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August 7, 2007

Dr. Michael T. Ryan
Chairman
Advisory Committee on Nuclear Waste and Materials
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Request for Comments on: Draft report for External Review – "Background, Status, and Issues Related to the Regulation of Advanced Spent Nuclear Fuel Recycling Facilities" dated June 26, 2007

Project Number: 689

Dear Dr. Ryan:

The Nuclear Energy Institute (NEI) [1] is pleased to comment on "Background, Status, and Issues Related to the Regulation of Advanced Spent Nuclear Fuel Recycling Facilities". NEI has a keen interest in the development and deployment of recycle facilities in the United States. In 2006 NEI commissioned a Task Force to review the status of recycling facilities deployed around the world and the potential for deploying such facilities in the United States. It is based on this work that NEI is supplying comments on your daft report.

NEI commends the ACNW&M for undertaking this effort. As stated in the Report's introduction, "In the conference report associated with FY 2006 Energy and Water Appropriation bill, Congress directed DOE to select a site for an integrated nuclear fuel recycle facility by 2007 and to initiate construction of one or more such facilities by FY 2010." It is the industry's position that such facilities should be regulated by the Nuclear Regulatory Commission and therefore, the ACNW&M has a major role in forming the basis for the regulation of such facilities.

Designated
ORIGINAL
per NEI

NEI's Task Force found that the technology for recycling currently exists and is being deployed everyday at several facilities around the world. It also found that there is an established regulatory framework which is in use for reprocessing and fuel fabrication facilities. Since the completion of the Task Force's work the International Atomic Energy Agency has conducted a series of meetings concerning the safety and regulation of such facilities. One of the major NEI Task Force findings

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was that the establishment of the United States' regulatory framework is one of the longest, if not the longest, lead time issues that must be addressed in closing the nuclear fuel cycle.

Overall the ACNW&M draft report provides a very good overview of the topic and the various issues. It also provides a good historical perspective. The largest hole in the report, however, is a lack of discussion of state of the art recycling and the current international framework for regulation of these operating facilities. It is certainly appropriate for historical reasons to discuss how the NRC regulated reprocessing facilities in the 1970s but the report fails to discuss how the NRC has moved from a deterministic agency in the 1970s to a risk-informed, performance-based regulator today. The report provides a general discussion of regulation but it fails to capture how this is being deployed by the international community of regulators and specifically how it is currently being utilized for the regulation of reprocessing facilities. It only makes sense that, if the regulatory program is going to continue to evolve in the risk informed arena the regulator needs to study what is being done today for the operating facilities. As the report then point out, the US stopped reprocessing in the 1970 but the rest of the world did not.

As the ACNW&M moves along in its considerations it must keep in mind one very important statement made in the report lines 4206 to 4208 " that is, the criteria for granting a license are expressed in terms of the requirements the applicant must meet but not the means by which the applicant meets the requirements". This is the heart of risk-informed, performance-based, versus deterministic regulation. The authors of the report need to seek out what requirements are being applied in the international regulatory community. This information should be utilized to develop what the requirements should be in the Untied States.

It is also important to note that there are currently four vendors who have just received awards from DOE for designing a reprocessing facility. While each of the four specific design information is proprietary, from the publicly available information none of the designs are such that a specific licensing process will work. This is evident as one proposal is using the pyroprocessing technique and the other three have variations of aqueous processes. It is also the reason why the reprocessing facility should be regulated more like a Part 70 facilities which have always been licensed by the terms an applicant must meet not like a Part 50 facility which was licensed by the means the applicant meets the requirements.

The report properly touches on environmental requirements and documentation. It is this specific area that the NEI Task Force felt is the most challenging. While the unsuccessful experience of the Generic Environmental Impact Statement on the Use of Mixed Oxide Fuel in Light Water Reactors (GESMO) is not likely to be repeated today the environmental impact is expected to be the most contentious issue in the development of the regulator framework. The report should delve further into this aspect.

For the benefit of the Committee, you will find attached a copy of the NEI Task Force report.

Please contact me 202-739-8126; fmk@nei.org with any questions or clarifications the ACNW&M may need on NEI's comments.

Sincerely,

Felix M. Killar, Jr.

NEI 06-07

NEI TASK FORCE REPORT ON RECYCLING

JULY 2006

NEI 06-07

Nuclear Energy Institute

NEI TASK FORCE REPORT ON RECYCLING

JULY 2006

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ACKNOWLEDGEMENTS

This report was prepared by the NEI Task Force on Recycling based on publicly available information. While the Task Force had hoped to gather information on the economics of recycling is was not able to accomplish this objective due to the limited amount of data. However, the Task Force would like to acknowledge the contribution of AREVA and the Boston Consulting Group for the economic data and the briefings on its ongoing economic study.

The Task Force would also like to acknowledge the efforts of the Electric Power Research Institute for providing a peer review of the report. As a result the Task Force believes the report is well grounded.

NOTICE

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EXECUTIVE SUMMARY

The NEI Task Force on Recycling evaluated alternative nuclear fuel cycles with consideration of fuel cycle economics,[1] level of maturity of the technology, timeframe required for commercial deployment in the United States, overall efficiency of the back-end of the nuclear fuel cycle, and the characteristics of the final waste form and resultant implications on repository disposal requirements. It also identify key issues and considerations that need to be addressed to achieve effective implementation or further development/evaluation of any technology(ies) that may so warrant in the United States.

The Recycling Task Force considered six alternative nuclear fuel cycles:

- Once-through fuel cycle using uranium dioxide (UO2) fuel
- Mixed-oxide (MOX) fuel cycle in thermal reactors
- Actinide conversion in a fast reactor fuel cycle with a MOX step in a thermal reactor
- Actinide transmutation in an accelerator fuel cycle
- Deep thermal conversion fuel cycle
- Direct actinide conversion (GNEP – approach)

The Recycle Task Force determined that the pursuit of reprocessing and advanced nuclear fuel cycles should neither delay nor replace the Department of Energy's repository project at Yucca Mountain.

The Recycle Task Force found that closing the back end of the fuel cycle offers sustainability-related benefits to the long-term uranium market. It has recently been estimated that recycling could reduce the U.S. demand for fresh uranium by 20 – 25%. It also determined that significant improvement in the utilization of Yucca Mountain Repository can be achieved through the use of advanced reactor for consuming the actinides.

The Recycle Task Force found there is insufficient economic data to compare alternative fuel cycle scenarios, with the exception of the direct disposal and MOX fuel cycles. Based on the data available, there is no significant economic difference between these two fuel cycles.

Fuel cycle scenarios dependent on the technical maturity of the components, in pursuing new nuclear technology the nuclear industry can not jump immediately from today's generation of thermal reactors to more advanced reactors

The Recycle Task Force found that the technical ability to fully close the fuel cycle in the U.S. is decades away; however, there is sufficient infrastructure and capacity internationally at advanced fuel cycle facilities to initiate a meaningful demonstration effort that seeks to recognize the many advantages cited in DOE's GNEP initiative in the timeframe of years rather than decades.

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[1] The Task Force was not able to establish a position on the economics of the various fuel cycles as there is a limited database and the Task Force did not generate any new data in this area.

Disclaimers

The Recycle Task Force did not attempt to address issues related to non-proliferation with respect to the alternative fuel cycle scenarios.

The Recycle Task Force did not attempt to address the impact of the various fuel cycle options on the 1 mill per kilowatt hour waste fee; however it is the consensus of members that the 1 mill fee should not be used for development technology to close the fuel cycle.

The Recycle Task Force did not address issues related to radiation exposure differences between the alternatives.

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NEI 06-07
JULY 2006

NEI TASK FORCE REPORT ON RECYCLING

1 INTRODUCTION

Recycling of Used Nuclear Fuel

Recently, the Administration and members of Congress have expressed an interest in reexamining the back end of the nuclear fuel cycle in the U.S. The intent of such an assessment is to determine whether recycling of used nuclear fuel should be adopted in some form in combination with the current policy of direct disposal in a geologic repository. Reprocessing is a method for separating the key elements that comprise nuclear fuel after it has been permanently discharged from the reactor core. Through reprocessing, uranium and plutonium can be recycled into new fuel. The remaining elements of interest consist of fission products and minor actinides. The principal minor actinides are neptunium and americium. The minor actinides can be recycled in a fast spectrum reactor or processed with the fission products as high-level radioactive waste into a stable glass-form and poured into metal canisters for long-term storage and ultimate disposal. This reprocessing technology has been used on a commercial scale for many years in a few countries.

