U.S.NRC
United States Nuclear Regulatory Commission
Protecting people and the environment

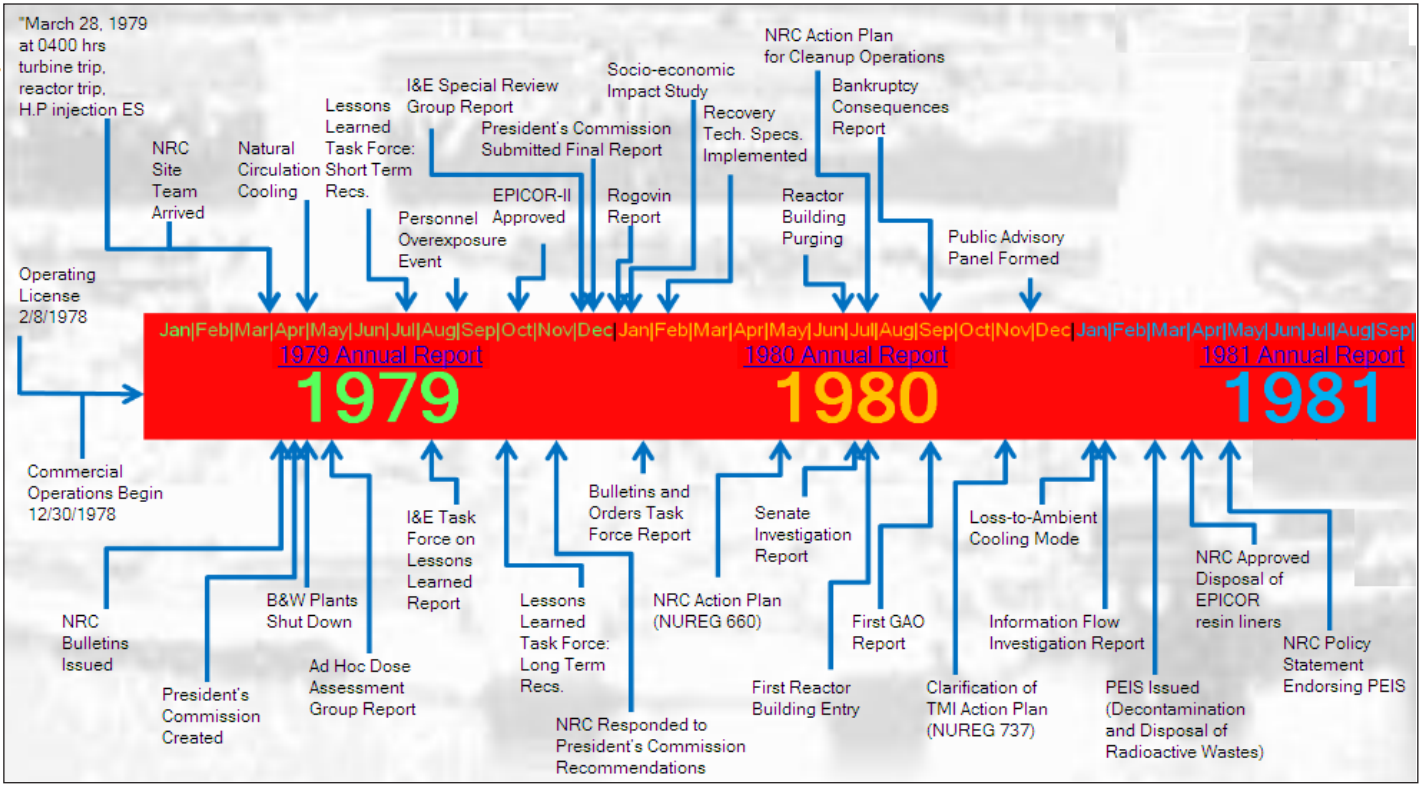
Three Mile Island Accident of 1979 Knowledge Management Digest

NUREG/KM-0001
December 2012
Office of Nuclear Regulatory Research

Three Mile Island on April 10, 1979, 13 days after the accident.

Table of Contents

President Jimmy Carter observes the radiation monitors in the Three Mile Island, Unit 2 control room on April 1, 1979, accompanied by Pennsylvania Governor Richard Thornburgh and the NRC's Harold Denton (front to back).



Three Mile Island Unit 2 Timeline

Introduction

Although it caused no deaths or injuries, the accident at the Three Mile Island, Unit 2 (TMI-2) nuclear power plant was the most serious incident in U.S. commercial nuclear power history. The accident began in the early morning hours of March 28, 1979, at the power plant near Middletown, PA, and its effects on nuclear safety and regulation continue to this day. Three Mile Island spurred the U.S. Nuclear Regulatory Commission (NRC) to tighten and heighten its regulatory oversight of the nuclear power industry to ensure safety for the public and the environment. Investigations and the implementation of lessons learned brought about sweeping changes in the U.S. nuclear industry. These included improvements in emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations. The NRC has intensively studied and documented the TMI-2 accident.

