehicles for both highway and air transportation are dependent for their energy supply upon the energy stored chemically in the form principally of liquid fuels, and, so far as can now be seen, will continue to be so. Heretofore these fuels have been obtained almost solely from the fossil fuels in which the energy was originally stored by photosynthesis. On the other hand, it has long been known to be possible to manufacture simpler but equally useful fuels by means of the schematic chemical reaction

$$\text{Energy} + CO_2 + H_2O \rightarrow \text{Fuel} + O_2.$$

This has not been done because the energy required for the reaction would have to be obtained by burning already synthesized fossil fuels.

With the advent of nuclear energy this situation is drastically changed. Here, with an almost unlimited supply of energy potentially available, it would be a comparatively simple matter to synthesize any desirable quantity of liquid and gaseous fuels from common inorganic substances such as water and limestone. Were this eventually to be done, our remaining fossil fuels, comprising already synthesized complex organic molecules, could be more effectively used as the raw material for an increasingly versatile chemical industry.

III. Eventual dependence upon low-grade deposits for our principal supplies of industrial metals, and of other nonfuel mineral products, must be anticipated.

Since this has been covered in a companion report on "Mineral Resources" by Dean F. Frasché, it will not be further discussed here. It is mentioned only to emphasize the fact that the nonfuel mineral resources, together with the energy resources and the population problem, constitute a triumvirate of perhaps the foremost problems now confronting the human race.

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ATIONAL POWER SURVEY

FEDERAL POWER COMMISSION—1964 PART I

WILLIAM ELECTRIC CO-OP • OHIO EDISON CO • GULF STATES UTILITIES CO • SOCORRO ELECTRIC CO-OP • LUBBOCK

ECTRIC CO-OP • WISCONSIN ELECTRIC POWER CO • CITY OF BAY CITY ELECTRIC DEPARTMENT • LONG ISLAND LIGH

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GUIDELINES FOR GROWTH OF THE ELECTRIC POWER INDUSTRY

OBJECTIVES OF THE SURVEY

It is the earnest hope of the Federal Power Commission that the National Power Survey, to which many outstanding people from all segments of the electric power industry have made important contributions, will set a standard and be a guide for the future planning of the industry. What we have set forth is not a blueprint but an illustration of a possible pattern of efficient development. We hope it will excite interest in the many opportunities for savings which should be explored.

We have also suggested that the American consumer should benefit from these savings in the form of lower rates and steady improvement in the already very high quality of service.

The goal we propose is an electric power industry animated by a broad and bold vision of its role in contributing to the growth and welfare of the Nation's economy. We have tried to suggest an outline for the coordinated growth of the industry in the future which will attain that objective.

To make this goal a reality will require cooperation among the men responsible for management of the power systems throughout the Nation. It will require that they concentrate their efforts on realizing and sharing equitably the enormous potential benefits of a truly integrated system of power supply embracing all segments of the industry and every State in the Nation.

JOSEPH C. SWIDLER, *Chairman.*

DAVID S. BLACK, *Vice Chairman.*

LAWRENCE J. O'CONNOR, Jr., *Commissioner.*

CHARLES R. ROSS, *Commissioner.*

OCTOBER 23, 1964.

NATIONAL POWER SURVEY

A REPORT BY

THE FEDERAL POWER COMMISSION

1964

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*Photograph.

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*Photograph.

PREFACE

On January 24, 1962, Chairman Joseph C. Swidler first announced the purpose of the Federal Power Commission to conduct a national power survey. President John F. Kennedy, in his Message on Conservation to the Congress of the United States, delivered February 28, 1962, expressed his endorsement of the proposal in the following terms:

> The ability to make long-range plans for the expansion of our Nation's electric power supply required by constantly growing power needs will be enhanced by a comprehensive nationwide survey to be undertaken by the Federal Power Commission. Under existing authority contained in the Federal Power Act, the Commission will project our national power needs for the 1970's and 1980's and suggest the broad outline of a fully interconnected system of power supply for the entire country. This information will encourage the electric power industry—both private and public—to develop individual expansion programs and intertie systems permitting all elements of the industry—and more importantly the consumers—to benefit from efficient, orderly planned growth. *I urge favorable action on the request for adequate funds to initiate this study of the Nation's power needs for the next 20 years.*

The Congress has made provision in successive budgets for the required funds.

The Report was prepared by the members of the Federal Power Commission and its staff. The staff work was carried out under the direction of F. Stewart Brown, Chief Engineer and Chief of the Bureau of Power. The members of the staff who made major contributions to the Survey are listed in the acknowledgments at the end of the report.

The National Power Survey on which this report is based was conducted in cooperation with all segments of the electric power industry. The Commission wishes to express its profound gratitude to the many executives and technical experts throughout the country who have given unsparingly of their time and effort. They are too many to name here, but we express particular indebtedness to the advisory committees, and especially the Executive Advisory Committee, of which Philip Sporn was Chairman and G. O. Wessenauer was Vice Chairman, and the General Technical Advisory Committee headed by Robert Brandt as Chairman and Charles Almon as Vice Chairman. As an illustration of the seriousness with which the advisory committees undertook their work and the extent of their contributions, the Executive Advisory Committee met with the Commission in Washington on 18 separate occasions. The members of all the committees are listed in the acknowledgments at the end of the report.

Notwithstanding our indebtedness and gratitude to the advisory committees, the Commission alone takes responsibility for the Survey Report.

Howard Morgan was a member of the Commission during the initiation and early programming of the Survey.

The Commission notes with sorrow the death on August 4, 1964, of Commissioner Harold C. Woodward, who helped to encourage and guide the work of the Survey. We also note with regret the death on April 6, 1963, of Dr. Paul J. Raver, who contributed greatly as a member of the Executive Advisory Committee in the formative stages of the Survey.

INTRODUCTION—BACKGROUND AND HIGHLIGHTS OF THE SURVEY

The electric utility industry of the United States stands at the threshold of a new era of low-cost power for all sections of our country. Many exciting new technological developments point the way. Larger and larger machines are being built which can generate electricity at progressively lower costs. These huge power plants burning fossil fuels are presenting a moving target for nuclear power plants which nevertheless are rapidly becoming more and more competitive. Extra-high-voltage (EHV) transmission lines can now move power economically for many hundreds of miles. EHV transmission has thus greatly enlarged the marketing area for large blocks of low-cost generation and has also increased the long-standing advantages of interconnecting power systems into power pools covering ever broader geographical areas.

The Nation's rapidly expanding use of electricity is expected to more than double and perhaps triple by 1980, and the physical plant of the industry will show corresponding growth. This large growth will give the industry an opportunity, assuming adequate research and development, to incorporate the many major technological advances into these new facilities. Consumers and the industry alike stand to gain if duplication of facilities is eliminated and this huge cost of more than $100 billion is invested in equipment which will meet the test of maximum efficiency.

The National Power Survey is a major undertaking by the Federal Power Commission, in cooperation with advisory committees drawn from all segments of the electric power industry, to give greater impetus to the trend toward integration of the Nation's power systems. The Survey suggests how all of our electric power systems can move from isolated or segmented operations, and from existing pools of limited scope, to participation in fully coordinated power networks covering broad areas of the country. In time, when justified economically, all the electric systems in the entire nation may be joined in a single interconnected network.

The National Power Survey was undertaken by the Commission because the many technological opportunities for further coordination of the Nation's 3,600 electric power systems suggested the need for broader planning of the coordinated growth of the industry than had yet been attempted. The Survey represents the first comprehensive study of the industry as a whole, covering the entire Nation and all ownership segments. The Survey suggests possibilities for further coordination in planning the large expansions of our power systems in the decades ahead while retaining the initiative of a pluralistic ownership pattern. In our opinion the technology of large scale generating stations and extra-high-voltage transmission interconnections has now reached the stage where closer coordination of the construction plans and operations of individual systems in the industry is highly feasible and necessary if the consuming public is to receive the benefits of lower cost electricity which our technology now makes possible.

A major purpose of the Survey is to point out possible patterns of expansion that may result in reduced costs and to indicate the order of magnitude of these savings. The Survey thus is encouraging the industry to initiate broader regional and interregional planning in which all ownership segments can plan and build facilities to meet their combined needs to the mutual advantage of themselves and their consumers. In short, the Survey was conducted by the Commission as the most effective means of carrying out the provisions of section 202 (a) of the Federal Power Act which directs the Commission to "promote and encourage . . . interconnection and coordination" of electric utility systems for . . . "the purpose of assuring an abundant supply of electric energy throughout the United States with the greatest possible economy and with regard to the proper utilization and conservation of natural resources . . ."

The importance of the congressional mandate to the Commission to encourage interconnections has never been greater than it is today. The swift march of technology makes the opportunity for progress toward a fully coordinated power supply network not remote but immediate. The challenge to the industry is the speedy adoption of the broad range of technological advances in the construction of the facilities required to meet the loads of tomorrow.

The industry's past achievements, which have made it by far the largest and among the most efficient sources of electric power supply in the world, give us every reason to expect that this new challenge will also be met.

The National Power Survey is confined to the electric power industry and thus tends to emphasize the opportunities for growth in the use of electricity in the decades ahead without a similar emphasis on the growth potential of natural gas or other forms of energy. The Commission from its own regulatory experience is, of course, aware that a similar pattern of growth could be projected for the natural gas industry, which has had a spectacular growth since World War II, and we wish to emphasize that the Commission does not in any way mean to imply a preference for one form of energy over another. On the contrary, as the Survey Report makes clear, the American consumer will be the final judge as to the precise share each form of energy will supply in our growing energy market. We all stand to gain from the healthy competition which is developing as the electric power industry and the natural gas industry both strive to improve their service and reduce their rates.

We emphasize that the future patterns of the Nation's power systems depicted in the Survey Report are not intended as blueprints, because no one can foresee the many changes in technology, operating conditions, or market potential that may occur in the years ahead. What we have set forth is an illustration of a possible pattern of efficient development. Our purpose is to excite interest in the many opportunities for savings that should be explored, rather than to propose any final answers. The Power Survey is intended as the beginning, not the end, of planning for the best possible power system of the future.

The Survey could not have been conducted without the public-spirited assistance of all segments of the industry and of other governmental and private agencies. This assistance was channeled through advisory committees created to advise the Commission on all aspects of the Survey. The committees included an Executive Advisory Committee and a General Technical Advisory Committee, special technical committees on transmission and interconnection, power requirements, generating stations, fuels, distribution, a legal advisory committee, and regional advisory committees.

The membership of all these groups included top executives and outstanding engineers, economists and lawyers from every branch and segment of the industry. Twenty-four committee reports have been published. These reports, many of which represent the best in advanced thinking on industry problems, in themselves are a major contribution to industry planning. They were helpful building blocks for the Commission's own Report. The committee memberships are listed in the acknowledgments at the end of the report, and the technical reports prepared by the Committees are published in a separate volume as a part of the Survey Report.