The expansion of nuclear power in the U.S. and the resulting need for fuel for these reactors, coupled with continuing delays in the development of a repository at Yucca Mountain have prompted some policy-makers to suggest re-evaluating reprocessing as one means of achieving national energy security goals. Adopting a recycling strategy using existing and future technology could significantly extend the total technical capacity of the proposed Yucca Mountain repository. In February 2006 the Bush administration announced its Global Nuclear Energy Partnership (GNEP), a comprehensive strategy to increase U.S. and global energy security, encourage clean energy development around the world, reduce the risk of nuclear proliferation, and improve the environment. According to this plan, the U.S. and its partners would provide and reprocess nuclear fuel to any nation, provided the accepting nation pledges not to enter into enrichment or reprocessing in its country.

Further, in addition to the United States, France, Japan and Russia continue to pursue research and development of advanced nuclear fuel cycle concepts that would significantly minimize the heat load, volume, and radiation levels of material requiring disposal in a geologic repository while making proliferation resistance improvements. The objectives of the advanced recycling under consideration by GNEP include reducing the volume of radioactive byproducts requiring disposal while also capturing the remaining energy value in the used fuel.

NEI Recycling Task Force

The NEI Recycling Task Force was formed to review existing and future fuel cycle technologies associated with the reprocessing, treatment, and recycling of used nuclear fuel, with a focus on maximizing repository usability. The objectives of this report of the Recycling Task Force were to: (1) start to evaluate alternative nuclear fuel cycles with consideration of fuel cycle economics,[2] level of maturity of the technology and timeframe required for commercial deployment in the United States, overall efficiency of the back-end of the nuclear fuel cycle, and the characteristics of the final waste form and resultant implications on repository disposal requirements; (2) identify key issues and considerations that need to be addressed to achieve effective implementation or further development/evaluation of any technology(ies) that may so warrant in the United States; and (3) prepare a draft industry paper for consideration by the NEI Used Fuel Working Group, Nuclear Strategic Issues Advisory Committee, and Executive Committee, identifying the important considerations associated with integrating such technologies into the back end of the U.S. nuclear fuel cycle.

2 NUCLEAR FUEL CYCLE OPTIONS

The Recycling Task Force considered six alternative nuclear fuel cycles:

- Once-through fuel cycle using uranium dioxide (UO2) fuel
- Mixed-oxide (MOX) fuel cycle in thermal reactors
- Actinide conversion in a fast reactor fuel cycle with a MOX step in a thermal reactor
- Actinide transmutation in an accelerator fuel cycle
- Deep thermal conversion fuel cycle
- Direct actinide conversion (GNEP – approach)

Each of these fuel cycles begins by consuming uranium oxide (UO2) fuel in a thermal reactor. Each cycle has the following same front-end stages:

- **Uranium mining and milling**—uranium ore is extracted and concentrated from underground mines, open pit mines or through in-situ leaching, and then is processed into uranium concentrates (U3O8).
- **Conversion**—uranium concentrates are converted into uranium hexafluoride, UF6, which is solid at ambient temperature and sublimes at moderately high temperatures.
- **Enrichment**—isotopic enrichment of UF6 increases the concentration of the fissile 235U (typically to an enrichment of 3% to 5% for commercial power reactors).
- **Fuel fabrication**—consists of conversion of the enriched UF6 into UO2, fuel pellet manufacturing, pellet sintering, fuel rod manufacturing, and assembling the rods into bundles.
- **Thermal reactor operation**— UO2 fuel is inserted into the core of a commercial nuclear power reactor for a period of about 4 to 6 years. During thermal reactor operation a large part of the U235 is consumed resulting in the formation of fission products and a small fraction of U238 is converted to Pu239 which also fissions in the reactor. Through neutron capture and decay, U235 and Pu239 also form relatively small amounts of other actinides, collectively referred to as "minor actinides."

The variations in these fuel cycles occur following permanent discharge of the used UO2 fuel from a commercial light-water reactor power reactor.

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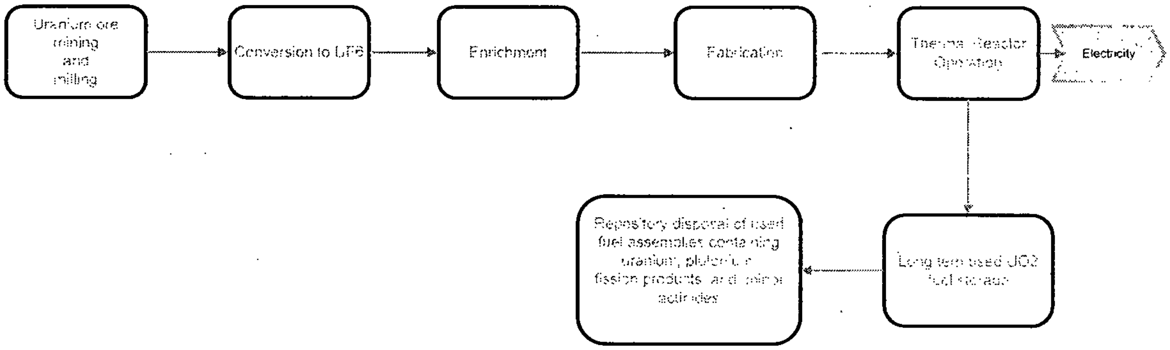
[2] The Task Force was not able to establish a position on the economics of the various fuel cycles as there is a limited database and the Task Force did not generate any new data in this area.

Once-through Fuel Cycle

In the once-through fuel cycle; the used nuclear fuel is treated as high-level radioactive waste material following its discharge from a thermal reactor. The remaining stages comprising the once-through fuel cycle are:

- **Interim storage of used UO2 fuel**—following discharge from the reactor, the used UO2 fuel is initially stored in water-filled pools and later may be transferred to dry storage systems.
- **Repository disposal**—direct disposal of the used nuclear fuel in a geologic repository is the fundamental premise for the once-through fuel cycle.

Figure 2-1 illustrates the key stages of the once-through fuel cycle. As indicated in this figure, each stage of this fuel cycle has been deployed on a commercial scale for many years in both the United States and internationally, with the exception of repository disposal which has undergone extensive R&D at this point.



Commercially deployed
No demonstrated technology - currently under development

Figure 2-1. Once-through Fuel Cycle
Stages & Level of Technology Maturity

Mixed-Oxide Fuel Cycle in Thermal Reactors

With the mixed-oxide (MOX) fuel cycle in thermal reactors, the UO2 fuel is reprocessed following its discharge from a thermal reactor. The stages comprising the back-end of the MOX fuel cycle are:

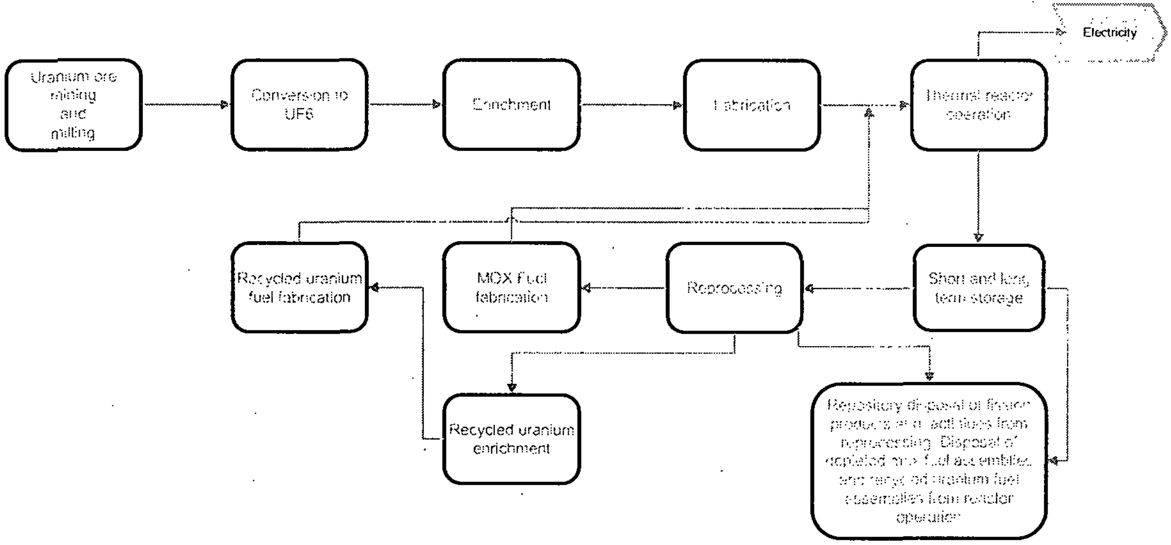
- **Used UO2 fuel storage**— following discharge from the reactor, the used UO2 fuel is stored in water-filled pools prior to reprocessing.
- **Reprocessing**—following discharge from the reactor, the used UO2 fuel is chemically processed to recover and recycle remaining fissile and fertile material.