This multimedia knowledge management digest is the first in the NRC's NUREG knowledge management (NUREG/KM) series. The agency intends for NUREG/KMs to preserve knowledge for future generations of the important historical events and research that have shaped the NRC's regulatory programs.

This knowledge management digest and the supporting DVD contain the reports that the NRC and other government organizations issued following extensive investigations in the accident. Although a few key documents have become available electronically, this NUREG/KM marks the first time that the NRC has digitized these historically important reports. On the DVD, the table of contents on the main welcome screen lists these reports and provides access to them.

In addition to the large collection of reports, the DVD also provides a multimedia presentation of the special NRC event, "The Accident at Three Mile Island—A Look Back: Preserving the Institutional Memory after 30 Years."

The Accident

The sequence of certain events—equipment malfunctions, design related problems, and operator errors—led to a partial meltdown of the TMI-2 reactor core, resulting in a very small offsite release of radioactivity. In an atmosphere of growing uncertainty about the condition of the plant, on the morning of March 30, 1979, Pennsylvania Governor Richard Thornburgh advised people within a 5-mile radius of the plant to stay indoors. He also advised pregnant women and preschool-age children to leave the area.

The NRC sponsored the Special Inquiry Group to investigate the accident and write NUREG/CR-1250. Volume 1 of that report contains an informative and nontechnical discussion of the accident, including onsite actions and offsite responses. Another good resource on the accident is the main report by the President's Commission on the Accident at Three Mile Island. Additional volumes of both these reports provide technical details.

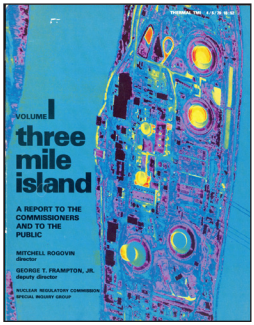
The NRC's training manual on reactor safety (NUREG/CR-6042, Section 2.2) provides a technical summary of the accident. The training manual also provides an overview of the regulatory implications of the accident (Section 2.3).

Shortly after the accident, NRC staff gathers in the NRC trailer office at Three Mile Island.

The chronology of events can be found in all of the above documents. The "Backgrounder" written by the NRC's Office of Public Affairs and in the NRC's 1979 annual report NUREG-0690, Chapter 2 contain additional nontechnical summaries of the accident. These and other reports on the accident are provided on the accompanying DVD (see the section Accident Overview).

Investigations and Lessons Learned

Two weeks after the accident, the President of the United States, Jimmy Carter, appointed a 12-member Presidential Commission to investigate the accident at Three Mile Island. This group, known as the "Kemeny Commission," conducted a comprehensive investigation of the accident and made recommendations based upon their findings. The "Kemeny Report" was issued in October 1979. The NRC published its initial response to the Presidential Commission's recommendations in November 1979 as NUREG-0632, "NRC Views and Analysis of the Recommendations of the President's Commission on the Accident at Three Mile Island." A subsequent report, NUREG-1355, "Status of Recommendations of the President's Commission on the Accident at Three Mile Island—A Ten-Year Review," updated that initial response to include each of the 44 recommendations made by the Kemeny Commission over a 10-year period.



To help gain a comprehensive insight into the accident, the NRC sponsored both internal and external investigations. The NRC asked the independent Special Inquiry Group, known as the "Rogovin Committee" to perform an investigation. The Special Inquiry Group provided a thorough analysis and assessment of the causes and implications of the accident. As already noted, the NRC published this work in NUREG/CR-1250, "Three Mile Island, A Report to the Commissioners and to the Public." Working internally, the NRC created a Lessons-Learned Task Force. The NRC task force identified and evaluated safety concerns originating from the TMI-2 accident that required licensing actions at other nuclear power plants. The NRC published the task force's conclusions in NUREG-0578, "TMI-2 Lessons Learned Task Force Status Report and Short-Term Recommendations," and NUREG-0585, "TMI-2 Lessons Learned Task Force Final Report."

Many other groups, both internal and external to the NRC, also performed separate investigations. These included the U.S. Congress and its General Accounting Office (GAO); the Ad Hoc Dose Assessment Group, which comprised various Federal agencies (see NUREG-0558); the NRC's Advisory Committee on Reactor Safeguards; the Bulletins and Orders Task Force of the NRC's Office of Nuclear Reactor Regulation (see NUREG-0645); the NRC's former Office of Inspection and Enforcement's Special Review Group (see NUREG-0616), the Task Force on Lessons Learned (see NUREG-0600), and investigation of information flow during the accident (see NUREG-0760); the NRC's Siting Task Force (site location requirements for nuclear power plants); the NRC's Emergency Preparedness Task Force; the Staff Panel on the Commission's Determination of an Extraordinary Nuclear Occurrence (see NUREG-0637); the NRC's Office of Nuclear Regulatory Research; and the NRC's former Office of Standards Development.