While these Advisory Committees have been invaluable to the Commission in the conduct of the Survey, their members are not responsible for any statement or conclusion in the Report. The Survey Report reflects innumerable helpful comments from our advisors, but none of them necessarily agrees with the many comprehensive conclusions.

The Power Survey Report was prepared by the Federal Power Commission and its staff and the Commission assumes full responsibility for the exposition, analysis, and conclusions of the Report. Nothing stated in the Report, however, is to be construed as Commission approval, disapproval, or recommendation of any particular project. The focus of the Report is on general lines of growth and power system development.

One of the most encouraging aspects of the National Power Survey is the manner in which representatives from all segments of the industry worked together to achieve positive results. The committee discussions and the reports in which the committee members joined have contributed to the industry's thinking and oriented its current planning toward greater coordination and cooperation among all sectors of the industry. The high degree of unanimity achieved within the various committees, all of them broadly representative of the elements of the industry, is in itself a demonstration of the broad range of common problems and the ability of industry representatives to work together to solve them.

One important immediate byproduct of the Survey has been an increased awareness of the need for the electric power industry to devote more manpower and money to joint projects for research and development of the technology to make the pace of progress ever swifter.

A comparison of the present Survey Report with the first "national power survey" begun by the Federal Power Commission in 1935 is illuminating. A final report was never issued, but in an Interim Report (Power Series No. 1, 1935) the Commission suggested that a future report "of the highest public interest" should deal with "improving the interconnection and coordination of existing power facilities." In support of such a study the 1935 Interim Report referred to the growth of interconnections as being "relatively haphazard, handicapped by intercompany rivalries and prejudices and by artificial barriers, such as State lines, prohibitory laws and a lack of uniformity in tax laws in adjoining communities." Fortunately, a good part of that indictment has been erased by the industry's progress in building interconnections during the past 30 years; yet even today many individual systems are subject to the same criticisms.

The early decades of this century witnessed the swift discovery of new uses of electricity and the unparalleled growth in the Nation's material and living comfort which these uses helped to make possible. Beginning in the 1930's the rural electrification movement accelerated the coverage of the outlying country areas so that today more than 98 percent of American farms are served by electricity, as high a percentage as anywhere in the world. Today, virtually every American home, business and community, however small, enjoys, and is vitally dependent upon, this most versatile of all forms of energy.

The phenomenal growth in the use of electricity in the United States, which on the average has doubled every decade for its 80-year history, is due in large part to the fact that the industry's technological progress has made electricity one of the best bargains available. The long-term trend of electric rates has been downward even in the face of inflation. In perspective the industry has set a high standard in meeting the Nation's power needs.

The goal of the Survey is to help continue and if possible accelerate the trend of lower unit costs which promotes increased use of electricity.

The particular means of achieving greater economy upon which the Survey has focused is for power systems to plan together for cost reductions on a more comprehensive basis than has yet been undertaken. Planning has always been a tool of utility management on an individual company basis. In some areas the planning unit has become the area pool. In others informal coordination arrangements have served to broaden the planning perspective. We believe these approaches should on the one hand be broadened further to include all areas of the country and the systems of all segments of the industry, and on the other hand should be intensified to include more complete coordination in the construction of new facilities as well as their operation.

The Survey makes clear that the manner in which the Nation's 3,600 separate power systems plan and build for the future is of national concern. All generation and transmission facilities, whether owned by private, cooperative, Federal or other public agencies, should be planned and built as part of large coordinated power networks to achieve the lowest cost of bulk power supply. The economies of scale in large generating units coupled with low-cost energy transportation suggests that individual power systems should join together in constructing new capacity either through joint projects or by staggering their construction programs. Diversity in load patterns offers additional opportunities for capacity savings through interchange arrangements over broad areas.

These considerations point up the Nation's interest in encouraging every power generating system to look far beyond its own service areas in its planning of new capacity and of interconnections for capacity savings. Planning to coordinate the investments in new facilities and the operation of all of the power systems over broad areas of the country is a must if we are to achieve the objective set forth in the Federal Power Act of "an abundant supply of electric energy throughout the United States with the greatest possible economy." The Nation can afford no less.

Growth in power consumption and closer coordination of power systems are the twin ingredients in the formula for reducing future power costs. Large-scale plants and other facilities which make full use of the new technology cannot be built without increased demands for power which will justify large additions to capacity and more intensive use of existing facilities. The Survey stresses the advantages of coordinated growth. Growth and coordination are interrelated, and we recognize that a large increase in per capita use of electricity by 1980 is vital to achieving the major savings which the Survey projects.

The Nation has a large stake in the electric utility industry's continued progress toward making the promise of the new technology a beneficent reality. Our total electric power bill in 1963 was approximately $14 billion. By 1980 Americans may be using nearly three times as much electricity but paying only about twice as much—about $30 billion a year—provided the industry continues to achieve net reductions in unit costs in the face of increased cost of labor, land, equipment and materials.

At stake by 1980 are possible savings of as much as $11 billion a year to the American consumer. Much of these savings will result from the lower unit costs brought about by growth in loads but the rate of growth will in turn depend on reduced unit costs and reduced rates that will encourage greater use, a cycle of continuously interacting cause and effect.

By 1980, the requirements for fuels of all kinds for our electric systems, expressed in terms of coal equivalent, may be as much as 900 million tons a year. Even a 5-percent improvement in generating efficiency will save 45 million tons a year and thus add measurably to the life of our limited low-cost fossil fuel supplies which will continue to be needed while we perfect the processes of nuclear fission and fusion for production of electricity.

Any study of our Nation's future energy needs must take into consideration that our population is growing rapidly and that our dependence on energy is increasing as we continue to raise our standard of living. In less than 50 years from now, some 400 million Americans are expected to constitute this Nation, more than double the present population. Achieving maximum efficiency from our energy resources is a prime economic goal today, but as our population grows it will become an absolute necessity for maintaining an industrial civilization with a high standard of living for all.

Minimizing energy costs in the years ahead will be a key element in maintaining our predominant position in the world. Our needs for the raw materials to feed our industries will be enormous and we know that while high-grade deposits of many minerals are limited, low-grade deposits are large. The key to transforming many of these low-grade mineral deposits into useful raw materials is low-cost energy. Water supply is already a problem in the West and as water supplies continue to dwindle in relation to expanded requirements, we must expect large electric power requirements for water treatment, desalination and the transportation of water between watersheds. Attaining an abundant low-cost energy base, which the Survey stresses, is among this Nation's most important long-term national concerns.

The Survey findings suggest that no longer need the availability of low-cost power be confined primarily to areas with low-cost hydro power or an economical fuel supply. Low-cost energy transportation is rapidly making all of the Nation's fuel and water power resources a common fund, economically available at great distances from their origin. The dramatic recent improvements in the cost of transportation of fuel by railroad and other modes, and in the transportation of energy itself through EHV transmission lines, will sharply reduce the differences in power costs among the various sections of our country. As power networks cover broader areas power costs should become more uniform and lower. High-rate areas stand to gain the most, first in reductions in power costs and then in an accompanying expansion in the use of electricity and the enjoyment of its benefits.

The Nation is beginning to realize that it has just as great an interest in the full development of our limited number of prime steam plant sites, as in the maximum development of our hydroelectric resources. A good steam plant site requires a location near the fuel source or the market, or both, access to plentiful supplies of condensing water, access to transportation, freedom from flood threat, favorable geological conditions, a large tract of land available at moderate cost, and other site advantages. A site which meets all these criteria should be put to maximum economic use for the benefit of the largest area it can serve.

The industry's pluralistic institutional structure, while perhaps inhibiting coordinated operations, has proven a powerful competitive stimulus to management improvement and cost reduction. The Nation's 3,600 separate electric power enterprises are operated by a great diversity of agencies, some investor-owned, others owned by cities, States, counties, public utility districts and cooperatives, as well as by the Federal Government. Together, they provide this country with a system of power supply which at the retail level is generally responsive to local needs and local control. However, the large number of separate systems coupled with rivalries and controversies between segments of the industry has frequently resulted in economically meaningless boundaries for utility system planning and operation which undoubtedly cost the power consumers of this country millions of dollars every year in wasted opportunities for cost reduction. These boundaries can be transcended without losing the benefits of the existing pluralistic institutional structure if all segments of the industry, and all the individual systems within each segment, would realize that their ideological differences are no bar to working together in establishing stronger regional and interregional power pools. To do so would strengthen all and diminish none.

The National Power Survey does not attempt to resolve or even examine all the existing or anticipated institutional problems of the electric utility industry. Rather, we are here concerned with demonstrating the opportunities of full utilization of our technology and our fuel, capital and management resources, and how they can improve the lives of all Americans in the years ahead.

We are aware that many controversial areas of public policy are related in one way or another to the industry's success in lowering power costs. These policy areas include the territorial integrity of the retail marketing areas of competing systems, the usefulness of public power programs as a yardstick to supplement regulation of privately owned systems, the differential revenue requirements because of variations in the tax, financing and earnings requirements of individual systems, the obligations of the large systems in their relationships with the small in power supply arrangements and in competitive situations, the proper role of statutory preferences to public and cooperative power distributors for the sale of power from Federal systems, and many others. We believe that the National Power Survey Report is not the appropriate medium for attempting to reconcile the conflicting views on these issues of public policy, if that were feasible, or to formulate or express our own views on these issues. The question of the proper scope of government in regulating or conducting economic affairs is one of the root problems in a democracy. We do not attempt to resolve it in this report.

We are convinced that none of these problems present an insuperable barrier to achieving the full benefits of a system of power supply in which the separate and independent ownership of individual systems is preserved, but their facilities are nevertheless coordinated in large power pools interconnected on a nationwide basis to achieve maximum economies. This was also the unanimous view of our Legal Advisory Committee, made up of outstanding lawyers from every segment of the industry. What is required is a good-faith effort by all segments of the industry to coordinate their efforts for mutual benefit. The opportunities afforded by our technology are not the special province of any segment of the industry. Their full utilization can and should be the goal of all segments.

The challenge facing the electric power industry is to continue the long-term trend of selling electricity to the consumer at steadily lower prices. We are suggesting an industry target for 1980 of approximately 1.2 cents per kilowatt-hour as the combined average retail price for all residential, commercial and industrial sales of electricity throughout the Nation. The comparable figure in 1962 was 1.7 cents and in 1940 it was 2.2 cents.

The Commission is aware that it is setting an ambitious goal. There are many items of cost that will undoubtedly increase and net reductions of this magnitude are difficult to attain. However, the electric power industry's performance has always confounded the prophets and exceeded the hopes even of those who believe in the promise of the future. We believe the goal is realistic. A large proportion of the reduction in average price will come from increased usage alone. If we consider, in addition to growth, the many other opportunities for reducing unit costs, who is to say that 1.2-cent power at retail on the average cannot be made available throughout the country by 1980? We believe that if the Nation's number one industry utilizes all of its resources and ingenuity it will meet this challenge. The purpose of the Survey is to suggest the general paths along which this important goal can be achieved.