- **Recycled U enrichment**—the residual uranium extracted from the used UO2 fuel is enriched to be reused in a thermal reactor
- **Recycled U fuel fabrication**—similar to fuel fabrication for the once-through UO2 fuel cycle except using recycled rather than fresh feed uranium
- **MOX fuel fabrication**—the residual plutonium extracted from the used fuel is converted into MOX fuel ("Mixed Oxide" consisting of a mixture of PuO2 and UO2) to be used in a thermal reactor. The uranium used can be natural, depleted, or it can be uranium recovered from reprocessing.
- **MOX fuel operation** – the current fleet of light water reactors with minor modifications can operate with from 1/3 to full cores of MOX fuel.
- **Used MOX fuel storage**— following discharge from the reactor, the used MOX fuel is stored in water-filled pools prior to direct disposal. It will be placed in long-term storage (in pools and possibly in dry casks after sufficient cooling) as needed following discharge from the reactor
- **Repository disposal**—the high-level radioactive waste, predominantly fission products and minor actinides, resulting from used UO2 fuel reprocessing will be disposed of in a geologic repository. Additionally, all used MOX fuel and some of the used UO2 fuel that may be unsuitable for reprocessing will also require direct disposal in a repository.

MOX recycle in thermal reactors provides a near term option for recycling using available technologies. By recycling the used UO2 fuel within 4 years after being discharged from a reactor, this recycling approach can increase the capacity of Yucca Mountain by a factor of 4 to 8 depending on how long the high level waste is cooled before disposal. This recycling approach produces 1 MOX assembly for every 8 reprocessed UO2 assemblies. If the used MOX is disposed of in Yucca Mountain then the capacity gain is eliminated since the used MOX contains the majority of the long term lived actinides that cannot be consumed in a thermal reactor. As such it is extremely unlikely that used MOX is disposed of in Yucca Mountain. Instead, this smaller quantity of used MOX is retained for advanced reactors that use plutonium, uranium, and minor actinides as fuel (See Section 6). The MOX recycle in thermal reactors provides an added advantage in reducing the number of advanced reactors needed to consume plutonium since 30% of the plutonium is consumed in one cycle of MOX in thermal reactors.

It is generally accepted that the reprocessing of used UO2 fuel and conversion to MOX fuel to be used in thermal reactors will only result in a marginal decrease of the long-lived minor actinides and have minimal value to the repository. However, as the cost of uranium and enrichment services continue to increase, the potential for MOX fuel becomes more economically viable. Therefore, this thermal reactor MOX cycle should be considered as an interim step. It is expected that nuclear power plants will eventually migrate from current reactors that use only UO2 fuel to more advanced reactors which use plutonium together with uranium and possibly minor actinides as fuel for long-term sustainability.

Figure 2-2 illustrates the key stages of the MOX fuel cycle in thermal reactors. As indicated in this figure, all stages of this fuel cycle, with the exception of the repository disposal stage, have been deployed on a commercial scale for many years internationally (in the United Kingdom, France and Japan). However, in the United States, the latter stages of this fuel cycle have only proceeded to a demonstration or R&D stage.



Commercially deployed
Technology demonstrated but not commercially deployed
No demonstrated technology

Figure 2-2. MOX Fuel Cycle in Thermal Reactors
Stages & Level of Technology Maturity

Actinide Conversion in a Fast Reactor with a MOX Step in a Thermal Reactor

For the actinide conversion in a fast reactor[3] fuel cycle with a MOX step, the used fuel, whether UO2 or MOX, from the thermal reactor is reprocessed following its discharge. The recovered plutonium, minor actinides, and uranium along with the unconverted actinides recovered from used fast reactor fuel is fabricated into new fast fuel The current estimate is it will require one fast reactor to consume the plutonium and minor actinides from three[4] thermal reactors. The stages comprising the back-end of this fuel cycle are:

- **Used UO2 fuel storage**— following discharge from the thermal reactor, the used UO2 fuel is stored in water-filled pools prior to reprocessing; some used fuel may not be appropriate for reprocessing and instead be directly sent for disposal.
- **Reprocessing of UO2 fuel**—following discharge from the thermal reactor, the used fuel is chemically processed to recover and recycle the remaining fissile and fertile material.

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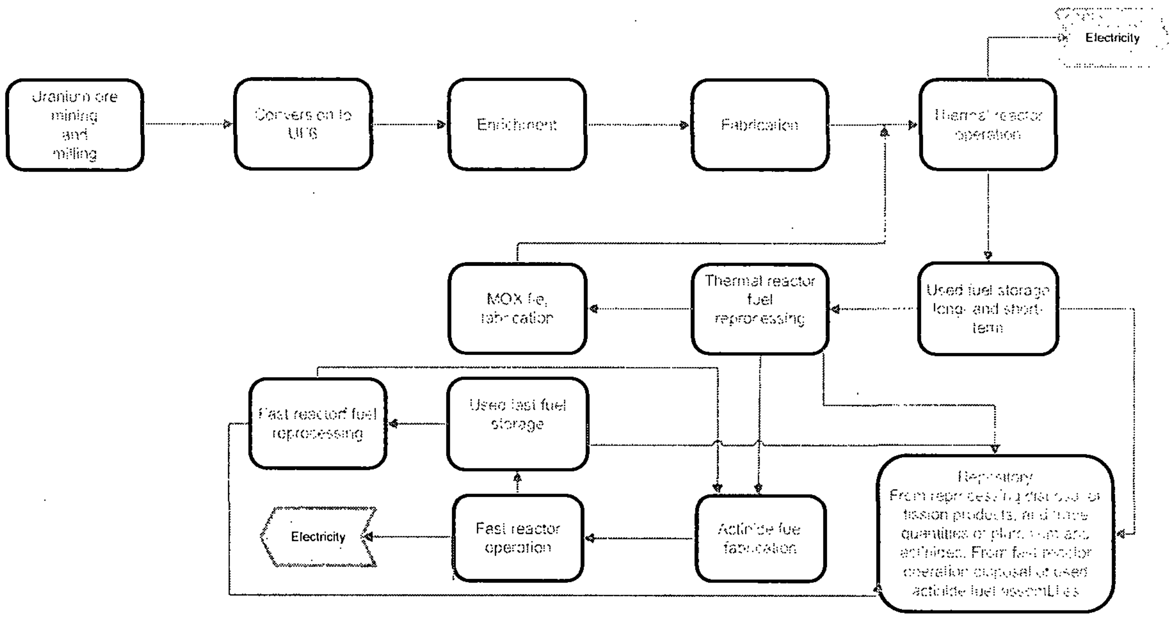
[3] A "fast reactor" is one in which the neutrons in the reactor have a much higher average energy than those in a "thermal reactor". Most actinides can serve as fuel in a fast reactor since they can be fissioned with high-energy neutrons.

[4] There are variations in this number depending on the assumptions used. MIT reported a ratio of .84/1 while ANL reports .25/1 ratio.