The DVD provides many of the key investigation reports on TMI (see sections **Government Investigations** and **NRC Investigations and Lessons Learned**).

Regulatory Actions

The NRC implemented a number of regulatory actions resulting from investigations and lessons learned reviews, and completed many more "spin-off" actions in the decades following the accident. The first wave of actions that the NRC approved, included NRC orders to individual licensees and generic communications, such as bulletins and generic letters issued to nuclear power plant licensees. The NRC used these regulatory tools in the days to months following the accident.

Once the various investigative groups had documented their findings, the Commissioners considered the recommendations. The agency consolidated all of the recommendations that the Commission approved into NUREG-0737, "TMI Action Plan," published in 1980. The plan included approximately 371 individual requirements. The NRC found that of these, 13,863 action plan items were applicable when reviewed against each specific licensed nuclear power plant. Some of these requirements involved changes to the internal NRC organization, processes, and practices. A few requirements caused the Commission to issue policy statements and specific changes to the NRC's regulations through the rulemaking process. Both of these long-term regulatory tools required extensive internal and external stakeholder involvement, and were completed during the 1980s. NUREG-0933, "Resolution of Generic Safety Issues," documents the prioritization and closeout of the TMI Action Plan requirements.

Generic Communications—Within 3 days of the accident, the NRC's Office of Inspection and Enforcement issued a series of bulletins instructing all operating power plant licensees to take a number of immediate actions to avoid repeating several of the events that occurred during the accident, and which contributed significantly to its severity (Bulletins 79-05, 05A, 05B, 05C, 06, 06A, 06B, 06C, and 08). The bulletins and related evaluations also substantially informed other staff activities, such as those associated with the generic study efforts of the Bulletins and Orders Task Force (NUREG-0645) and the Lessons Learned Task Force (NUREG-0585). The NRC issued other types of generic communications including generic letters that transmitted information and usually required action or a response, and information notices related to issues in which the licensees considered action appropriate. The DVD provides most of the generic communications relevant to TMI-2 (see the section titled **Generic Communications and Policy Statements**).

TMI Action Plan—Each of the investigating groups organized their recommendations in a different way. These recommendations were collected and transformed into discrete, scheduled tasks in NUREG-0660, "NRC Action Plan Developed as a Result of the TMI-2 Accident." NUREG-0737, "Clarification of TMI Action Plan Requirements," documents the specific items from NUREG-0660 that the Commission approved for implementation at nuclear power plants. In October 1980, the NRC issued NUREG-0737 for implementation in Generic Letter 80-090. This report comprises specific items, and includes additional information about schedules, applicability, method of implementation review, submittal dates, and clarification of technical positions. The Generic Issues Program prioritized and tracked the TMI Action Plan items contained in NUREG-0660 and NUREG-0737. NUREG-0933, "Resolution of Generic Safety Issues," documents the closeout of action items.

The DVD provides the above NUREGs and other select NUREGs that were associated with the implementation and closeout of TMI Action Items (see the section titled **Industry Wide Regulatory Actions**).

Rulemaking and Regulatory Guides—In most cases, the NRC implemented the TMI Action Plan issues through the review of new licensee applications and the imposition of confirmatory orders and specific license conditions (not through specific changes to the NRC's regulations). In several instances, implementation of the TMI Action Plan resulted in new or modified regulations. These regulations, and a few others that could be considered relevant to the TMI accident, included the following: upgrading emergency planning regulations in 1980, requirements related to hydrogen control in Mark I and Mark II containments for boiling water reactors (BWRs) in 1981, upgrading operations

personnel and staffing requirements at nuclear power plants in 1983, issuing a licensee event report rule in 1983, requirements related to hydrogen control in Mark III containments for BWRs and ice condenser containments for pressurized water reactors (PWRs) in 1985, improving the backfitting process for power reactors in 1985, improving personnel dosimetry processing in 1987, updating the operator licensing requirements in 1987, and mandating participation in the Emergency Response Data System program in 1991.

In general, a regulatory guide (RG) describes one acceptable method for implementing agency regulations. Regulatory guides are not substitutes for regulations, and the NRC does not require that licensees comply with them. Notable regulatory guides that the NRC revised or created during the implementation of the TMI Action Plan included RG 1.8, "Qualification and Training of Personnel for Nuclear Power Plants"; RG 1.97, "Criteria for Accident Monitoring Instrumentation for Nuclear Power Plants"; RG 1.101, "Emergency Planning and Preparedness for Nuclear Power Reactors"; and RG 1.149, "Nuclear Power Plant Simulation Facilities for Use in Operator Training and License Examinations." NRC annual reports provided on the DVD summarize relevant rulemakings and regulatory guides (see the section titled **NRC Annual Reports**).

