# Three Mile Island Unit 2 Case Study Overview

***IAEA International Workshop on Managing the Decommissioning and Remediation of Damaged and Legacy Nuclear Facilities***

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***Penrith, United Kingdom***

**John P. Clements**

***Health Physicist,***

***Division of Decommissioning, Uranium Recovery, and Waste Programs***

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# Accident Overview

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- A combination of equipment malfunctions, design-related problems and worker errors led to TMI-2's partial meltdown and very small off-site releases of radioactivity

# Accident Progression

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**Potential Factors Leading to the Accident**

- TMI-2 had repeated problems with the condensate polishers (the filtration systems that remove dissolved minerals from the feedwater system)
- Plant crew was using a mixture of air and water to break up resin that had clogged a resin transfer line
- Faulty valve in one of the polishers allowed some water to leak into the air-controlled system that opens and closes the polishers' valves and may have been a factor in their sudden closure just before the accident began
- This malfunction probably triggered the initial pump trip that led to the accident

# Accident Progression

- At about 4 a.m. on Wednesday, March 28, 1979, TMI-2 experienced a failure in the secondary, non-nuclear section of the plant
- A mechanical or electrical failure prevented the main feedwater pumps from sending water to steam generators that remove heat from the reactor core
- The plant's turbine-generator and then the reactor itself automatically shut down
- Immediately, pressure in the primary system (the nuclear portion of the plant) began to increase

# Accident Progression

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- To control pressure, a pilot-operated relief valve (a valve located at the top of the pressurizer) opened -*The valve should have closed when the pressure fell to proper levels, but it became stuck open*
- Control room instruments incorrectly indicated that the valve was closed leaving staff unaware that cooling water was pouring out of the stuck-open valve
- As coolant flowed from the primary system through the valve, other instruments available to reactor operators provided inadequate information, and no instrument showed how much water covered the core

# Accident Progression

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- Plant staff assumed if the pressurizer water level was high, the core was properly covered with water and did not realize the plant was experiencing a loss-of-coolant accident
- Water escaping through the stuck valve reduced the primary system pressure so much that reactor coolant pumps had to be turned off to prevent dangerous vibrations
- To prevent the pressurizer from filling completely, staff reduced emergency cooling water amounts into the primary system – starving reactor core of coolant, causing it to overheat
- Fuel overheated to the point at which the zirconium cladding ruptured and the fuel pellets began to melt
- Later found that about half of the core melted during the early stages of the accident

# Current Conditions at TMI-2

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- TMI-2 reactor is permanently shut down and all its fuel has been removed, minus ~900 kilograms of residual debris
- Reactor coolant system is fully drained and the radioactive water was decontaminated and evaporated
- Radioactive waste from the accident was shipped off-site to an appropriate disposal area, and the reactor fuel and core debris was shipped to the Department of Energy's Idaho National Laboratory
- Current plan is to keep the TMI-2 facility in long-term, monitored storage until the operating license for the TMI-1 plant expires – it will be decommissioning sometime after that point

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# LEGAL FRAMEWORK

# Regulatory Approaches/Issues

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- The NRC was clearly established as the regulatory body at the time of the accident
- Regulations to protect public health and safety were in effect
- Many regulatory requirements to allow for decontamination and remediation of TMI-2 were handled through the NRC's existing licensing process

# Regulatory Approaches/Issues

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- A specialized U.S. NRC team was established shortly after the accident - including representatives of the NRC's Office of Inspection and Enforcement (IE), the 5 NRC Regions, and the Office of Nuclear Reactor Regulation (NRR)
- A Public Affairs Office was established in Middletown, PA, and staffed on a 24-hour basis

# Regulatory Approaches/Issues

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- The NRC site team initially supported emergency response functions
- Within days of the accident, the site team performed on-site recovery activities, which can be broken down into four major areas:
  1) Reviewed system modifications and system additions
  2) Reviewed all procedures (emergency and normal operation and maintenance) which were necessary to post-accident activities
  3) Provided close and continuous monitoring for the operations
  4) Provided consultation, review, and analysis of the ongoing rad-waste, cleanup, and health physics activities