- **MOX fuel fabrication**—the residual plutonium and uranium extracted from the used UO2 fuel are converted into MOX fuel to be used in a thermal reactor.
- **Actinide fuel fabrication**—the minor actinides with some uranium and plutonium extracted from the used thermal reactor fuel are incorporated along with the residual actinides from used fast reactor fuel into new fast reactor fuel.
- **Fast Reactor**—the fast reactor operates with fast neutrons, which enable it to use all actinides including uranium, plutonium, americium, and neptunium as fuel. While producing electricity it consumes most of the actinides. During consumption of the actinides, the fast reactor can operate in a mode which produces fissile material for future operating cycles.
- **Used fast reactor fuel storage**— following discharge from the fast reactor, the used fast reactor fuel is stored prior to reprocessing; some used fuel may be actinide depleted and not appropriate for reprocessing and instead be directly sent for disposal.
- **Reprocessing of fast reactor fuel**—following discharge from the fast reactor, the used fuel is chemically processed to recover and recycle any remaining actinides.
- **Repository disposal**—the high-level radioactive waste, predominantly fission products, resulting from reprocessing will be disposed of in a geologic repository. Additionally, a small inventory of the used fuel discharged following thermal reactor operations as well as some used fast reactor fuel that may be unsuitable for reprocessing will also require direct disposal in a repository.

(While not shown here, excess recycled uranium could be enriched and fabricated for utilization in a thermal reactor.)

Figure 2-3 illustrates the key stages of the actinides conversion in a fast reactor fuel cycle with a MOX step. As indicated in this figure, actinide fuel fabrication, fast reactor operation, used fast reactor fuel storage, reprocessing of used fast reactor fuel, and the repository disposal stage, have not been deployed on a commercial scale internationally or domestically. The United States is currently just beginning, through GNEP, to evaluate this technology for commercial deployment.



Commercially deployed
Technology demonstrated but not commercially deployed
No demonstrated technology

Figure 2-3. Actinide Conversion in a Fast Reactor with a MOX Step in a Thermal Reactor Fuel Cycle
Stages & Level of Technology Maturity

Actinide Transmutation in an Accelerator Fuel Cycle

With actinide transmutation in an accelerator fuel cycle all of the used thermal reactor fuel is reprocessed following its discharge. The remaining actinides and fission products of concern are fabricated into actinide pellets which are inserted into the accelerator to transmute them to shorter-lived waste products which are then sent to the repository. The accelerator is coupled with a reactor; the effectiveness of the accelerator to convert the actinides is dependent on the subcriticality of the reactor. The stages comprising the back-end of this fuel cycle are:

- **Used UO2 fuel storage**— following discharge from the thermal reactor, the used fuel is stored in water-filled pools prior to reprocessing.
- **Reprocessing**—following discharge from the thermal reactor, the used fuel is chemically processed to recover and recycle remaining fissile and fertile material.
- **Accelerator actinide pellet fabrication**—the actinides remaining from the used thermal reactor fuel along with any fission products of concern are converted into actinide pellets to be transmuted in an accelerator.
- **Accelerator**—the accelerator uses high energy protons to drive the transmutation of actinides and fission products of concern. The accelerator is coupled with a reactor.
- **Used actinide fuel storage**— following discharge from the accelerator, the used fuel is stored prior to disposal.

- **Repository disposal**—the high-level radioactive waste, predominantly fission products resulting from reprocessing, will be disposed of in a geologic repository along with the used actinide fuel. Additionally, a small inventory of the used thermal reactor fuel discharged may be unsuitable for reprocessing and therefore will require direct disposal in a repository.

(While not shown here, a fast reactor can also be employed to consume some of the actinides prior to going to the accelerator. If this is deployed it would require additional facilities: fast reactor fuel fabrication, used fast reactor fuel storage, and fast reactor fuel reprocessing facilities. (Note: Excess recycled uranium could be enriched and fabricated for utilization in a thermal reactor; MOX fuel could also be used in a thermal reactor.)

Figure 2-4 illustrates the key stages of the actinide transmutation in an accelerator fuel cycle. As indicated in this figure, beyond reprocessing, the fuel cycle has not been deployed on a commercial scale.

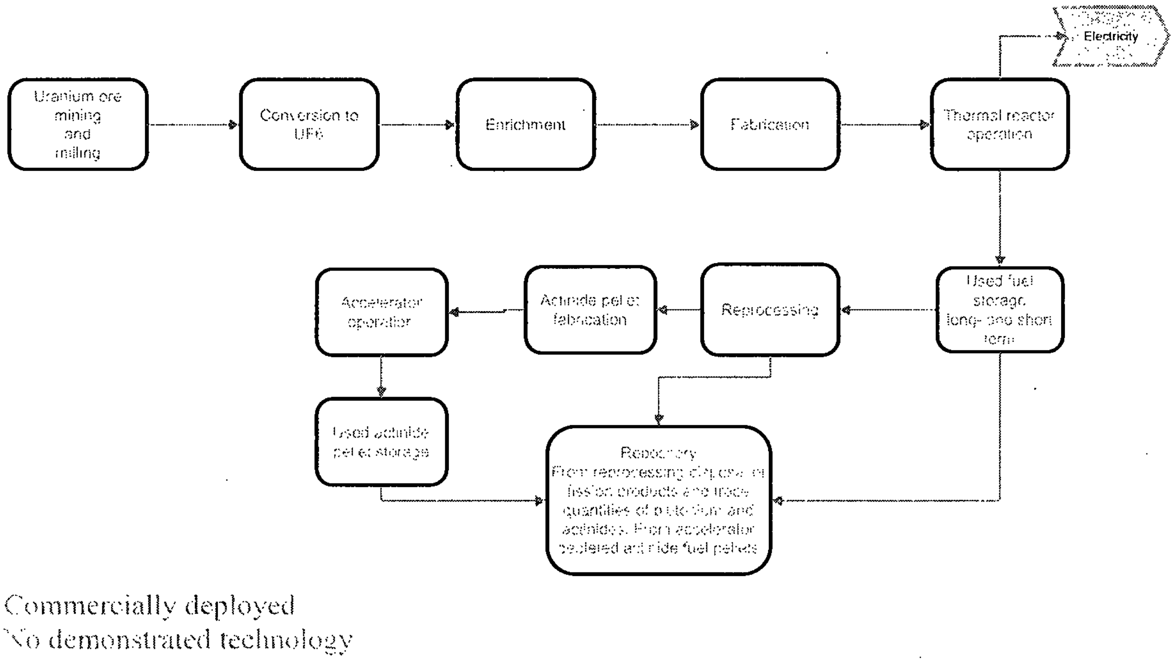


Figure 2-4. Actinide Transmutation in an Accelerator Fuel Cycle Stages & Level of Technology Maturity

Deep Thermal Conversion Fuel Cycle

The deep thermal conversion fuel cycle utilizes high temperature gas-cooled reactors (HTGRs) for the consumption of plutonium and minor actinides produced in light water reactors. It is currently estimated that one deep-conversion HTGR will consume the actinides from approximately 1.4[5] light water reactors. Following the reprocessing stage of the used fuel discharged from the thermal reactors, the plutonium and minor actinides are fabricated into HTGR fuel. The stages following light water reactor operation comprising the backend of the deep thermal conversion fuel cycle are:

- **Used UO2 fuel storage**— following discharge from the thermal reactor, the used nuclear fuel is stored in water-filled pools for a short period prior to reprocessing.
- **Reprocessing**—following discharge from the thermal reactor, the used nuclear fuel is chemically processed to recover and recycle any remaining fissile and fertile material.
- **High-temperature gas reactor fuel fabrication** – the plutonium and minor actinides recovered in reprocessing along with some uranium are fabricated into fuel for the HTGR.
- **High-temperature gas reactor (HTGR)** —HTGRs use the recycle uranium and plutonium along with the minor actinides as fuel to generate electricity and more completely convert the plutonium and actinide inventories into less long-lived species.
- **Used HTGR fuel storage**— following discharge from the HTGR, the used fuel is placed in dry storage prior to being sent to the repository.
- **Repository disposal**— used HTGR fuel along with the fission products and some minor actinides from used UO2 fuel reprocessing will require disposal in a geologic repository.