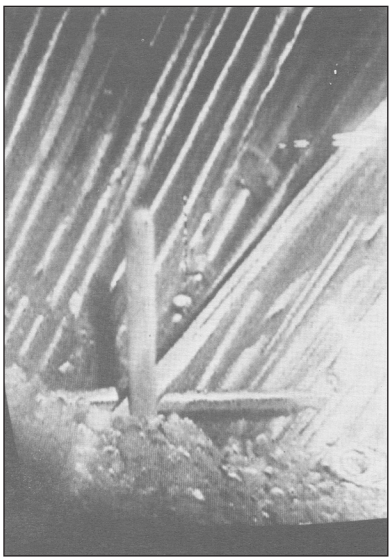
NRC Commission Policy Statements—Several policy statements that the Commission issued were directly or indirectly related to the TMI Accident. A policy statement is not a regulation and does not impose specific regulatory requirements, but rather provides the Commission's rationale and motivation for future regulatory positions. Two notable policy statements that continue to have far-reaching regulatory applications include "Severe Reactor Accidents Regarding Future Designs and Existing Plants," issued in 1985, and "Safety Goals for the Operations of Nuclear Power Plants," issued in 1986. The former provided the basis for redirecting NRC research programs and other regulatory programs, while the latter provided the basis for backfitting and regulatory analyses, and for the use of probabilistic risk assessment in risk-informed decisions on plant-specific changes to the licensing basis. The DVD contains NRC Commission policy statements relevant to TMI-2 (see the section titled **Generic Communications and Policy Statements**).

Research

The NRC's approach to safety changed dramatically after the TMI-2 accident. The agency's emphasis shifted from providing safety by relying on the traditional design basis approach to relying on a multifaceted approach, which emphasized improved operations, human factors considerations in control rooms and

emergency procedures, realistic performance of systems and containments under severe accident conditions, and probabilistic risk assessments (PRAs) to identify generic and plant-specific vulnerabilities. NRC research and development (R&D) programs also reflected this change.

After the accident, the scope and diversity of the NRC's efforts in severe accidents increased substantially. Some examples included allocating additional resources to R&D activities, such as the construction of new experimental facilities, the development of analytical tools, and, in general, the development of the information needed to gain greater insights into severe accident behavior. Since the accident, the NRC, and to some extent the industry, have developed a large body of information on severe accidents, including the probability of severe accidents, core-melt phenomenology, associated accident sequences, and the effects of severe accidents on plant systems, components, and structures, especially those that provide barriers to fission product release to the atmosphere, such as the reactor containment structure.



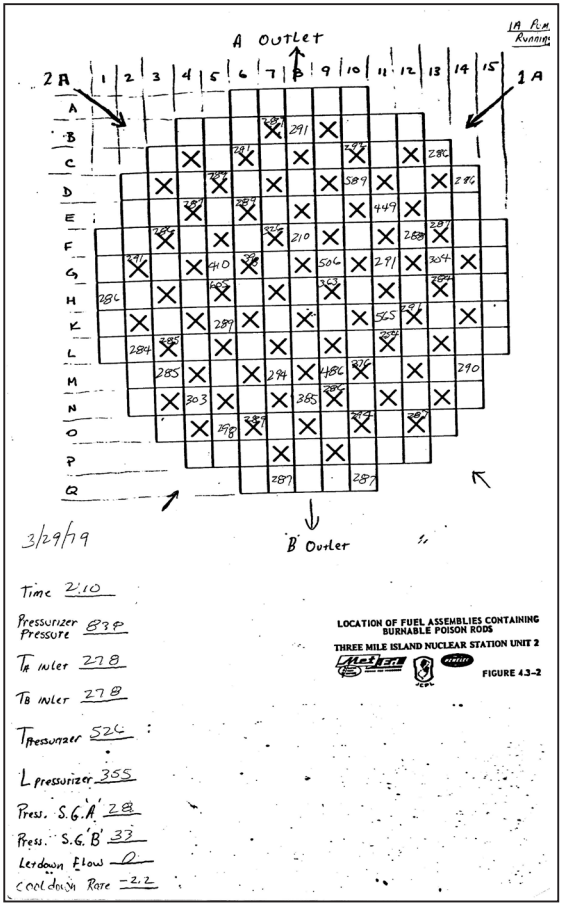
Closed-circuit television inspections of the reactor core revealed a rubble bed approximately 5 feet below the normal location of the top of the fuel assemblies.

The U.S. Department of Energy (DOE) also supported an extensive research program, known as the "TMI-2 Accident Evaluation Program," to develop a consistent understanding of the accident. The primary objective of the program was to develop an understanding of core damage progression in the upper core region, the heat up and the formation and growth of the molten central region of the core, the relocation of approximately 19 metric tons of debris to the lower head, and the release of fission products to the reactor vessel and the containment.