A guide to an understanding of the industry today and evaluation of its development in the future is the makeup of the so-called "fixed charges." The term "fixed charges" covers the costs which vary with the investment and which are independent of the extent to which that investment is used. Return on investment including bond interest and earnings on the equity capital, depreciation, insurance and property taxes are all items in this category, and the term is also commonly used in the utility industry to cover the income taxes associated with the authorized level of earnings.

For public and cooperative agencies fixed charges are approximately half the level of those of the investor-owned companies. This is due to financing advantages resulting from Federal and state tax exemptions and (in the case of the cooperatives) Federal loans at low interest, and also to the fact that the non-profit nature of the public and cooperative systems makes it possible for them to operate on the basis of a lower earnings level.

The institutional characteristics which result in the fixed charge variations are based upon constitutional and policy considerations which are important and deep-seated and beyond the scope of this report to appraise.

For purposes of most project comparisons the Commission has used fixed charges of about 11 percent, which it determined to be a reasonable weighted average of the combined industry's fixed charges which may be expected for plants built in the next 15 years, thus assuring that projects will be compared on uniform standards. Because hydroelectric generation is often an important part of Federal multipurpose projects to develop a fuller use of our water resources, such projects were also tested on the basis of a fixed charge scale for Federal projects to assure that any meritorious project would not be overlooked. For the purpose of computing the average cost of power in particular regions of the nation on a meaningful basis we used a composite fixed charge based on the fixed charges of the particular power enterprises in the region. These varying fixed charges were not used for any comparisons of projects or project evaluations but merely to provide a realistic basis for estimating power costs in 1980.

A survey of the opportunities for the 1970's must begin with knowledge of the electric power industry as it is serving the Nation today. To fill that need, chapter 1 presents a comprehensive and we believe objective description of the present makeup of the industry with enough of its history to give some insight into the evolution of its special pluralistic structure. The chapter concludes with some interesting statistics on existing rates throughout the country.

The key to the future of the industry is its growth. We are projecting that power demands in 1980 will require the production of 2.8 trillion kilowatt-hours of electricity or more than 2½ times the estimated production of 1.1 trillion kilowatt-hours in 1964. Chapter 2 presents the national and regional demand forecasts which support this projection. The chapter also suggests some of the ways in which electricity can add to the comfort and convenience of the daily lives of everyone.

Chapters 3 through 14 review and project the technology which will be available for building and operating tomorrow's power generating plants and outline complementary or alternative paths of development. Chapter 3 is devoted to fuels and fuel transportation, and chapter 4 to conventional steam plants. Chapter 5 which discusses nuclear plants is of particular interest as it projects a greatly enlarged role for nuclear plants as a source of low-cost power for the decades ahead. Hydroelectric power resources are discussed in chapter 6, peaking power including pumped storage in chapter 7, and the so-called exotic sources in chapter 8.

Chapter 9 of this group is one of general public interest because it deals with environmental considerations such as the means by which pollution of the air and our rivers can be minimized. The chapters which follow, 10–14, outline the developments in extra-high-voltage transmission, both AC and DC, the emerging trends in distribution systems, and the improvements in controls for intersystem operations, developments which are crucial to the broad expansion of our power networks to permit the efficient flow of power from generation source to the ultimate consumer. These chapters also explain the concepts of coordination and the diversities in load patterns and reduction in reserve requirements which full coordination can achieve.

The heart of the Report is chapter 15 which first discusses the criteria for power system planning, and next presents an illustrative pattern of power generation and transmission by 1980, with full regional and countrywide coordination and an indication of the savings that could be achieved as compared with the individual planning decisions of the Nation's power systems. The staff studies support estimates of potential net economies in the order of $11 billion annually from increased usage and from closely integrated power networks covering broad areas of the country, fully recognizing, of course, that the offsetting costs of attaining closer coordination must be accounted for in determining the net savings.

We again emphasize that the depicted patterns are not intended as blueprints. Detailed engineering, which we have not undertaken, must precede any construction, and would undoubtedly point to major departures from the tentative proposals in the Report. What is intended and what we think is shown is the magnitude of the savings and the general outline of a possible approach to the job which can, and we are confident will, be accomplished.

Chapter 15 also suggests, region by region, the general mix of nuclear, hydro, and conventional steam capacity, the general range of desirable unit sizes, and the possibilities for EHV interties. Thus, the Report maps a hypothetical pattern of high-voltage transmission lines and generating capacity for each part of the country. These studies represent the first time that an overall outline for planning the coordinated growth of all of the power systems of this country has been prepared with the view of achieving a common goal of maximum efficiency.

Chapter 16 of the Survey is devoted to the smaller systems which constitute about 3,200 of the approximately 3,600 power systems in the Nation. We have explored the various alternatives by which small systems in every segment of the industry can participate in fully coordinated power networks and thus obtain their power supply from low-cost sources so that they too can share in the benefits of our new technology.

Chapter 17 brings to a focus the economic significance of the patterns of growth we have visualized. It projects the potential savings to consumers which will result from the growth and technological improvements projected in the Survey Report. The chapter suggests the magnitude of these possible savings region by region and projects an overall reduction in the unit cost of electricity of 27 percent by 1980. The reductions are expected to be greatest in New England where existing rates are the highest and to be quite small in the Pacific Northwest which already enjoys the lowest average rates of any region.

The Commission believes that this Survey of the industry in the decades ahead should have a healthy influence on the more immediate management decisions for meeting the loads of the late 1960's and early 1970's. The Report directs attention to the enormous amount of new capacity that will be required, the importance of maximum utilization of our best sites, both hydro and steam, the need for affording small systems a share in the economies of scale, the energetic load-building program that will be required if projected loads are to be achieved or exceeded, and the large savings inherent if individual systems plan and build together rather than separately.

The Report does not consider interconnections and further coordination among systems or existing power pools as a goal in itself. On the contrary, each investment must be justified by economic consideratons, such as direct cost savings, improved service, or greater flexibility and reliability. The potential interconnections we suggest hold promise of meeting this test on the basis of our planning studies but they are intended to be illustrative only and suggestive of further detailed investigations rather than definitive proposals.

The emerging pattern of power supply does not point entirely in the direction of long transmission distance between sources of generation and loads. The competitive pressure of EHV transmission and other new developments in energy transportation, such as the coal slurry pipeline, have stimulated the railroads to introduce improved transportation techniques and to reduce their rates. Such rate reductions improve the economics of plants distant from the coal fields and closer to load because the rates for coal transportation sometimes constitute more than half of the cost of coal delivered to load centers.

A more general use of nuclear plants will also have its influence on transmission line requirements. Fuel transportation costs are not a significant item for nuclear plants, and would not necessarily be higher for plants close to loads than for those located at a distance. On the other hand, the advantages of scale are so pronounced in nuclear stations that large nuclear plants feeding electricity into strongly interconnected grids serving many load centers are likely to constitute an attractive pattern of development in the future.

There are many collateral benefits of a coordinated power supply system with a strong transmission grid integrating the facilities over large areas. Steam generating plants can be located in relatively remote areas with the resulting alleviation of air pollution in metropolitan centers. In the event of extreme air pollution conditions generation in the problem area could be temporarily curtailed and power could be obtained from other sources in the interconnected grid. Strong interconnections are added insurance during many other kinds of emergencies because they make possible transfers of power supply over large areas. This consideration can be of great defense importance because many defense plants such as the aluminum smelters and atomic diffusion plants which are heavy users of power can be fully activated or reactivated on short notice. New industrial plants can be built in a much shorter time than large generating stations which require lead times of 3 to 5 years; power-oriented industries would have greater flexibility in location and in start-up dates with widespread power pooling. The flexibility of strong EHV grids will also permit better utilization of hydroelectric resources so that surplus energy will not be wasted to the sea.

In summary, we look for the construction by 1980 of an EHV transmission system throughout the country which will provide great flexibility for generating station locations.

It is our earnest hope that the National Power Survey, to which many outstanding participants from all segments of the industry have contributed a great deal of supporting information and analysis, will set a standard and be a guide in the future planning of the industry. The goal we propose is an electric power industry animated by a broad and bold vision of its role in contributing to the growth and welfare of the Nation's economy. We have tried to outline a coordinated power system of the future which will meet that test.

CHAPTER 5

NUCLEAR POWER

Twenty-five years ago laboratory scientists first realized that energy released by nuclear fission in chain reactions could be used for electric power generation. In the intervening years the technology of nuclear power generation has moved from the laboratory to commercial plants. Considering the extreme difficulty and complexity of the technology, the pace of progress has indeed been remarkable.

The 970,000 kilowatts of nuclear electric generating capacity now in operation have demonstrated technical feasibility and practical reliability. While these first developmental plants have cost more than alternative conventional facilities, the prospects for nuclear power are now sufficiently promising to exert great competitive pressure. They have contributed both to major reductions in the price of coal and coal transport, and served as a powerful stimulus for improvement in alternative power generating sources.

In the future, nuclear energy will play an important part in setting ceilings for prices of power in an increasing number of locations. As nuclear ceilings are lowered in coming years the areas they cover will greatly broaden with resulting lower power costs to consumers.

Notwithstanding the excellent progress to date, the future of nuclear energy in the power industry depends on rates of progress along many difficult paths and also the extent to which improvements are achieved in reducing the cost of electricity from conventional plants. Conclusions are therefore subject to wider than usual variation, as influenced not only by the optimistic or pessimistic character of the analyst with respect to nuclear technology, but also by his familiarity with the prospects for advancement in competing sources of power supply.

The demonstration that nuclear power is practical and reliable is sufficient to assure its utilization in applications which take advantage of one or both of its two most important unique qualities. These are the ability to produce large quantities of electricity from a very small although not inexpensive inventory of fuel, and to operate without requiring combustion air which avoids releasing large quantities of combustion products to the atmosphere. These attributes alone, however, will not assure extensive use of nuclear energy as a source of electricity for the power industry in the foreseeable future. Nuclear power must offer electricity at a cost lower than other available means, if it is to be widely used. It is toward this end that the major research and development effort is now directed.

FIGURE 48 *The 60,000 kilowatt Shippingport Atomic Power Station near Pittsburgh, Pennsylvania, is the world's first full-scale nuclear plant used exclusively for civilian power production. The station, which began producing power in December 1957, is a joint project of the Atomic Energy Commission and the Duquesne Light Co.*

Energy Release from Fissionable Nuclear Materials

Like ordinary fossil fuel-fired plants, nuclear power plants use heat to produce steam to drive turbine generators. The kilowatts of power capacity and the kilowatt-hours generated from either source are undifferentiated and are transmitted and distributed in the same way. The major difference is that conventional thermal plants use heat produced by combustion of fossil fuel in a furnace, but nuclear plants use heat produced by fission of nuclear fuels in a reactor. Basically a nuclear reactor is substituted for a fossil fuel boiler.