(While not shown here, excess recycled uranium could be enriched, and fabricated for utilization in light water reactors. MOX fuel could also be utilized in light water reactors.)

Figure 2-5 illustrates the key stages of the deep thermal conversion fuel cycle. As indicated in this figure, all stages of this fuel cycle — with the exception of the fuel fabrication with actinides and repository disposal — have been deployed on a commercial scale for many years internationally (in the UK, France, and Japan). However, in the United States all of the latter stages of this fuel cycle have only proceeded to the technology demonstration stage.

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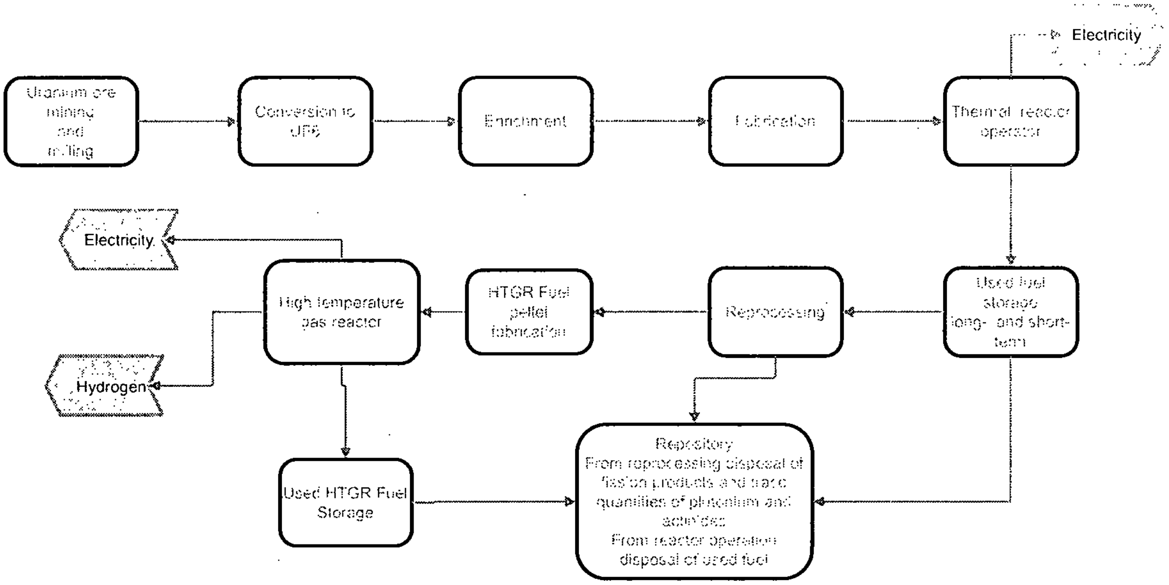
[5] This number is based on work conducted by General Atomics. A thermal reactor can also be used for this purpose, however, studies conducted by General Atomics and ANL indicate a HTGR is more effective. In addition the HTGR has the ability to produce hydrogen which could not be done as effectively with a thermal reactor.



Commercially deployed
Technology demonstrated but not commercially deployed
No demonstrated technology

Figure 2-5. Deep Thermal Conversion Fuel Cycle Stages & Level of Technology Maturity

Direct Actinide Conversion (GNEP)

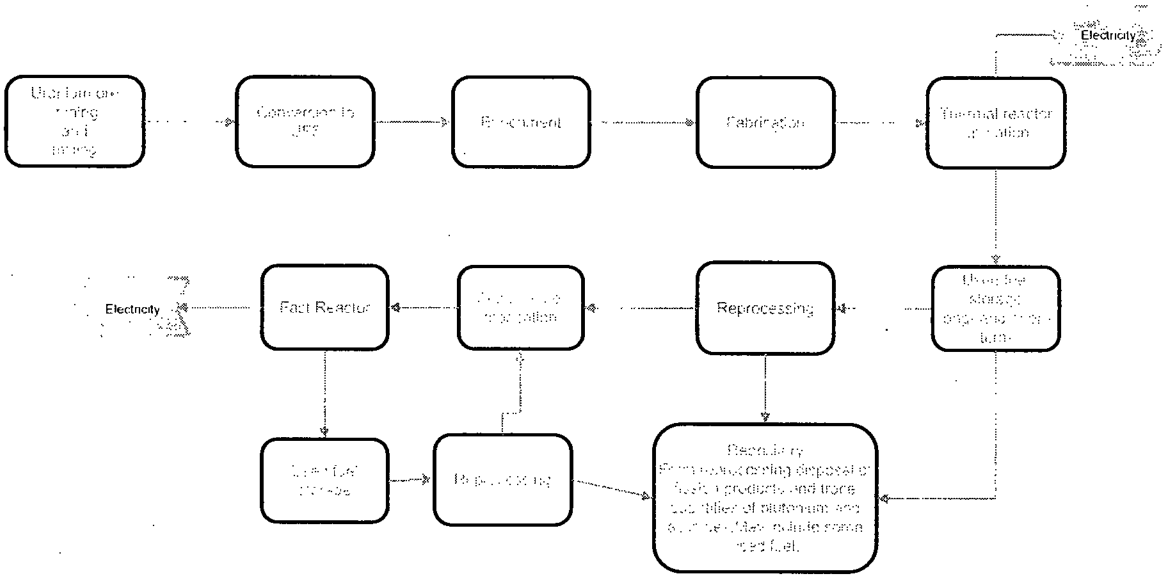
Direct actinide conversion in a fast reactor fuel cycle converts the actinides in used UO2 fuel produced in thermal reactors into shorter-lived fission products. The used thermal reactor fuel is reprocessed following its discharge. The fuel for the fast reactor is derived from the used thermal reactor fuel as well as from the unconverted actinides from used fast reactor fuel. The current estimate is it will require one fast reactor to consume the actinides from five thermal reactors. The stages comprising the back-end of this fuel cycle are:

- **Used UO2 fuel storage**— following discharge from the thermal reactor, the used nuclear fuel is stored in water-filled pools prior to reprocessing.
- **Reprocessing**—following discharge from the thermal reactor, the used UO2 fuel is chemically processed to recover and recycle remaining fissile and fertile material.
- **Actinide fuel fabrication**—the minor actinides and plutonium and uranium extracted from the used thermal reactor fuel are converted along with the residual actinides from used fast reactor fuel into actinide fuel to be used in a fast reactor.
- **Fast Reactor**—the fast reactor operates with fast neutrons which enable it to use all actinides — including uranium, plutonium, americium, and neptunium— as fuel. It consumes the actinides while producing electricity.
- **Used fast reactor fuel storage**—following discharge from the fast reactor, the used nuclear fuel is stored prior to reprocessing.

- **Reprocessing**—Following discharge from the fast reactor, the used fuel is chemically processed to recover and recycle any remaining actinide material.
- **Repository disposal**—the high-level radioactive waste, predominantly fission products resulting from reprocessing, will be disposed of in a geologic repository. Additionally, a small inventory of the used fuel discharged following thermal reactor operations that may be unsuitable for reprocessing and so will also require direct disposal in a repository.

(While not shown here, excess recycled uranium could be enriched, and fabricated for utilization in a thermal reactor. As currently designed, GNEP does not include MOX fuels in thermal reactor recycle; however it can be included if economically demonstrated.)

Figure 2-6 illustrates the key stages of the direct actinide conversion fuel cycle. As indicated in this figure, actinide fuel fabrication, fast reactor operation and the repository disposal stage have not been deployed on a commercial scale.