Collaboration between the Government and nuclear industry organizations also contributed important post accident research. In 1980, four organizations—the General Public Utilities (GPU), the Electric Power Research Institute (EPRI), the NRC, and the DOE—formed a group known as "GEND," signing a coordination agreement to implement the TMI-2 Information and Examination Program. This program executed R&D activities relating to the cleanup of TMI-2 and the study of the accident for the enhancement of nuclear power safety and reliability. The

group documented the results of this program in a series of about 200 GEND and GEND-INF (informal) reports, as well as many other technical reports issued by the NRC, the DOE and its laboratories, EPRI, and GPU.

The DVD provides many of the NRC reports, which document R&D activities relating to the TMI-2 accident and its unique recovery and cleanup (see the section titled **Recovery and Research Activities**). GEND reports are also provided on the DVD (see the section titled **GEND Research Reports**). NRC annual reports provide summaries of NRC research activities (see section titled **NRC Annual Reports**).

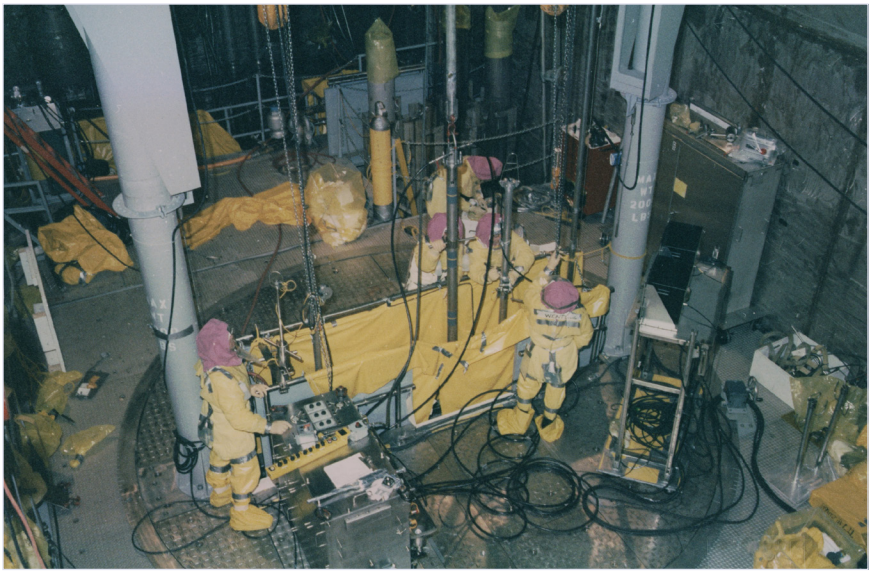


At left is a status page recorded at the NRC Operations Center on the second day of the accident showing temperature readings that were measured by plant technicians with a handheld voltage meter on the wires from reactor core exit thermocouples. These thermocouples were temporary installed to measure coolant temperatures above the reactor fuel in support of startup testing of the new reactor. We now know that many of these temperature readings were measured at newly formed false junctions located in the "liquefied fuel" regions of the core. Today, all pressurized water reactors are required to have redundant, qualified, Class 1E instrumentation for core exit thermocouples, sub-cooling margin monitors, and reactor coolant inventory monitors.

Timelines

Plant Recovery and Cleanup Milestones—By the close of the weekend of March 30/April 1, 1979, TMI-2 was determined to be in a stable shutdown condition. On Sunday, April 1, 1979, President Jimmy Carter, Rosalynn Carter, and Governor Thornburgh visited the damaged unit. Within 2 weeks, the governor's precautionary advisory to pregnant women and preschool-aged children to vacate the area within a 5-mile radius of TMI was lifted. Within 1 month, the reactor was placed in natural circulation, with decay heat flowing to the condenser and out of the cooling towers. The purging of radioactive Krypton gas from the reactor building atmosphere, followed by the first reactor building entry by two utility staff, was accomplished after the first anniversary of the accident. Shortly before the second anniversary, the reactor was placed in loss-to-ambient cooling mode, where heat losses are transferred into the reactor building ambient and out through the reactor building fan coolers.

The reactor vessel head was removed in 1985, while the removal of loose fuel debris from the reactor vessel began later that year, and was completed in 5 years. Workers used numerous manual and hydraulically powered long-handled tools to perform a variety of functions, such as pulling, grappling, cutting, scooping, and breaking up the core debris. In 1986, 7 years after the accident, a special



Workers perform defueling operations from a shielded defueling work platform (DWP), which is located 9 feet above the reactor vessel flange. The platform has a rotating surface with 6-inch steel shield plates, and is designed to provide access for defueling tools and equipment into the reactor vessel.

core sampling drilling rig was used to reveal the extent of the hard crust layer of the damaged core (see inside back cover). Between 1986 and 1990, the DOE shipped the fuel debris by rail to the DOE site at the Idaho National Laboratory and placed the debris in wet pool storage for study and safekeeping. The evaporation of 2 million gallons of slightly contaminated accident-generated water at TMI was completed in 1993 over a 2- to 3-year period.