In the fission process, if the nucleus of a fissionable atom, for example an atom of uranium isotope 235,[1] is struck by a neutron moving with suitable speed, the heavy atom will split apart into several lighter weight atoms (i.e., it will fission) and will emit radiation and neutrons. As a result of the fission, a very small part of the atom's mass is converted into energy which propels neutrons and other particles at high speed and thereby provides heat. A neutron released by fission of one atom can strike another atom of U^{235} and make it fission in turn. Continuation of this process constitutes the so-called "nuclear chain reaction." Chain reactions in a very small quantity of fissionable nuclear material can cause fission of billions of individual atoms which together can release great quantities of heat.

Fission of about one half of 1 percent of 75 tons of nuclear material in a 500-megawatt nuclear power plant of contemporary design will produce heat in a year roughly equivalent to the heat from burning a million tons of coal in a 500-megawatt conventional power plant. Accordingly, fuel transportation costs for nuclear plants are de minimus and nuclear plants may therefore be located far from sources of nuclear fuel and closer to markets. In areas in which fossil fuel costs are relatively high, nuclear plants may thus be able to remove as a handicap to economic progress the former high level of energy costs.

Conversion of Fertile Materials to Fissionable Materials

A key step in the process of utilizing nuclear energy to generate electricity is the conversion of materials rich in nuclear energy into fissionable materials. The only significant material subject to nuclear fission in its natural form is the isotope of uranium designated U^{235}. Uranium as mined is about 0.7 percent U^{235} and 99.3 percent U^{238}. Uranium isotope 238, which is not generally fissionable in its natural state, contains approximately 140 times as much of the basic raw material resources of natural uranium as uranium 235 which is fissionable. Fortunately, uranium 238, which is called a fertile material, can be converted into plutonium 239, which also is fissionable in a nuclear reactor. Some of the plutonium formed during operation of the reactor will fission and release energy. The rest of the plutonium produced in the reactor (and unused U^{238}) can be removed during discharge of the used fuel, and can be separated chemically either to be reinserted as fresh fuel into the same reactor, or inserted into other reactors, to produce additional energy. This so-called "plutonium re-cycle" can be repeated in several successive stages, and thus would be able to convert part of the fertile U^{238} to fissionable plutonium. The process is still difficult to accomplish economically because the radioactive character of plutonium precludes direct handling and requires remotely controlled operation, processing, and maintenance to achieve safety. However, experts anticipate that within several years the plutonium re-cycle will be providing more nuclear energy from a unit of uranium ore than obtainable from the fissioning of the small amount of uranium 235 which it contains.

Thorium available in a natural state is mostly composed of thorium isotope 232 (Th^{232}), which generally does not fission but which is fertile and can be converted to uranium isotope 233 (U^{233}), which can fission and release energy. However, considerable time and effort may be needed to develop processes to cope with the radioactivity[2] which accompanies U^{233} before that material can be utilized at low cost.

Fast and Thermal Reactors

The various reactor concepts can be divided generally into two classes, "fast" reactors, and "thermal" reactors. The terms refer to the relative speeds of the neutrons which cause the fissioning process in the reactor to continue. Neutrons, when first emitted during fission, move rapidly and are called fast neutrons. Neutrons which start at high speed can be slowed down to thermal speed by deliberate insertion of materials specially chosen for this purpose, called moderators. Almost all of the nuclear power plants now in operation depend primarily on thermal neutrons to maintain the nuclear reaction.

Fast reactors have high concentrations of fissionable material, and are relatively compact but complex. In a fast reactor, the life cycle of neutrons

[1] Most elemental materials exist in several slightly different forms which reflect small differences in the number of neutrons in their atomic structure. The different forms of the same element are known as isotopes.

[2] The radioactivity arises from the slow decay of U^{232}, small amounts of which accompany the formation of U^{233}.

is much shorter than in thermal reactors. The speed of reaction makes operation of the fast reactor more difficult to control. The concentrated fuel in a relatively small volume in the fast reactor also represents a large investment. Thus it would be desirable to operate the reactor at a very high rate of heat generation so that the fixed charges on the fuel investment could be spread over a large number of units of energy output. Difficult engineering and metallurgical problems must be overcome to remove heat at the rates dictated by economy.

Economically, it is desirable that as large a proportion as possible of the neutrons released in the

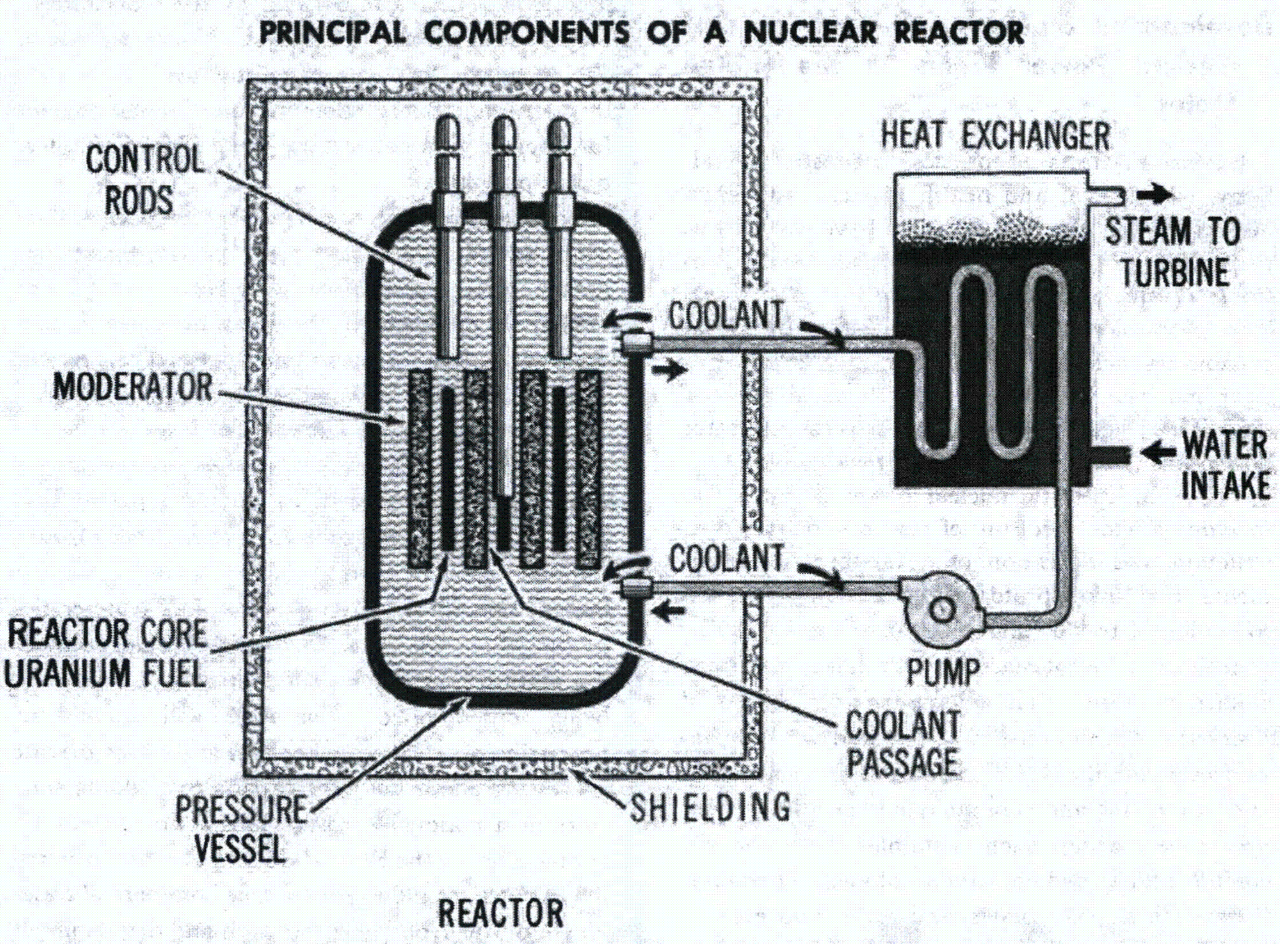

FIGURE 49 *This simplified diagram depicts the principal components of a nuclear reactor. In some reactors the coolant serves also as the moderator and in other types the heat exchanger is eliminated. In some types of reactors, the coolant is a liquid, in others it is a gas.*

reactor should be used to produce new fuel. The fast reactor is generally superior in this respect, due primarily to two factors: (1) more neutrons are released in fissions caused by fast neutrons, so that there are more excess neutrons available to be absorbed by fertile isotopes; (2) fast neutrons are less likely than are thermal neutrons to be absorbed and wasted in the structural materials of a reactor. This means that fast reactors typically can produce more new fuel per unit of fuel consumed than can thermal reactors. A reactor capable of producing more fuel than it consumes is called a "breeder" reactor.

Experts differ as to whether it would be best to use thorium with neutrons slowed to thermal speeds to achieve breeding, or whether it would be best to use uranium and fast neutrons to produce plutonium to achieve breeding. It is conceivable that both of those processes may be used in the future in order to provide more complete utilization of available nuclear fuel resources. Because no one can determine now the relative advantages and disadvantages of various alternative or combinations which may prove to be most beneficial for future energy supply, research and development is proceeding on both approaches.

Development of Nuclear Technology and Nuclear Power Plants in the United States

Extensive efforts in physics, chemistry, metallurgy, radiological and health sciences, and engineering during the past 25 years have provided a foundation for nuclear power generation. Programs in nuclear weapons production and naval ship propulsion have provided major industrial capabilities including facilities for large volume nuclear material enrichment and chemical processing. These activities have been of great value for development of civilian nuclear power plants.

The U.S. domestic nuclear power program has included a wide spectrum of research, design, construction and operation of a number of experimental and small prototype nuclear power plants to explore a broad range of reactor types. Many concepts of thermal reactor power plants have been studied and tried. These have included the use of fissionable uranium (U^{235}) fuel, and in some instances plutonium or U^{233}, in various concentrations and in metallic and ceramic materials with various protective coatings, such as stainless steel, and zirconium alloys, and in various physical configurations, such as rods, plates, and tubes, and even in fluid form as liquid metals, molten salts, or slurries. Heat may be removed from the fuel by circulation of ordinary or heavy water, steam, gas, organic liquid, and liquid metals. The moderator which slows down movement of the neutrons may be ordinary water, heavy water, graphite, beryllium, or organic fluids. The heat-removing fluid may also serve as the moderator. In general, the goals are a simple, economical fuel and reactor system from which heat can be extracted at high rates and high temperatures and a fuel form which can be operated for a long time without replacement. In addition, neutrons should be conserved for production of as much new fuel as practicable.

Early stages of civilian nuclear development have been accelerated by Government expenditures which the Atomic Energy Commission estimates totaled $1,275 million by 1963. These programs have included financial assistance to privately owned projects, research in Government laboratories, savings to individual companies from the use of the Government's large volume fuel preparation and processing, and waste disposal by the Government for national security programs. Other assistance has included "buyback of plutonium" or waiver by the Atomic Energy Commission of rental charges for nuclear materials during early years of nuclear power operation.