Commercially deployed
Technology demonstrated but not commercially deployed
No demonstrated technology

Figure 2-6. Direct Actinide Conversion (GNEP) Stages & Level of Technology Maturity

3 LICENSING STATUS & REGULATORY CONSIDERATIONS

The existing licensing basis for the nuclear fuel cycle in the United States is based on UO2 fuels. Any variation from this approach, including the use of MOX fuels or fuel cycles that incorporate actinide conversion, will require a generic licensing proceeding by the Nuclear Regulatory Commission (NRC).[6] During the 1960s and early 1970s, experience was gained with MOX fuel fabrication and its use in LWRs in the United States. At this time, plutonium operations were conducted under provisional operating licenses issued by the U.S. Atomic Energy Commission (AEC). In 1974, there was a significant change in regulatory development. AEC was replaced by the Energy Research and Development Agency and NRC. Environmental regulations were evolving, and the concept of environmental impact analysis was emerging. At the time, there was still an active program to move toward nuclear fuel reprocessing and use of MOX fuel. A series of hearings was initiated related to the Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed-Oxide Fuel in Light-Water Cooled Reactors (GESMO) to begin the process of licensing the use of MOX fuel under the emerging regulations. The process continued until 1977, when then-President Carter announced an executive decision to forego the use of plutonium in commercial reactors and canceled the GESMO hearings. The executive policy remained in effect until President Reagan officially lifted the ban on plutonium recycle in 1983. However, there was never an initiative to resume hearings on licensing plutonium recycle. Revisiting or initiating new licensing proceedings similar to the GESMO proceedings presents a significant regulatory barrier that would need to be overcome early in the process if the U.S. is to move away from a once-through fuel cycle.

Beyond the generic environmental impact, there is no regulatory framework supporting a closed fuel cycle in the U.S. It would likely take years for NRC to develop this framework along with the accompanying regulatory guidance and supporting information for any deviation from a uranium-based fuel cycle. This would require developing and implementing appropriate regulations, starting with securing experienced staff, and ending with the development of the necessary staff guidance. This issue also relates to setting regulatory priorities and directing resources within NRC and the nuclear industry as a whole.

The nuclear energy industry, like many other segments of America's industrial infrastructure, faces a critical shortage of qualified workers in the coming decade. The industry is already grappling with the expectation of a significant number of experienced workers retiring in the coming years. Nearly half of industry employees are over 47 years old, and less than 8 percent of employees are younger than 32 years old. This imbalance suggests a potentially inadequate supply of trained employees to replace departing personnel. Estimates indicate that nuclear energy companies may lose an estimated 23,000 workers over the next five years. During this same timeframe, NRC will likely be faced with over 30 additional plant life extension applications, numerous applications for combined construction and operating licenses for new nuclear plants, along with additional early site permit applications, a license application from the Department of Energy for the Yucca Mountain repository, and additional design certifications

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[6] The regulatory framework for Yucca Mountain is not complete at this point in time. Changes to the EPA standard for Yucca Mountain will need to be reflected in the regulatory requirements.

for new nuclear plant designs. The efforts needed to support a generic licensing proceeding and to develop the regulatory framework for closing the back end of the U.S. fuel cycle will require significant additional resources.

One additional regulatory consideration worth noting is that of waste confidence. NRC has from time to time reconsidered its Waste Confidence decision of 1984 and modified its determinations in view of recent developments. In its latest reconsideration, NRC made reasonable assurance that a repository would be available within the first quarter of the twenty-first century. A finding of other than confidence by NRC could significantly impair the licensing of new nuclear plants, the continued operation of existing plants, and the provision of used fuel storage capacity. The pursuit and consideration of advanced fuel cycles and the potential for closing the back end of the nuclear fuel cycle should be done in a manner that augments but not changes the existing Waste Confidence proceeding. Options should promote waste confidence by demonstrating added flexibility and alternatives for long-term management and pre-disposal treatment and conditioning of used nuclear fuel.

4 TIMEFRAME FOR COMMERCIAL DEPLOYMENT

Figure 4-1 presents a relative comparison of the timeframe for bringing each of the key fuel cycle technology components to commercial scale deployment in the United States, compared to international experience. Each technology component is distinguished as being either a) already commercially available, b) available for commercial scale deployment within the next decade, c) available for commercial scale deployment within the next two decades, or d) unlikely to be commercially available for more than two decades. It should come as no surprise that the more advanced fuel cycles are also the ones that will likely take significantly more time to become commercially viable.

Commercially Deployed
Deployed within next decade
Deployed within next two decades
Deployment over two decades away

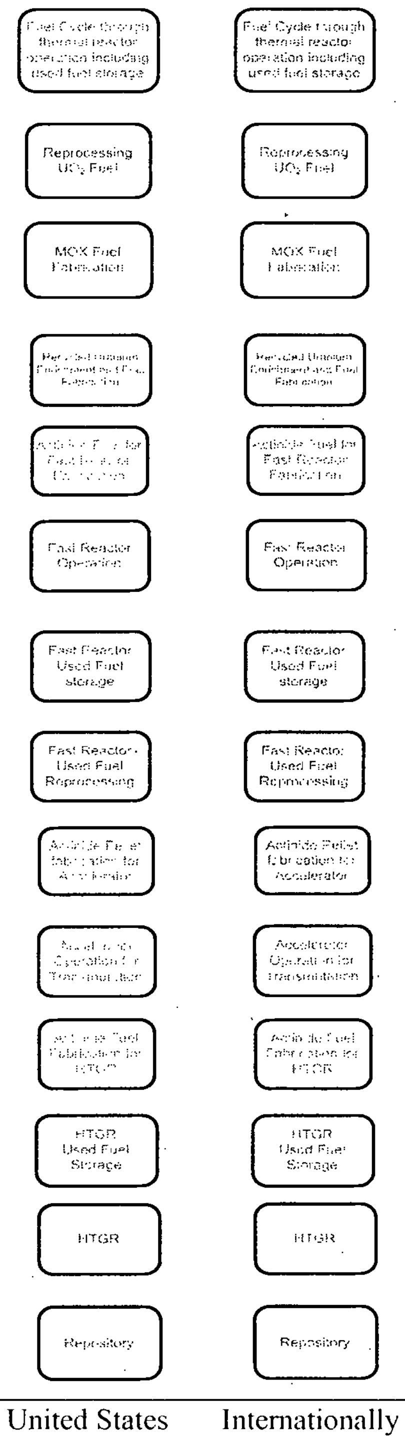

Figure 4-1. Timeframe for Commercial Deployment

5 FUEL CYCLE EFFECT ON REPOSITORY LOADING

Figure 5-1 illustrates the impact on the capacity of Yucca Mountain by fuel cycle type. It assumes the current fleet of reactors and current design of Yucca Mountain. The percentages are for approximation purposes only. Since the final waste form from each fuel cycle is not fully known, definitive numbers are not available. This is only for demonstration purposes and to show the relative merit of the various fuel cycles with respect to disposal capacity. The estimates are based on information provided from each of the organizations working on supporting the specific fuel cycle.

The focus on benefits to the repository has been primarily on the consumption of actinides in a fast reactor, a HTGR, or through the use of an accelerator. However, to gain the biggest benefit to the repository, other fission products must also be addressed. These are strontium and cesium, due to the heat they generate. In all of the fuel cycles it is assumed that these fission products will be held for decay before being introduced into the repository for permanent disposal. Once-through fuel cycle, and any MOX used fuel will be held for fission product decay at least 50 years prior to disposal; all other cases the fission products separated during reprocessing will be held at least 50 years prior to permanent disposal in the repository. (See section 6 for an alternative to direct disposal of used MOX fuel.)