In late 1993, TMI-2 was placed in NRC-approved post-defueling monitored storage, a passive monitored state in which the plant will remain until the licensee decommissions both units simultaneously. From 2000 to 2001, the fuel debris was moved into NRC-approved aboveground, dry storage at a DOE facility to await final disposal.

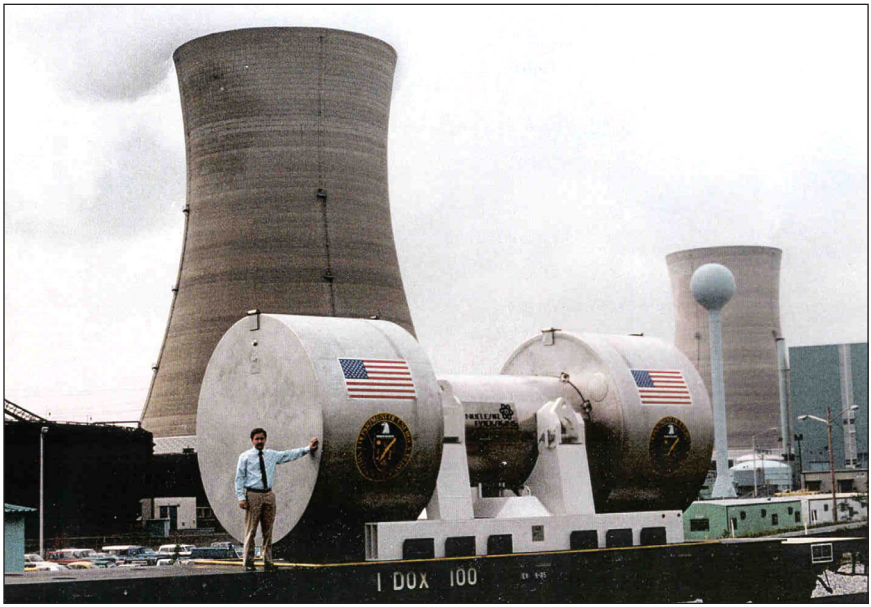
NRC Actions at TMI—The NRC played an active role as the regulator, first by responding to the accident, then by approving and overseeing recovery activities by the licensee and its contractors. A team began to form with the arrival of the NRC's Region I inspectors during the first day of the accident, and continued to expand throughout the weekend with the arrival of engineers, scientists, and public affairs specialists from headquarters and other regional offices. Early in 1980, the NRC established the TMI Program Office (TMIPO) within the NRC's Office of Nuclear Reactor Regulation to provide overall direction for the TMI-2 cleanup operations and inspections (see NUREG 0698). About 30 NRC employees staffed the onsite TMIPO office during the first few years.

Important NRC actions during TMI-2 recovery included:

- Issuance of the environmental assessment (NUREG-0591) and Commission order to use the Epicor-II system in the decontamination of intermediate-level contaminated accident water in the auxiliary building in October 1979.
- Issuance of the Commission order to implement the TMI-2 recovery technical specifications in February 1980 (NUREG 0647).
- Issuance of the environmental assessment (NUREG-0662) and Commission order to purge radioactive krypton gas from the reactor building atmosphere in June 1980.
- Issuance of the NRC action plan for cleanup operations in July 1980 (NUREG-0698).
- Issuance of the draft Programmatic Environmental Impact Statement (NUREG-0683) for public comment in August 1980 and implementation in February 1981.

- Creation of the public Advisory Panel for the Decontamination of Three Mile Island in November 1980 (see NUREG/CR 6252).
- Issuance of the Commission Policy Statement endorsing the Programmatic Environmental Impact Statement in May 1981.
- Issuance of the safety evaluation report on the use of the Submerged Demineralizer System to process the highly contaminated accident-generated water in the reactor building sump and reactor coolant system in June 1981 (NUREG 0796).
- Issuance of an amendment to the memorandum of understanding with the U.S. Department of Energy in March 1982 to accept the entire reactor core and highly radioactive solid waste for research and long-term storage (see NUREG-0698, Revision 2, Appendix A).
- Approval of the licensee's safety evaluation for the refurbishment and use of the reactor building polar crane in November 1983.
- Issuance of Supplement 1 to the Final Programmatic Environmental Statement (NUREG-0683) on dealing with occupational radiation dose in October 1984.
- Issuance of certificates of compliance in April 1986 for two shipping casks to be used for shipment of fuel debris to DOE by rail.
- Issuance of Supplements 2 and 3 to the Final Programmatic Environmental Statement (NUREG-0683) on the final disposal of 2.1 million gallons of slightly contaminated accident generated water in June 1987, and on dealing with post-defueling monitored storage and subsequent cleanup in August 1989.
- Approval in April 1989 to use the evaporator for the final disposal of 2.1 million gallons of accident-generated water.