Both government and industry recognize that when specific types of nuclear power plants approach levels competitive with fossil fuel plants, further development of these reactor types should proceed without government financial assistance. The industry will be assuming financial independence in other ways. Legislation was enacted in August 1964, which in effect requires private ownership of new fuels needed for reactor use after December 31, 1970, and calls for terminating all outstanding leases of fuels by June 30, 1973. At the present time all irradiated nuclear fuel is processed by the AEC. However, a privately owned processing plant is now under construction and others are being contemplated. The AEC will discontinue processing of private reactor fuel as soon as private processing plants have the capability of doing such work at a reasonable cost. This action represents another step by the Federal Government to place the nuclear reactor industry on a true commercial basis. However, the frontiers of research and development for further new scientific and technical advances in perfecting breeder reactors and other more advanced nuclear reactors will still need Government sponsorship and financial aid.

Nuclear Power Plants Already Operated or Nearing Operation

Thirteen civilian nuclear power plants,[3] in the United States, varying in sizes from 11,400 kilo-

[3] Figures 48 through 51 and 121 and 130 illustrate a few of these plants.

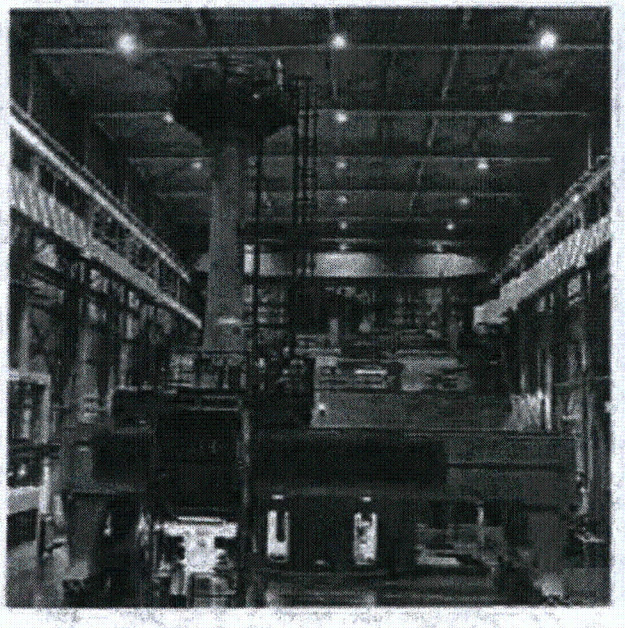

FIGURE 50 *This fuel handling machine at the Hallam Nuclear Power Facility near Lincoln, Nebraska is used to exchange new and spent fuel elements in the sodium-graphite reactor located beneath the circular control rod mechanism housing (bottom center of photo). The mast is heavily shielded to protect plant personnel from the high degree of radiation given off by fuel elements withdrawn from the reactor for transfer to storage cells.*

watts[4] to 200,000 kilowatts, with a combined net capability of about 970,000 kilowatts, are now considered operable. Three of these are pressurized water plants, six are boiling water, one has a sodium cooled-graphite-moderated reactor, one is organic moderated and cooled, one uses heavy water for coolant and moderator, and one is a sodium cooled fast breeder.[5] These plants are listed in table 28 with their individual capacities, start-up dates, and other relevant information.

Table 29 presents similar data for the five major plants now well under construction and expected to be placed in service in 1965 to 1967. The total capacity of these five plants will be about 1,730,000 kilowatts. The largest plant in this list, rated at 800,000 kilowatts, is also unique in that it is a dual-purpose plant. The reactor, a plutonium production reactor at Richland, Wash., first went critical in 1963. It is owned by the United States and operated as one of AEC's defense facilities. The by-product heat which it generates will be used to drive turbines at a power plant being constructed for the Washington Public Power Supply System. For these plants (except the special case of the dual-purpose plant) the cost of power produced will be higher than that from alternative conventional sources.

[4] Reactor engineers frequently differentiate between the heat capacity of a reactor, mw(t), and the electrical capacity of the plant, mw(e). Typically it is feasible to convert only about a third of the reactor's heat energy into electrical energy. In this chapter all figures expressed in kilowatts (kw) or megawatts (mw) refer to electrical output.

[5] The fast breeder, though having a nominal electrical capacity of 60,000 kw (equivalent to about 200,000 kw heat capacity) is still limited to very low power level operation (1 mw heat capacity). Operation at higher power levels will be sought beginning this year.

Current Development of New Large Nuclear Power Plants

Three additional plants not yet under construction but scheduled for completion by 1968 are listed in table 30. Their aggregate capacity is some 1.5 million kilowatts. All are water reactor plants and each is considerably larger than any of the existing U.S. nuclear plants except the Hanford dual-purpose plant.

Utilities are sponsoring these major plants for start-up between 1967 and 1968. Their action indicates confidence by utility management officials that there will materialize the engineering improvements, increased outputs, fuel cost reductions in subsequent core loadings and other anticipated im-

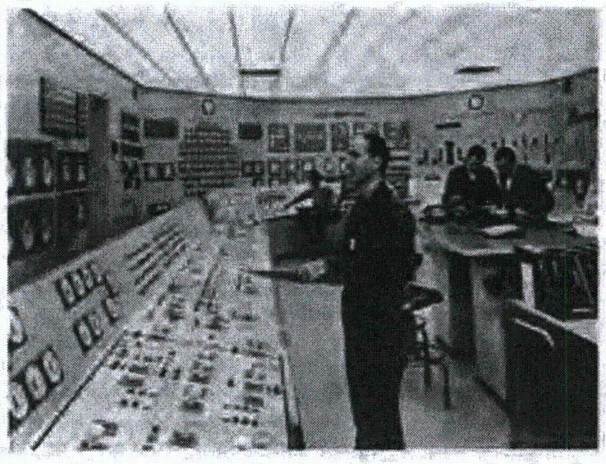

FIGURE 51 *The control room of Dresden Nuclear Power Station permits monitoring the operation of the project, including the many instruments, controls and devices installed as added safety features. This 200,000 kilowatt generating plant of the Commonwealth Edison Company was the first full scale privately financed nuclear power station.*

TABLE 28

Operable Nuclear Power Plants [1] as of July 1, 1964

Name, owner or operator	Location	Type	Capacity net kw	Startup
Shippingport Atomic Power Station (AEC and Duquesne Light Co.).	Shippingport, Pa.....	Pressurized water.....	60, 000	1957
Dresden Nuclear Power Station (Commonwealth Edison Co.).	Morris, Ill...........	Boiling water.........	200, 000	1959
Yankee Nuclear Power Station (Yankee Atomic Electric Co.).	Rowe, Mass..........	Pressurized water.....	175, 000	1960
Big Rock Nuclear Power Plant (Consumers Power Co.).	Big Rock Point, Mich..	Boiling water.........	72, 000	1962
Elk River Reactor (AEC and Rural Cooperative Power Association).	Elk River, Minn......	Boiling water.........	23, 000	1962
Hallam Nuclear Power Facility, Sheldon Station (AEC and Consumers Public Power District).	Hallam, Nebr........	Sodium graphite......	75, 000	1962
Indian Point Unit No. 1 (Consolidated Edison Co. of New York, Inc.).	Indian Point, N.Y....	Pressurized water.....	[2] 255, 000	1962
Carolinas-Virginia Tube Reactor (Carolinas-Virginia Nuclear Power Associates, Inc.).	Parr, S.C............	Pressure tube, heavy water.	17, 000	1963
Enrico Fermi Atomic Power Plant (Power Reactor Development Co.).	Lagoona Beach, Mich.	Fast breeder.........	60, 900	1963
Humboldt Bay Power Plant, Unit No. 3 (Pacific Gas & Electric Co.).	Humboldt Bay, Calif..	Boiling water.........	50, 500	1963
Piqua Nuclear Power Facility (AEC and City of Piqua).	Piqua, Ohio..........	Organic cooled and moderated.	11, 400	1963
Boiling Reactor Nuclear Superheat Project (AEC and Puerto Rico Water Resources Authority).	Punta Higuera, P.R...	Boiling water, integral nuclear superheat.	16, 300	1964
Pathfinder Atomic Power Plant (Northern States Power Co.).	Sioux Falls, S. Dak....	Boiling water, nuclear superheat.	58, 500	1964

[1] Based on tables included in AEC report TID–8200 (10th revision).

[2] Approximately two-thirds contributed by the nuclear reactor and one-third by the oil-fired superheater.

TABLE 29

Nuclear Power Plants Under Construction [1] as of July 1, 1964

Name, owner or operator	Location	Type	Capacity net kw	Startup
Peach Bottom Atomic Power Station-HTGR (Philadelphia Electric Co.).	Peach Bottom, Pa.....	Gas cooled, graphite moderated.	40, 000	1965
La Crosse Boiling Water Reactor (AEC and Dairyland Power Cooperative).	Genoa, Wis..........	Boiling water.........	50, 000	1965
Hanford New Production Reactor (AEC and Washington Public Power Supply System).	Richland, Wash......	Pressure tube.........	800, 000	1965–6
San Onofre Nuclear Generating Station (Southern California Edison and San Diego Electric Co.).	San Clemente, Calif...	Pressurized water.....	375, 000	1966
Connecticut Yankee Atomic Power Station (Connecticut Yankee Atomic Power Co.).	Haddam Neck, Conn..	Pressurized water.....	462, 000	1967

[1] Based on tables included in AEC report TID–8200 (10th revision).

TABLE 30

Planned Nuclear Power Plants Announced[1] as of July 1, 1964[2]

Name, owner or operator	Location	Type	Capacity net kw	Startup
Malibu Nuclear Plant (Los Angeles Department of Water and Power).	Corral Canyon, Calif..	Pressurized water.....	463, 000	1967
Nine Mile Point Plant (Niagara Mohawk Power Co.).	Oswego, N.Y.........	Boiling water.........	500, 000	1968
Oyster Creek Station (Jersey Central Power & Light Co.).	Oyster Creek, N.J....	Boiling water.........	515, 000	1968

[1] Based on tables included in AEC report TID–8200 (10th revision).

[2] The announced proposal to construct a 325,000-kilowatt nuclear plant at Bodega Bay has recently been dropped.

provements in performance and costs on which the advantages of these projects are based. The Oyster Creek Station, the most recently announced project of this group, will be constructed at a cost per kilowatt considerably less than that of any earlier plant. This and other recent proposals appear to mark the beginning of marketing practices by major nuclear reactor manufacturers which take into account the opportunities for repetitive use of established reactor designs.

The program of nuclear power plant development summarized in tables 28, 29, and 30, represents the results of a program of cooperation between industry and Government. Over the years many difficulties were overcome and an enormous scale of both executive and technical effort was required to bring these projects into being. In this effort, thousands of Government and industry people have been trained in a new technology, and have achieved a high degree of competence and a capability for much further development of nuclear power for civilian use.