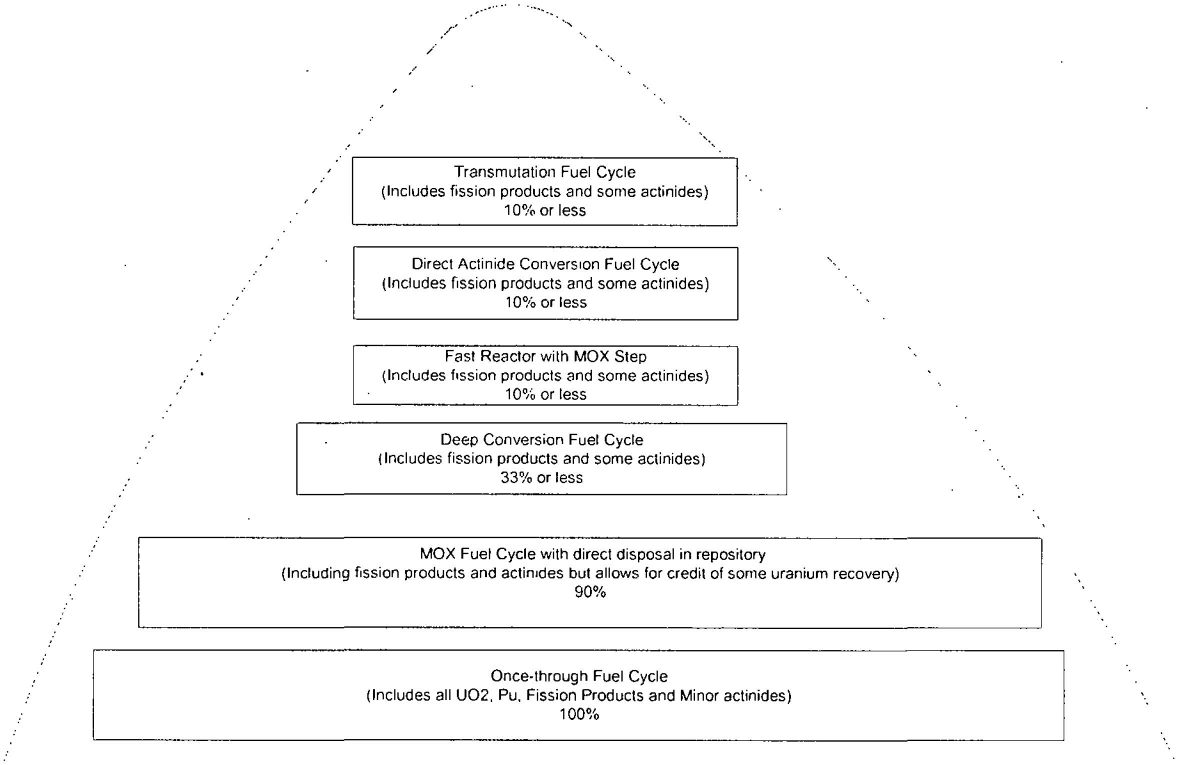

Figure 5-1. Amount of Yucca Mountain Capacity Used by Each Fuel Cycle

6 ECONOMIC EVALUATION

Basis of Economic Evaluation

None of the fuel cycles in this report have been fully deployed in the United States to date (the once-through cycle will only be fully deployed when a repository is operational). The economic evaluation is therefore limited to a review of published data and the identification of areas of economic uncertainty.

Once-Through Fuel Cycle

The U.S. Department of Energy (DOE) publishes life cycle cost estimates for the design, construction and operation of the Yucca Mountain repository. $10B has already been spent on the Yucca Mountain repository design. The most recent DOE estimates show an investment of $46B to develop a repository that is capable of storing 84,000 tons (excluding costs for storing used fuel at nuclear power plants and costs for disposing of non-commercial high level waste). The DOE life cycle cost estimate has increased by 80% from the initial estimates of $26B (in 2005$ excluding non-commercial waste). Used fuel continues to be generated, and additional repository capacity will be required for fuels discharged after 2020. Even if Yucca Mountain's current legal capacity of 70,000 metric tons was increased to around 120,000 tons, this would only accommodate fuels discharged up to 2035. The YM Project faces many challenges including the submittal of a license application to the NRC. Factors which will need to be recognized in the future DOE life cycle cost estimate are;

- The redesign of the surface facilities for Thermal Aging and Disposal (TAD) canister fuel,
- The design, licensing, fabrication and operation of TAD canister systems,
- Increasing cost estimates for the Nevada rail link,
- Continued delays in the program,
- Expanding the current legal capacity limits, and
- Second repository costs.

There are no repositories for used fuel and/or fission products operating in the world today and therefore no international economic operational data for comparative review. With expectations of increased nuclear generation capacity in the United States, the need to maximize the utilization of Yucca Mountain will be inevitable. However, it is generally acknowledged that the technical capacity of Yucca Mountain is significantly higher than the current legislative limit.

The MOX Fuel Cycle

Various groups have studied the economics of the Once-through and MOX fuel cycles. (MIT, Harvard, University of Chicago for example). None of these studies had access to reliable industrial economic data for recycling. The following are summaries of these reports.

MIT Report on the Future of Nuclear Power

"The Future of Nuclear Power", July 29, 2003, ISBN 0-615-12420-8
(http://web.mit.edu/nuclearpower/)

This study presented the interrelated technical, economic, environmental, and political challenges facing a significant increase in global nuclear power utilization over the next half century and what might be done to overcome those challenges. This study found that the long-term waste management benefits of advanced closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs. The report stated, "We believe that the world-wide supply of uranium ore is sufficient to fuel the deployment of 1,000 reactors over the next half century and to maintain this level of deployment over a 40-year lifetime of the fleet... Closed fuel cycles will be more expensive than once-through cycles, until ore resources become very scarce. This is unlikely to happen, even with significant growth in nuclear power, until at least the second half of this century, and probably considerably later still."

The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel, Final Report,

Harvard University, DE-FG26-99FT4028, Final Report (August 12, 1999 – July 30, 2003), M. Bunn et al, December 2003

This paper concluded that reprocessing and recycling using current or near-term technologies would substantially increase the cost of nuclear waste management, even if the cost of both uranium and geologic repositories increase significantly. This study concluded, even making a number of assumptions that were quite favorable to reprocessing, that shifting to reprocessing and recycling would increase the costs of spent fuel management by more than 80% (after taking account of appropriate credits or charges for recovered plutonium and uranium from reprocessing). Reprocessing (at an optimistic reprocessing price) would not become economically practical until uranium reached a price of over $360 per kilogram — a price not likely to be seen for many decades, if then. Either the current 1 mill/kilowatt-hour nuclear waste fee would have to be substantially increased, or billions of dollars in tax money would have to be used to subsidize the effort. Since facilities required for reprocessing and transmutation would not be economically attractive for private industry to build, the U.S. government would either have to build and operate these facilities itself or give private industry large subsidies.

The Economic Future of Nuclear Power,

University of Chicago, "The Economic Future of Nuclear Power," August 2004

The principal findings of the Chicago study demonstrate that future nuclear power plants in the United States eventually can be competitive with either natural gas or coal. The study used publicly available estimates for both direct disposal costs and reprocessing costs. It found that reprocessing would have little influence on the assistance required to make the early plants cost competitive. The reprocessing costs represent only a small percentage of total costs for these early plants (i.e., about 5% of their LCOE's).

Boston Consulting Group Study for AREVA[7]

Boston Consulting Group (BCG), funded by AREVA, performed an independent study which examined a range of nuclear fuel management options. These included the economic assessment of an exclusive once-through strategy, as well as a portfolio strategy, in which recycling is complementary to the development of a repository. BCG had access to AREVA know-how and proprietary data from more than two decades of industrial-scale commercial recycling experience. BCG concluded that a balanced portfolio with recycling of all newly discharged fuel and some of the legacy fuel along with direct disposal of some once-through used fuel, for legacy fuel that cannot benefit from early recycling, is comparable in economics to the once-through-cycle for all legacy and future discharged fuel. The portfolio of recycling and repository offered important benefits over the once-through-cycle in terms of increased capacity of Yucca Mountain to last this century, effective hedge against rising fuel prices through the availability of MOX and reprocessed uranium, and proven flexible recycling technologies . A business study could determine an appropriate financing strategy.

Based on the technical limitations for Yucca Mountain in terms of heat content and volume, adopting a strategy of early treatment to reduce americium content in the final waste product could lead to significant savings in repository space. Reduction factors can be between 4 and 8, depending upon the intermediate storage time of the treated high level waste and the disposal path for the hulls and end. For the past 5 years AREVA has studied enhancements to recycling technology used at its La Hague facility. This effort has resulted in several advancements including the total elimination of pure plutonium separation at any stage during treatment. This new recycling process produces a mixture of plutonium and uranium which could be used to feed a MOX fuel fabrication facility inside a single integrated treatment plant. Used MOX was assumed to be retained in storage at the integrated plant for use in future fast reactors or multiple recycling. The BCG study included a range of alternatives for treating the used MOX fuel, from direct disposal to recycling in a thermal reactor to recycling in a fast reactor.