The NRC wrapped up onsite NRC involvement at TMI 2 by the time that the agency terminated the TMI-2 Project Directorate in February 1988. The NRC's TMI resident inspector office took over the inspection program for TMI-2 and a headquarters project directorate assumed responsibility for the technical review and project management functions. In September 1993, the NRC approved the "post-defueling monitored storage" at TMI-2 and associated license conditions and technical specifications. The last meeting (78th overall) of the 10-member public Advisory Panel for the Decontamination of Three Mile Island Unit 2 was held in September 1993 (see NUREG/CR-6252 for lessons learned).



The NRC issued certificates of compliance to the Department of Energy in April 1986 for two shipping casks used to ship fuel debris by rail to the Department of Energy's Idaho National Laboratory.

The timeline feature on the DVD provides a summarized chronology of key recovery milestones and NRC actions. Users may read a short description of many of the actions by clicking on the text on the timeline from the interactive window on the DVD (see the section titled **Timeline**).

Retrospectives

For the 30th anniversary of the TMI-2 accident, the NRC hosted a special all-day event titled, "The Accident at Three Mile Island—30th Anniversary, A Look Back: Preserving the Institutional Memory." The event featured several presentations, including an overview of the accident by Brian Sheron, Director of the NRC's Office of Nuclear Regulatory Research; perspectives from TMI-2 Reactor Operator Edward Frederick; lessons learned from TMI-2 by Gary Holahan, Deputy Director of the NRC's Office of New Reactors, and former member of the TMI-2 Lessons Learned Task Force; and a historical perspective by NRC Historian Sam Walker.

A press conference during the early days of the accident with Pennsylvania Governor Richard Thornburgh (right) and Director of the NRC's Office of Nuclear Reactor Regulation, Harold Denton (left).

Following the individual presentations, the NRC hosted a panel discussion titled "Remembering the Accident." The panel included a distinguished group, all of whom made key decisions during the accident: Richard Thornburgh, former Governor, State of Pennsylvania; Harold Denton, former Director, NRC Office of Nuclear Reactor Regulation, and lead Federal onsite manager; and Jessica Mathews, former assistant to President Jimmy Carter.

The DVD provides a multimedia presentation of this event (see section titled **Multimedia**).

DVD Topics

To help navigate the DVD, the outline below provides topics and headings that the user can access directly from the interactive window. The user may also click on the text on the Timeline for a short description and related documents.

Important Note: Many of the documents on the DVD are historical in nature, and may contain information that is obsolete or superseded by today's regulations and research results. Please refer to the NRC's public Web site (www.nrc.gov) for current information on regulations, Commission policy statements, regulatory guidelines, regulatory processes, and research results.

Main Welcome Screen

- Introduction by Dr. Brian Sheron, Director of the Office of Nuclear Regulatory Research, NRC
- List of Documents Found on this DVD
- Knowledge Management Digest (NUREG/KM-0001)

- Accident Overview
- Timeline
- Historical Documents
    - Government Investigations
    - NRC Investigations and Lessons Learned
    - Generic Communications and Policy Statements
    - Industrywide Regulatory Actions
    - GEND Research Reports
    - Recovery and Research Activities
    - NRC Annual Reports

- Multimedia
    - NRC Special 30th Anniversary Event
    - Photo Gallery

Three Mile Island Accident of 1979 Knowledge Management Digest

Prepared by:

Brian McGrattan
Don Marksberry
Felix Gonzalez
Carolyn Siu
Amy Bonaccorso
Mark Henry Salley

Contributions by:

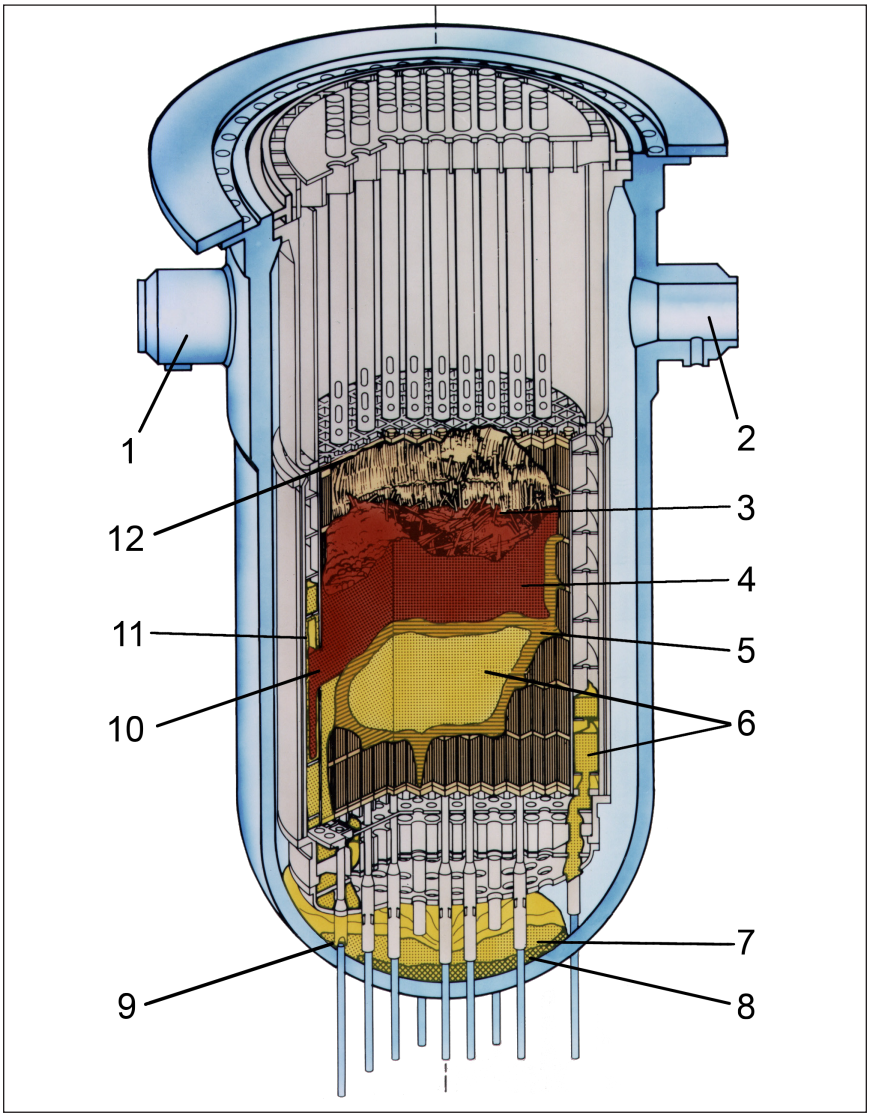
Publications Branch in the Division of Administrative Services of the NRC Office of Administration

The Department of Energy's Idaho National Laboratory

Dickinson College Community Studies Center

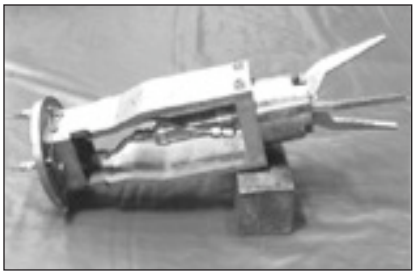
National Archives and Records Administration

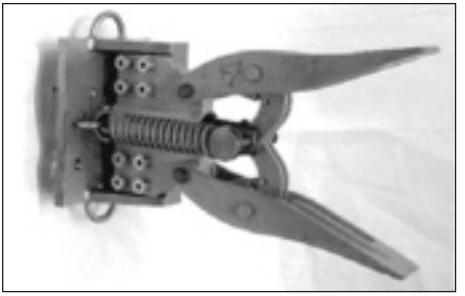
Independent spent fuel storage installation for the dry storage of the fuel debris from TMI-2 located at the Department of Energy's Idaho National Laboratory.

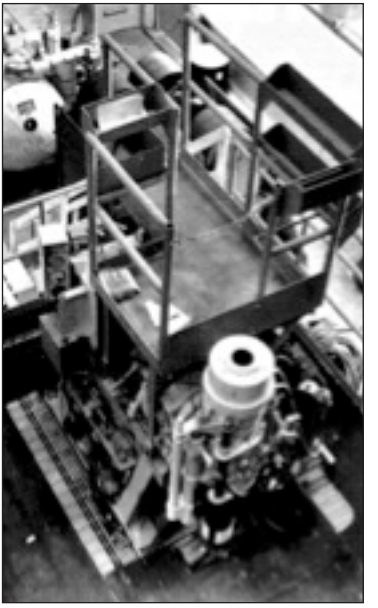


TMI-2 Core End-State Configuration. *In 1988, the NRC reported the final state of the damaged TMI-2 reactor core, shown above. The accident was terminated by reflooding of the core. This action did not immediately stop further core melting, but it did prevent the core from melting through the reactor vessel.*

Notes: (1) cold leg Loop 2B inlet, (2) cold leg Loop 1A inlet, (3) cavity, (4) loose core debris, (5) crust, (6) previously molten material, (7) lower plenum debris, (8) hard layer debris, (9) damaged in-core instrument guide, (10) hole in baffle plate, (11) coating of previously molten material on bypass region interior surfaces, (12) upper grid damage (NUREG/CR-6042).







Numerous manual and hydraulically powered long-handled tools were used to perform a variety of functions, such as pulling, grappling, cutting, scooping, and breaking up the core debris. These tools were used to load debris into defueling canisters positioned underwater in the reactor vessel. Later, a core boring machine (lower right) was used to break apart once liquefied materials.

This DVD was developed using Visual Basic Professional 2008. Make sure you have Windows XP and Visual Basic framework 3.5 or above for the DVD to work correctly.

NUREG/KM-0001
December 2012