Effect of Unit Size and Output on Capital and Operating and Maintenance Costs

As previously noted, the nuclear power plant is much like a conventional steam plant except that a nuclear reactor is used instead of a furnace burning fossil fuel. Shielding must be provided to avert hazardous radiation during normal operation, and special containment facilities and other safeguards must be incorporated to control the escape of radioactive material in the improbable event of a reactor accident. For these and other reasons, a nuclear plant is likely to have higher construction costs than a conventional plant. However, comparative design studies have indicated that the capital costs per unit of capacity for a nuclear plant should decline even more rapidly with increasing capacity than do conventional plant costs. Accordingly, the capital cost disadvantage of nuclear plants in comparison with conventional plants will be less significant for larger plants.

More specialized operating staff and higher maintenance costs for some equipment are required for nuclear than for conventional plants. Accordingly, nuclear plants have been relatively more expensive to operate and maintain than conventional plants. However, this difference is expected to decline with increasing nuclear plant capacity and greater operating experience.

Fuel Cycle Costs

Fuel cycle costs estimated by AEC in its Report to the President in November 1962, anticipated a substantial improvement by 1980 of the energy yield in subsequent fuel loadings in either the present types of water reactors or in improved reactors. In more recent quotations for new plants, nuclear suppliers have anticipated simplification and improvement in fuel fabrication and other fuel cycle improvements, and quotations have assumed lowered cost achieved by larger volume of sales.

These potential improvements point in the direction of increased output over initial design capacities, decreased unit costs in dollars per kilowatt of capacity, and decreased fixed charges and fuel cycle and other costs per kilowatt-hour.

Larger Unit Capacities

In view of the sharp effect of increases in unit size in reducing the cost of nuclear power, the maximum sizes in which it is possible to build nuclear plants is of special interest. As shown in table 28, the largest nuclear plant now in operation in the United States has a capacity around 200,000 kilowatts. The present plants are single reactor, single turbogenerator plants. In view of the good experience with water reactors, most manufacturers are now ready to provide single reactor, single turbogenerator stations in sizes up to about 500,000 kilowatts to 600,000 kilowatts. The more experienced builders consider single units of 700,000 to 1,000,000 kilowatts to be feasible with little additional development work.

An important factor tending to limit the size of water reactors is the dimensions of the reactor pressure vessel. An 11-foot internal diameter is about the extreme upper limit for a vessel that can be shipped by rail. It can contain the fuel assemblies for roughly a 300-megawatt to 400-megawatt pressurized water plant, or a 100- to 200-megawatt boiling water plant.

Manufacturers now believe they could make a vessel up to nearly 17 feet internal diameter which would be suitable for a 1000-megawatt pressurized water plant. Such a vessel would weigh some 600 tons. Since a boiling water reactor operates at a much lower pressure than a pressurized water reactor, its pressure vessel can be built to a larger diameter without exceeding vessel wall thickness limitations. Perhaps a vessel up to nearly 26 feet in internal diameter could be considered for a boiling water plant. This may permit a capacity of about 1500 megawatts.

Such huge pressure vessels could be transported by barge or specially designed trailer. However, few highways afford the necessary vertical clearances. Field construction of such large vessels is probably technically feasible but would require essentially a temporary and costly full-scale shop at the site. Practically, therefore, very large steel vessels could be installed only at sites which are reasonably accessible by barge. While this limitation may seem serious at first thought, it may not prove unduly restrictive. The majority of the Nation's population centers are in proximity to our extensive coastline or to large lakes and rivers which are commercially navigable and which in addition can supply the enormous cooling water demands of very large plants. Other less well developed types of nuclear reactors may be placed in commercial operation in the next 10 to 15 years which are more adaptable to partial fabrication and assembly on the site and thus provide a basis for larger scale nuclear generation in locations not accessible to water transportation.

Nuclear Power Stations with Several Reactor Units

Construction of mammoth nuclear electric power stations with several reactor units at one site may be anticipated. The handicap of rigorous site requirements could be overcome, at least in some degree, by building several reactor units at a single site. This assumes that the individual reactors are sufficiently independent so that an accident with one would not significantly increase the chances of accidental release of radioactive material from another. In this case an exclusion area larger than that provided for a single reactor probably would not be necessary. Unit costs could also be reduced by sharing of fuel handling and other facilities among the units, and perhaps in the case of some designs, by the use of common containment.

Fully exploiting the multiunit approach could result in a very large capacity nuclear station, suggesting the possibility of several utility systems joining forces to establish a nuclear generation center. While such a development would conserve nuclear plant sites, the economies of construction and operation would have to be balanced against the extra costs of transmitting the power from a single source throughout extensive market areas. The establishment of a large capacity transmission grid covering broad areas of the country, which later chapters in this Report suggest are economically feasible, would tend to minimize the transmission costs and enhance the potential savings in the construction of such a nuclear complex.

Nuclear Plant Capacity Factors

Estimates of nuclear plant production costs generally employ the assumption that the long-term average output of nuclear plants will be about 80 percent of maximum capacity. Insofar as availability is concerned this assumption may even be conservative. Considering the generally low pressures and temperatures in the nuclear steam cycle of contemporary water reactors designs, the nuclear turbogenerators and heat exchangers of these reactors may prove relatively dependable compared to today's high temperature conventional plants. Reactor refueling, maintenance, and other factors could account for offsetting sources of outages for nuclear plants in comparison with conventional plants. Attempts are being made to reduce outages for refueling. For example, some reactor designs provide for on-line refueling but it may be that the cost of the equipment to expedite this operation will be greater than the savings.

Availability itself may not control the extent to which a particular nuclear plant will be used. Load conditions, and possibilities for use of other low cost alternatives including improved nuclear plants, will determine the load factor of each plant. Considering the fuel cost advantages likely for large reactors, it is expected that large nuclear plants will be favored for the highest level of output in the system complex. At times during the prime years of the plant's life nuclear units may operate at plant factors between 80 and 90 percent, declining subsequently as lower cost base load plants, probably of improved nuclear type, are added to the system. The pattern should follow that of conventional plants except that nuclear plants will be used at higher load factors, because of their lower operating costs.

Flexibility of Nuclear Plant

The prediction of base load operation, as discussed above, is appropriate for the early economically competitive nuclear plants, but it may not be appropriate for all plants when nuclear power becomes a substantial fraction of a system's power supply. Typically, minimum night-time system loads are only about a third of the day-time peaks. When more than this fraction of the peak is supplied by nuclear plants, there must be some reduction in off-peak output to follow the load decline. Further increases in the nuclear capacity will then require that these plants be increasingly prepared to "follow" the system load variation. All experience thus far indicates that nuclear plants have excellent loading flexibility—actually superior to large conventional steam units. However, future nuclear plants designed for high pressure and temperature operation may lose this margin of superiority.

Radiation Hazards and Safeguards to Protect Public Health

Nuclear fission is accompanied by the emission of direct radiation and by the formation of a variety of radioactive fission fragments that will emit radiation over various time periods during which they decay. Therefore, it is imperative to provide safeguards to avoid contamination of the working areas of the plant and the environment surrounding the plant.

Government and industry have acted in three ways to avoid serious consequences: (1) by safeguards to prevent or to reduce to minor levels normal routine release or accidental release of hazardous radiation and radioactive products within the reactor structure; (2) by containment structures and other safeguards to keep within the plant any accidental release of hazardous radiation which occurs; and (3) by zoning measures to prevent whatever radiation and radioactive products may escape inadvertently, in spite of multiple safeguards, from causing harm to the inhabitants in the vicinity.

It is difficult to determine the kinds and extent of radiation doses which under innumerably different kinds of conditions should be regarded as likely to cause harm. The Atomic Energy Commission, international agencies, and others have evolved standards and criteria based upon exposure data and expert judgment as to what limitations and requirements may be essential to achieve adequate protection. Further experience may lead to tightening or relaxing the criteria which may be applied in the future.

The AEC has placed much stress on safety in its civilian nuclear program. Research and development in radioactive waste management has been underway for many years, and a companion program in reactor safety was started in 1955. An expanded and accelerated program was initiated in 1961 which includes a wide range of engineering scale tests and evaluation studies relating to reactor safety.

The chance that some accident might occur has led to major efforts to reduce the likelihood of accidents and minimize the consequences, efforts which to date have been highly successful. To assure a high degree of safety, nuclear reactors must be designed and operated with the utmost care to reduce the probability of accidental dissemination of radioactive products. These safeguarding steps must include great care in plant design, extensive instrumentation and monitoring, requirements for precision and reliability of components, provision of multiple auxiliaries and services to reduce risks of equipment or operating failure, special care in fuel handling and storage, provision of shielding and structural and operating safeguards intended to contain direct radiation and radioactive fission products, appropriate means for controlled release of radiation when desirable, rigorous control to assure proper construction, operating procedures, and maintenance, and frequent inspection and testing of all safety procedures and equipment.

The radiation hazards of a nuclear accident can be further reduced by prescribing restricted or exclusion areas in the plant vicinity. Thus, if substances emanating from a reactor must travel several miles through the air before they can reach substantial numbers of people, their hazardous character can be reduced not only by natural dispersion and dilution in the atmosphere but also through partial decay of the radioactive and toxic products during the time of movement out of the restricted zone. Therefore, AEC has utilized distance from the reactor to people as one of the several safeguards in nuclear plant site selection criteria.

Each situation must be analyzed individually but the following figures estimated for a water reactor plant are roughly indicative of the effect of present AEC requirements. A reactor with an electrical output of 500 megawatts probably would have an exclusion area with a radius of about 0.9 mile, which is equivalent to about 1,600 acres. The low population zone would extend to roughly 14 miles from the plant. The reactor site would be required to be no nearer than about 18 miles from the nearest population center of about 25,000 people. Of course as further knowledge and experience is gained these distances may be adjusted.

The possible effect of earthquakes is an additional question often raised in connection with the location and design of nuclear plants in earthquake-prone areas. A recent AEC report on earthquakes [6] analyzes various ways in which earthquakes might cause mechanical or structural failure and disrupt plant equipment, services, or protective controls and thereby produce effects on reactors which could lead to more severe consequences. The analysis outlines the special considerations and precautions in site selection, design, and engineering to be taken in the planning and construction of the plant to offset the effect of unusual seismic forces. The geological conditions at sites for nuclear plants proposed for an earthquake-prone area must receive especially thorough examination and all parts of the facility must be checked for strength and functional performance to resist the shock loadings that can be imposed by severe earthquakes.

Accidents can happen but in view of the multiple safeguards and precautions built into a nuclear plant a combination of events which could produce a nuclear accident involving harmful radiation effects in inhabited areas is extremely improbable. If any reasonably conceivable accident were to occur, such as a break or major leak in a line of the primary cooling system, ultimate release of harmful radiation would not occur except as a result of a series of failures of safety features. A breakdown of all of the numerous independently operative safety controls for stopping the reactor process must have occurred before the nuclear material conceivably could melt down and produce heat and pressure which could cause radiation and radioactive products to escape from the reactor area. Even then no public harm would result without the further combination of the failure of the containment shell or suppression chambers to retain the radioactive materials. If some of the radioactive material did escape from the plant, it would be subject to the effects of decay and dilution in reaching inhabited areas. The consequences of any nuclear accident are greatly minimized by the criteria, standards and procedures employed by AEC in the licensing, testing, operation, maintenance, and inspection of nuclear projects. The safety record in the operation of utility sponsored nuclear-electric plants to date has been exceptionally good.