The BCG estimates included significant contingencies and additional cost for adapting proven industrial-scale technologies to meet U.S.-specific requirements. The portfolio strategy requires early financing in the 2010-2020 timeframe.

By adopting recycling, 20-25% of the U.S. nuclear fuel supply will come from recycled products (MOX and recycled uranium fuels). This provides a significant supply overhang and may lower dependence on foreign uranium supplies.

BCG concluded that the cost of a U.S. recycling strategy portfolio employing MOX has a net present cost of $48-53B. This is based on new recycling plant openings in 2020 with receipts of 2,500 tons of used fuel per year and the storage of used MOX fuel for future use in fast reactors or multiple recycling. BCG also estimated the cost of a once-through cycle with Yucca Mountain extensions and a second repository to be $47-50B. Given the intrinsic uncertainties

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[7] At this time this study has not been made publicly available. However, AREVA and BCG have briefed the Recycle Task Force on the study. BGC will provide a final report to AREVA by summer 2006, which AREVA may choose to publish in the public domain.

around the assumptions used, the study concluded that the economics of the two alternatives are comparable.

MOX Fuel Cycle in Thermal Reactor

No commercial deployment to date in the United States; however, the MOX fuel cycle is deployed in France, the UK, Russia, and Japan. The economics are not well known in the United States, beyond the BCG study, due to no reprocessing infrastructure or regulatory structure. There are published economic studies based on the European experience (NEA/OECD - *Les aspects économiques du cycle du combustible nucléaire*, 1994).

Actinide Conversion in a Fast Reactor Cycle with a MOX Step

No commercial deployment to date and no published economic data for review.

Actinide Transmutation in an Accelerator Fuel Cycle

No commercial deployment to date and no published economic data for review.

Deep Thermal Conversion Fuel Cycle

No commercial deployment to date and no published economic data for review.

Direct Actinide Conversion Fuel Cycle (GNEP – approach)

No commercial deployment to date and no published economic data for review.

7 GLOBAL NUCLEAR ENERGY PARTNERSHIP

On February 6, 2006, the U.S. Department of Energy (DOE) announced its Global Nuclear Energy Partnership (GNEP). The GNEP initiative is a comprehensive strategy to increase domestic and global energy security through the safe expansion of clean nuclear power. The end state of this strategy is a global system of nuclear fuel supplier nations that will enable developing nations to affordably acquire nuclear energy without increasing the risk of nuclear proliferation. GNEP is based on the principle that energy and security go hand-in-hand. GNEP is intended to develop and demonstrate new proliferation-resistant technologies to recycle nuclear fuel and reduce waste. Through GNEP, the United States will work with other advanced nuclear nations to develop a fuel services program that would provide nuclear fuel and recycling services to nations in return for their commitment to refrain from developing enrichment and recycling technologies. GNEP is designed to allow developing nations to reliably access clean nuclear energy as an electricity source in a safe and cost effective manner.

The GNEP initiative includes a broad implementation strategy encompassing the following key elements:

- A new generation of Advanced Light Water Reactors (ALWR) in the United States
- New recycling technologies that enhance proliferation resistance while extracting residual energy value, reducing waste volumes and maximizing safety.
- A comprehensive plan to manage spent nuclear fuel in the United States, including permanent geologic disposal at Yucca Mountain.
- Advanced conversion reactors that recycle nuclear fuel while converting residual actinide elements.
- A fuel services program to enable nations to acquire nuclear energy economically while limiting proliferation risks, by voluntarily limiting access to enrichment and reprocessing facilities.
- Small scale reactors designed for the needs of developing countries.
- Improved nuclear safeguards to enhance the proliferation resistance and safety of expanded nuclear power.

The elements of the GNEP initiative were released late during the efforts of the NEI Recycling Task Force. As a result, this report does not examine the approach proposed by GNEP in detail. While additional details continue to be developed and released by DOE, one point remains clear—this is an extremely ambitious initiative. DOE is seeking constructive input from industry, the international community, and other key stakeholders as it further refines implementation strategies for GNEP. The Department faces a major challenge to demonstrate to the public and elected officials how this initiative can be implemented while maintaining the management and financial commitment necessary to meet its contractual obligation for disposition of used nuclear fuel. As the Department of Energy further develops the framework for this partnership, industry must remain actively engaged to ensure that the long-term technology roadmap squarely addresses major concerns about nuclear energy, so our political leaders, policymakers and the public accept the roadmap as a legitimate, necessary and credible undertaking.

8 FINDINGS

- The Recycle Task Force determined that the pursuit of reprocessing and advanced nuclear fuel cycles should neither delay nor replace the Department of Energy's repository project at Yucca Mountain. Permanent disposal of the byproducts of recycling will be required at a repository no matter what technologies might be deployed. Additionally, the Yucca Mountain repository is still needed for many of the DOE wastes and other wastes not suitable for advanced fuel cycles, including some legacy commercial used nuclear fuels.

- The Recycle Task Force found that the most significant issue and obstacle facing all of the fuel cycle scenarios, especially the closed fuel cycles, is that of the regulatory and licensing process. With EPA forced to revisit the disposal standard for Yucca Mountain, this continues to remain a key issue for the current baseline approach of once-through fuel cycle. It presents a larger obstacle to all closed fuel cycle scenarios for the following reasons:

  - The existing licensing basis for the nuclear fuel cycle in the United States is based on UO2 fuel. Any variation from this approach, including the use of MOX fuels or fuel cycles that include actinide consumption will require a new supporting licensing proceeding similar to the GESMO proceeding of the late 1970's.
  - Detailed regulatory guidance for these alternative fuel cycles would take years to establish to the same extent that it currently exists today for UO2 fuel.
  - The personnel required to support the licensing processes associated with alternative fuel cycles, while maintaining the existing licensing processes for the uranium based fuel cycle will be substantial.
  - It is likely that the timeframe for these additional resources will coincide with other competing resource needs, including ongoing plant license renewals, new plant licensing, and Yucca Mountain licensing.

- The Recycle Task Force found that closing the back end of the fuel cycle offers sustainability-related benefits to the long-term uranium market. While the Task Force did not try to quantify this benefit from a cost standpoint, it has recently been estimated that recycling could reduce the U.S. demand for fresh uranium by 20 – 25%.

- The Recycle Task Force found there is insufficient economic data to compare alternative fuel cycle scenarios, with the exception of the direct disposal and MOX fuel cycles. Based on the data available, there is no significant economic difference between these two fuel cycles. A detailed economic analysis of other fuel cycle scenarios is called for. The Task Force expects that the cost of incorporating actinide conversion in thermal reactors, fast reactors, or in accelerators will be more expensive.

- Fuel cycle scenarios dependent on the technical maturity of the components, in pursuing new nuclear technology the nuclear industry can not jump immediately from today's generation of thermal reactors to more advanced reactors. Rather, the industry is taking a stepwise approach in first pursuing proven technologies, using advanced light water reactors and HTGRs before proceeding with fast reactors. Revolutionary approaches have historically not proven viable from a commercial, regulatory or technical/infrastructure standpoint. A stepwise approach is essential as the United States explores closing the back end of the nuclear fuel cycle.

- The Recycle Task Force found that the technical ability to fully close the fuel cycle in the U.S. is decades away; however, there is sufficient infrastructure and capacity internationally at advanced fuel cycle facilities to initiate a meaningful demonstration effort that seeks to recognize the many advantages cited in DOE's GNEP initiative in the timeframe of years rather than decades.

Disclaimers

- The Recycle Task Force did not attempt to address issues related to non-proliferation with respect to the alternative fuel cycle scenarios.

- The Recycle Task Force did not attempt to address the impact of the various fuel cycle options on the 1 mill per kilowatt hour waste fee; however it is the consensus of members that the 1 mill fee should not be used for development technology to close the fuel cycle. Further, it is understood future economic analysis of alternative fuel cycles should consider the financing required to support such fuel cycles.

- The Recycle Task Force did not address issues related to radiation exposure differences between the alternatives. This matter would be addressed during generic environmental impact studies for closing the fuel cycle.