# Regulatory Approaches/Issues

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- Existing Technical Specifications, which were part of the licensing basis for the site, also remained in place unless they no longer applied to the damaged and non-operational facility

- New “Recovery Technical Specifications” were generated to assist in remediation and were added to the licensing basis for the site

# Regulatory Approaches/Issues

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- Even with an established regulatory body and licensing process, some adaptations to the regulatory approach (i.e., decision making and approval processes) were implemented to facilitate remediation

  - TMI Program Office (TMIPO)
  - Programmatic Environmental Impact Statement (PEIS)
  - Design objective “ALARA” effluent criteria as mandatory limits for TMI-2

# Regulatory Approaches/Issues

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**TMI Program Office (TMIPO)**

- Established on April 1, 1980 to oversee TMI-2 recovery and cleanup operations

- Management and technical expertise in key TMI-2 cleanup activities such as:

  - Radiation protection
  - Radiological assessment
  - Radiological waste treatment, and
  - Nuclear safety

# Regulatory Approaches/Issues

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**TMI Program Office (TMIPO)**

- Following regulatory responsibilities:

  - Planning and managing all NRC involvement in TMI-2 cleanup activities
  - Obtaining information about and evaluating the current facility status
  - Analyzing and reviewing the licensee's proposed actions and procedures
  - Preparing technical review documents on the safety and environmental impacts of licensee-proposed cleanup actions

# Regulatory Approaches/Issues

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**TMI Program Office (TMIPO)**

- Following regulatory responsibilities:

  - Approving or disapproving the licensee's proposed actions and procedures
  - Advising the NRC Commissioners on major cleanup actions
  - Coordinating the NRC's TMI-2 cleanup activities with other governmental agencies, as necessary, such as the DOE and EPA
  - Informing State and local governments and the public on the status and plans for cleanup activities

# Regulatory Approaches/Issues

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**TMI Program Office (TMIPO)**

- Following regulatory responsibilities:

  - Overseeing day-to-day licensee activities to ensure that operations were implemented in accordance with NRC regulations, the facility's operating license, technical specifications, NRC orders, recovery plans, and approved procedures
  - Ensuring that activities are carried out in compliance with approved NRC limits and procedures
  - Coordinating with the NRC Office of Inspection and Enforcement on its TMI-2 inspection activities

# Regulatory Approaches/Issues

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## Programmatic Environmental Impact Statement (PEIS)

- Environmental Impact Statement (EIS) is a document required by the U.S. National Environmental Policy Act when a major federal action significantly affects the quality of the human environment
- The PEIS was developed after the City of Lancaster, PA expressed concerns, and pursued litigation, regarding potential disposal of processed accident generated water into local waterways
- Per commission directive on November 21, 1979, NRC staff prepared the draft PEIS dealing with the decontamination and disposal of radioactive waste resulting from the TMI accident

# Regulatory Approaches/Issues

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## Programmatic Environmental Impact Statement (PEIS)

- Draft PEIS was released for public comment on August 14, 1980

- Discussed four fundamental activities necessary to the cleanup:
  - Treatment of radioactive liquids
  - Decontamination of the building and equipment,
  - Removal of fuel and decontamination of the coolant system
  - Packaging, handling, storing, and transporting nuclear waste

# Regulatory Approaches/Issues

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## Programmatic Environmental Impact Statement (PEIS)

- Statement addressed the principal environmental impacts that can be expected to occur as a consequence of cleanup activities, including:
  - Occupational and off-site radiation doses and resultant health effects
  - Socioeconomic effects, and
  - The effects of psychological stress

# Regulatory Approaches/Issues

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## Programmatic Environmental Impact Statement (PEIS)

- On February 27, 1981, the NRC issued the final version of the PEIS (NUREG-0683)