Nuclear Plant Locations and Air Pollution

Increasing efforts to reduce air pollution may advance the consideration of nuclear power plants in some areas. These plants do not release hydrocarbons or other chemical substances which could contribute to air pollution problems. Should much more elaborate and expensive air cleaning equipment than that now in use be demanded of con-

[6] AEC—Technical Information Document—7024. *Nuclear Reactors and Earthquakes August 1963.*

ventional plants, this increased cost would make nuclear power plants relatively more attractive.

While it is likely that an extended record of good experience will be required before nuclear plants are built in close proximity to densely populated load centers, this does not mean that the beneficial effects of nuclear plants in reducing air pollution is not already of value. There are few locations where major new conventional plants would be located where freedom from atmospheric pollutants would not be a valuable feature.

Nuclear Hazard Insurance

Liability insurance presents special problems for nuclear power plants. Experience to date has been limited to a few years and a small number of plants. Accidents have been few in number and damage small, but there is little statistical basis for establishing risks. Meanwhile, conceivable risks and liability have been considered to exceed the financial capability of the private insurance industry. Accordingly, Congress in 1957 authorized the Federal Government to provide liability protection up to $500 million for any single nuclear accident. The reactor operators have paid the Government an annual fee of $30 per megawatt of reactor heat capacity for liability coverage. This usually amounts to about $100 per megawatt of electrical capability.

Owners are required to secure the prescribed amount of private liability insurance up to a limit of $60 million, depending upon size of nuclear plant, as a prerequisite to licensed operation and procurement of federally sponsored liability protection. This is in addition to the Federal liability insurance. Insurance company premiums for nuclear plants are at present higher than premiums for conventional operations.

Basic Assumptions in Projecting Nuclear Capacity

It has been the national policy, in seeking to overcome initial economic hurdles in the development of nuclear reactors and support facilities, to have the Federal Government absorb part of the cost of early nuclear plants. Cost support has taken several forms, such as providing research and development, design, and construction assistance; providing fuel and fuel-cycle services at less than full cost; and paying premium prices for new fuel produced in reactor operation. Manufacturers also have assisted in nuclear development by providing equipment at less than normal profit, and utilities have made substantial research and development expenditures.

However, any considerable nuclear power industry must stand on its own financial feet. Estimates of nuclear power costs used in this Survey are generally predicated on a large-scale nuclear power industry and escalation of unit sizes well above those that have been built to date. The scale of nuclear capacity additions projected later in this survey is based on assumptions of cost believed to be consistent with private ownership of plant and fuel, fuel manufacturing, and reprocessing facilities, and normal profits for equipment manufacturers. It is assumed, however, that the Federal Government will continue to participate to some extent in hazard insurance against nuclear loss beyond private coverage.

The projection of nuclear power generating capacity has been made without investigation to determine actual availability of satisfactory sites.

Wide Range in Conditions and Plant Costs

There can be a wide spread in the unit cost of power from a nuclear plant depending on the plant location, size, and design. Some of the factors which account for the variation in cost are differences in reactor type and size, the capacity achieved under actual operating conditions, accessibility for transportation of pressure vessels and other major items of equipment, site conditions, the type and expense of condenser cooling systems, local levels of construction costs, and needs for transmission to load centers. The cost of generation from competing fossil-fired steam plants can also vary significantly from area to area for many of the same reasons and in addition because of the variation in the type of fuel used as it affects the design of the plant and the cost of fuels.

The important point to keep in mind is that the competitive relation between nuclear plants and conventional alternatives can vary markedly from one region to another throughout the country. This is true not only because conventional plants are more economical in the coal and gas fields but because nuclear costs vary from region to region. General comparisons have only limited value.

Estimated Range of Future Nuclear Costs and Competitive Levels to 1980

During the early part of 1963, the Subcommittee on Nuclear Development of the Generating Stations Special Technical Committee made an analysis of cost trends of nuclear power stations. Their studies indicated substantial declines in costs for plants installed between 1967 and 1980. Since the Subcommittee completed its analysis, major nuclear manufacturers have better defined their intended lines of production and have announced prices considerably below the expected levels. For that reason the Commission's staff has prepared revised estimates to reflect these changed circumstances in its projections of potential nuclear use by 1980.

The rough staff estimates summarized in table 31 may serve as a general indicator of the competitiveness of water type nuclear plants with alternative conventional plants anticipated between now and 1980. The tabulation records the assumed differentials in capital and operating costs between nuclear and coal-fired conventional plants and concludes with a competitive rating of nuclear generation expressed as a range in coal costs in cents per million Btu.

Dates assumed for initial operation, and the "name plate" (net) capacities assumed to be available on those dates are shown respectively on lines 1 and 2 (of table 31). Amounts by which the capital costs of nuclear plants are estimated to exceed capital costs of conventional fossil fuel plants, expressed in dollars per kilowatt of expected plant net capability, are shown on line 4. The lower limits of estimated capital cost differentials reflect the assumption that nulcear plant capabilities may prove to exceed nominal capacities by between 10 to 20 percent. Capital cost differentials are translated into mills per kilowatt-hour in line 5. Line 6 shows the amounts, expressed in mills per kilowatt-hour, by which the operating and maintenance costs for nuclear plants may exceed those for conventional plants. The figures include the cost of nuclear hazard insurance. On line 7 is shown the estimated range of total fuel cycle costs for the nuclear plants.

The estimated nuclear fuel costs are those expected to be attained after the first core is exhausted, 3 to 5 years after the indicated date of initial service. The figures are estimated on the basis of private ownership of fuel after 1970. Line 8 is the total of lines 5 through 7 and thus is the amount, in mills per kilowatt-hour, by which total nuclear power costs may be estimated to exceed conventional plant costs exclusive of coal costs. In other words, if the conventional plant had a fuel cost, in mills per kilowatt-hour, just equal to the appropriate figure on line 8, its total costs would be the same as the total costs of the nuclear plant. The "break-even" fuel costs of line 8 are translated into cents per million British thermal units in line 9. That is, if the cost of coal delivered to a conventional plant is higher than the indicated figure in cents per million British thermal units, the nuclear plant would be more economical. Thus, if a 300-mega-

TABLE 31

Approximate General Range of Competition Between Nuclear and Coal Fired Generation

1. Year plant placed in service	1967	1970	1975	1980
2. Nominal plant output—kilowatts	300, 000	500, 000	1, 000, 000	1, 200, 000
3. Projected investment cost of alternative conventional plant (reference base for line 4)—$/kw	130	122	110	107
4. Approximate additional investment cost of nuclear plant compared to alternative fossil fuel plant. Dollars per kw of capacity	40–60	10–30	0–15	0–12
5. Effect of additional investment in nuclear plant on energy cost—mills per kwh	0. 7–1. 1	0. 2–0. 5	0–0. 3	0–0. 2
6. Effect of additional operation and maintenance of nuclear plant on energy cost—mills per kwh	0. 3	0. 2	0. 1	0. 1
7. Nuclear fuel cost—mills per kwh	1. 8–2. 1	1. 5–1. 9	1. 2–1. 6	1. 0–1. 4
8. Cost of fossil fuel—in mills per kwh (total of items 5, 6, 7) at which total power cost of nuclear generation or fossil fuel generation would be about equal under generalized conditions assumed herein. (Referred to as "break even" cost.)	2. 8–3. 5	1. 9–2. 6	1. 3–2. 0	1. 1–1. 7
9. Break-even fossil fuel cost in item 8 converted to cents per million Btu of fossil fuel cost	31–39	21–29	15–22	12–19

watt nuclear plant placed in service in 1967 and costing $40 per kilowatt more than a conventional coal-burning plant obtained its fuel at the minimum predicted price, it would be expected to be fully competitive with its coal-burning alternative using 31 cents per million British thermal units coal by about 1970.

By about 1975, large nuclear plants are projected to be competitive with coal in the 15–22 cents per million British thermal units range, and by 1980, in the 12–19 cents range. At the lower range, nuclear plants would be able to compete successfully as the supplier of most of the expanding utility energy requirements. This will bring strong pressures to bear on other energy forms to find ways to lower their costs and so extend the period of competition. In any event, the electricity consumers are sure to gain in lower costs for electricity.

The cost of conventional coal fired generating plants will decrease with increasing unit size, and with improvements in plant design and construction. The increments in cost of nuclear plants in relation to conventional plants as given in line 4 of table 31, are based on a moving target of conventional plant costs. Line 3 presents projections of these decreasing investment costs of coal-fired plants for average construction conditions. The resulting range in total generating cost of power from nuclear plants (at the busbar), based on the factors included in table 31 are given in line 3 of table 32. The computation assumes an 80 percent plant factor for nuclear projects.

TABLE 32

Projected Range in Nuclear Generation Costs

1. Year plant placed in service	1967	1970	1975	1980
2. Nominal plant output—kilowatts	300, 000	500, 000	1, 000, 000	1, 200, 000
3. Range in generating cost (at busbar) for nuclear plants—mills/kwh	5. 4–6. 0	4. 3–5. 0	3. 5–4. 1	3. 2–3. 8

Other less well developed nuclear plant concepts may eventually achieve better economy than the water reactors considered in table 31. For example, reactors using heavy water as a moderator (which enables neutrons to be used more effectively for continuing the fission chain reaction—and which might be used with natural uranium or with fuels having lower enrichment and lower costs) may be able to make better use of the energy potential of nuclear materials. Other arrangements, such as the "seed and blanket" type, seek to achieve higher yields by converting larger portions of fertile materials such as U^{238} into plutonium, or thorium into U^{233}, and thereby obtain higher conversion ratios.

Estimated Nuclear Capacity Installations by 1980

The rate of installation of new nuclear generating plant capacity is dependent not only upon the realization of projected declines in nuclear plant and fuel costs, but also upon the attitudes of utility management. It seems likely that utility management will be alert to use proven types of nuclear plants, but will be reluctant to undertake the construction of unproven types. Even for proven types, a 4-year or longer design and construction period is needed for the larger plants, and this period must be followed by several years of operation before projected costs are achieved. Therefore, any decision to proceed with a nuclear plant must be in anticipation of the low cost results to be achieved some eight years in the future with due allowance for higher costs in the first several years of operation.

As a result of its studies which were completed prior to recent lower price quotations, the Generating Stations Special Technical Committee estimated that 40 million kilowatts of nuclear capacity would be installed in the contiguous United States by 1980. In recognition of current rapid nuclear power developments and the lower cost estimates presented above, the Federal Power Commission staff estimates that nuclear power installations by 1980 will aggregate nearly 70 million kilowatts. The general location of this capacity is discussed in chapter 15.

Nuclear Fuel Reserves

While estimates of uranium reserves in the United States are revised periodically, it is generally agreed that those minable at reasonable cost appear to be relatively limited. Reserve estimates which include allowances for "undiscovered" resources must involve a high degree of uncertainty. However, in practice when a substantial market is developed for a resource, additional supplies usually are discovered. As indicated in table 33, the latest estimate of total known and undiscovered uranium resources minable at $5 to $10 a pound of uranium oxide, (U_3O_8) is about 900,000 tons of metal.

The significance of these reserve estimates in relation to present commercial reactors may be judged from a rough analysis. A 1,000-megawatt water moderated nuclear plant will require an initial fuel charge of about 150 metric tons of uranium enriched to perhaps 2.5 percent U^{235}. Since the content of U^{235} in natural uranium is only 0.7 percent and also because only about two-thirds of the U^{235} content of the natural uranium can be extracted economically, some 800 metric tons of uranium must be mined in all to provide the initial enriched fuel charge.

TABLE 33
Tons of Nuclear Materials Obtainable at Various Costs [1]

URANIUM RESOURCES OF THE UNITED STATES

Present cost in dollars per pound of U_3O_8 with present recovery technology	Approximate known deposits (tons of metal)	Unappraised and undiscovered resources (tons of metal)
$5–$10	142, 000	770, 000
$10–$30	140, 000	500, 000
$30–$100	12, 300, 000	20, 000, 000
$100–$500	No Est.	4, 000, 000, 000

THORIUM RESOURCES OF THE UNITED STATES

Present cost in dollars per pound of ThO_2 with present recovery technology	Approximate known deposits (tons of metal)	Unappraised and undiscovered resources (tons of metal)
$5–$10	100, 000	800, 000
$10–$30	100, 000	1, 700, 000
$30–$100	No Est.	30, 000, 000
$100–$500	No Est.	6, 000, 000, 000

[1] Based upon recent estimates in staff papers for the Interdepartmental Energy Study, using mining and processing costs estimated by AEC for $5 to $10 per pound sources, and by U.S. Geological Survey for various other types of deposits.

The fissioning of 1 metric ton of U^{235} will release enough heat to generate about 7 billion kilowatt-hours, or approximately the electrical output of 1,000-megawatts of nuclear plant capacity for a year at 80 percent plant factor. Thus keeping the 1,000-megawatt nuclear plant in operation apparently would require mining some 200 metric tons of natural uranium a year to provide the U^{235} consumed. This calculation overstates requirements, as the water reactor postulated can generate new fuel equal to perhaps half of that destroyed, reducing the natural uranium requirement to about 100 metric tons a year.

On the basis of these figures a 1,000-megawatt nuclear plant operated for 35 years would require the mining of some 4,000 metric tons of natural uranium, or about a half of 1 percent of the total uranium reserves thought to be minable at $5 to $10 per pound. By about 1980, perhaps 10 percent of the estimated total $5–$10 a pound reserves will have been used, and annual rates of consumption will be approaching 1 percent. The plants then in operation would require some 30–40 percent of those reserves for their continued operation through their prospective future lives.

Some very general conclusions may be drawn from these rough estimates:

1. Present estimates of low cost U.S. uranium reserves are adequate to support lifetime operation of nuclear plants based on present ordinary water reactors or other reactor types of low efficiency well into the 1980's.
2. A large and expanding nuclear industry will someday require the development of reactor types that can produce more fuel than they consume, i.e., "breeders." In the meantime, reactors having higher "conversion ratios" than present water reactors, that is, reactors which can regenerate fuel in larger proportions to that consumed, are needed to extend the usefulness of uranium reserves. To illustrate, a reactor which could produce new fuel at the rate of ¾ rather than ½ that consumed would require mining only about half as much natural uranium.
3. So long as prospects remain good that economical breeders can be developed in the reasonable future, there should be little inhibition in the development of nuclear power on the scale predicted in this report to 1980.

4. While the discovery of new reserves and the development of high ratio converters would considerably extend this suggested time scale, it does not obviate the eventual need for breeders.

In considering the rate at which the water reactors use nuclear fuel, it should be kept in mind that even though these reactors do not use fuel as effectively as might be desired, almost all the unused material may be recovered if the fuel is reprocessed and used as feed for breeder reactors when they are developed. At present, reprocessing is difficult and expensive because it involves working with highly radioactive materials on a small scale.

Development of High Conversion Ratio Reactors and Breeders

The AEC and the industry are now engaged in research and development on "plutonium recycle," and on higher conversion ratio reactors which can help provide the technology needed for development of increased energy yields and breeder reactors. In December 1963, the AEC announced a comprehensive program of breeder reactor development with the objective of placing in operation a commercial, economically competitive 1,000-megawatt plant by 1989. Four conceptual core design studies of fast breeder reactors were under way at the end of 1963, and start-up of a 200-megawatt prototype is tentatively scheduled for 1973. Several demonstration plants in the 400- to 800-megawatt range are expected to be built in the early 1980's. This program holds out the hope that energy yields from a given quantity of nuclear material may eventually be increased so greatly that they would permit economic use of the full potential of nuclear ores.

Nuclear Heat for Desalting Sea Water

The problem of providing adequate water supplies for certain areas, primarily in the western United States, has been growing steadily, and the concern of local and Federal authorities has spurred the development of several possible desalting schemes for sea water and high-mineral content inland water supplies. Evaporation is one of the obvious methods being explored, but normal fuel costs present a severe handicap.

Workers in AEC's Reactor Development Program have contended, however, that both unit capital costs and unit fuel costs should continue to decline for nuclear plants 10 to 50 times the size of those generally considered large today, and that the expected very-low-cost energy from such reactors possibly could provide an economical source of heat for large water evaporating plants. The heat could be supplied either directly from the reactors or as low pressure exhaust steam from steam turbines driving electric generators.

Of course conventional steam plants also offer opportunities for use in combination with water evaporating plants. We discuss nuclear possibilities here only because the studies to date have been made in connection with nuclear plants.

The report of an interagency task group appointed by the Director, Office of Science and Technology,[7] which made a preliminary analysis of such long-range opportunities expresses the conclusion that nuclear power costs could be reduced appreciably below the best fossil fuel-fired plant costs if the nuclear plant could be built with perhaps 8,000–10,000 megawatts of capacity. Such a plant would include several integrated reactors and generating units.

Obviously no single power system in the United States could now contemplate the installation of such a plant, which in itself would be as large as any single major system in the country excepting TVA. But groups of systems, by pooling their generating plant additions, might share responsibility for such a power supply. Such plants, including the desalination portions, are only in the early conceptual stages and cost estimates must be regarded as highly conjectural. Of course, the foregoing approach would be justified only if the plan proved to be more economical than alternatives after considering required transmission, necessary reserves and other factors. Nevertheless, the meshing of water needs and power needs—whether supplied by nuclear or conventional means—at appropriate sites may offer opportunities for both lower cost demineralized water and lower cost electric energy.

Summary and Conclusions

Nuclear power technology has shown rapid advances in the last decade. Plants now in the plan-

[7] An Assessment of Large Nuclear Power Sea Water Distillation Plants, March 1964—Office of Science and Technology.

ning stage are expected to be competitive with conventional steam-electric generation in many areas of the country in the next decade. Anticipated reductions in the cost of fabricating and reprocessing nuclear fuels together with lower construction costs should further improve its competitive position.

By 1980 it is estimated that nuclear generation will be competitive in nearly all parts of the country. The 65 to 70 million kilowatts of nuclear capacity projected for 1980 would move nuclear power from an experimental stage to a major source of electric power supply. Moreover it may approach the limit of the capacity that can be designed, manufactured and installed between now and then.

Nuclear Capacity

Approximately 70 million kilowatts of nuclear capacity has been included in the general pattern for 1980, constituting about 13 percent of the total installed capacity needed at that time. Nuclear plants operating in the base of the load at an average capacity factor of 85 percent are expected to supply about 19 percent of the energy needs in 1980. These estimates are about 70 percent greater than the general projections contained in the National Power Survey Advisory Committee Report No. 15 [4] on Nuclear Development and in the Atomic Energy Commission's Report to the President, 1962, on Civilian Nuclear Power.

The Advisory Committee in 1963 summarized the present uncertain but nevertheless promising outlook for future growth in nuclear power as follows:

"The present report has been limited to the period to 1980, considering essentially the water moderated and cooled reactors. However, many other reactor types are in varying stages of development. Should any of these concepts prove economically more attractive than the water type the result will be to accelerate the growth of nuclear capability during this period.

"There is now sufficient operating experience on certain types of converter reactors to provide a basis for confidence in the reliability and flexibilty of such plants for central station service, and to encourage confidence in the ultimate attainment of good economy. This basis of operating experience is expanding rapidly both in terms of kilowatt-hours of generation and in terms of the range of nuclear technology represented.

"It is noted that while at least some types of nuclear plants can be built in very large sizes, the application of current guidelines restricts the availability of suitable nuclear plant sites. As more operational and test data are obtained, and improvements in design achieved, this problem should be greatly reduced.

"Areas of high fuel cost will be the first to increase their nuclear capacity, but when nuclear costs are sufficiently reduced, other areas are likely to install nuclear capacity. In some cases it may be that reasons other than cost, perhaps such as the reduction in air pollution, will play a part.

"It appears that with a vigorous development in breeder reactors, the fast breeder has the potential of being economically competitive as well as contributing importantly to the extension of our uranium resources for the future demands for electric power. . . ." [5]

In the brief time since the Advisory Committee report was prepared in the early part of 1963, a number of developments have occurred which indicate that the committee's general projections for nuclear capacity in 1980 may have been too conservative. Foremost among these are the results of bids for the Oyster Creek nuclear plant of Jersey Central Power and Light Company, which place a point on the index of projected nuclear generation costs substantially lower than other prior reference points.

Table 54 summarizes the amounts of nuclear power assumed in this analysis for each load study area. Assumed choices between nuclear power and conventional steam-electric generation were made largely on the basis of comparison of both investment and operating costs. Trends in future costs of conventional fuels and construction of conventional plants have been assumed to be downward but not at the same rate of decrease as for nuclear stations. In a few instances, involving supply for densely populated metropolitan areas, it was judged advisable to project nuclear energy sources beyond strict economic indications. Such plants, located in the fringe of metropolitan areas, could assist in meeting total loads without contributing further to the problem of air pollution.

As table 54 indicates, nuclear power is expected to make a strong showing in New England, Florida and the West coast. These are areas where generating costs are sufficiently high to permit present or early nuclear plants to be competitive. Some utility executives in these areas look upon nuclear power as a principal source of electric energy supply from now on. They view nuclear plants and production costs as having a greater opportunity for future cost reduction than thermal generation under the fuel supply situations which now exist. We have also projected that nuclear power will make a moderate entrance into the Great Lakes and mid-continent region. The val-

[4] Prepared by the Generating Stations Special Technical Committee, 1963.

[5] Advisory Committee Report No. 15, pages 177 and 178 of Part II.