- NRC staff held 31 meetings with the public, media, and local officials, and the final PEIS included the staff's responses to nearly 1,000 comments received on the draft statement (following a 90-day comment period)

# Regulatory Approaches/Issues

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**Programmatic Environmental Impact Statement (PEIS)**

- The final PEIS reaffirmed the draft statement's conclusion that the:
  - Decontamination of the TMI-2 facility, including the removal of the nuclear fuel and radioactive waste from the TMI site, was necessary for the long-term protection of public health and safety
  - That methods exist or can be suitably adapted to perform the cleanup operations with minimal release of radioactivity to the environment
  - Only environmental impact that might be of significance would be the cumulative radiation doses to the cleanup workers

# Regulatory Approaches/Issues

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**Programmatic Environmental Impact Statement (PEIS)**

- On April 27, 1981, the Commission issued a policy statement endorsing the final PEIS

- Later issued a supplement stating that the PEIS allows staff to act on each major cleanup activity if the activity and associated impacts fall within the scope of those assessed in the PEIS

- PEIS became a crucial document in the regulatory approval process, as all cleanup methodologies proposed by the licensee would have to first be evaluated against the PEIS

# Regulatory Approaches/Issues

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**Programmatic Environmental Impact Statement (PEIS)**

- PEIS approach provided a clear framework in which the TMIPO could approve procedures and methodologies proposed by the licensee without further Commission approval

- Still accountability to and frequent communication with the Commission - For example:
  - TMIPO weekly status reports were generated, which provided a detailed chronology of the plant status, environmental monitoring results, the licensee's recovery activities, NRC actions, and public meetings

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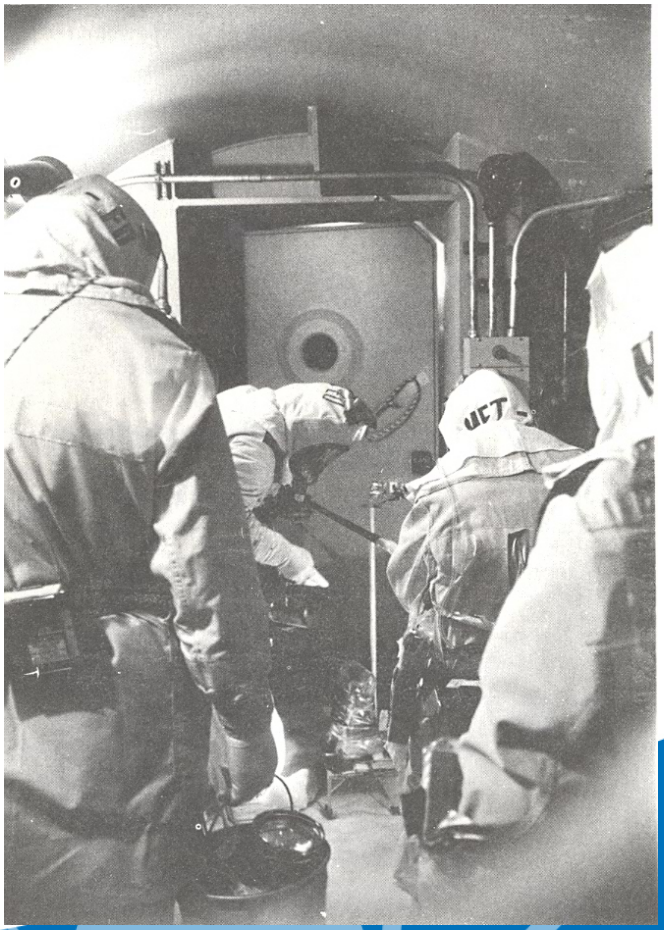
# Technical Issues

# Technical Issues – Post Emergency State of the Facility

- Fuel melting and reactor core damage had occurred
- Contaminated coolant water remained in the basement of the containment building
- The containment building was contaminated but remained in-tact and functional
- First entry into the reactor building containment was conducted by two utility staff on July 23, 1980 (image to the right)



# Technical Issues – Post Emergency State of the Core

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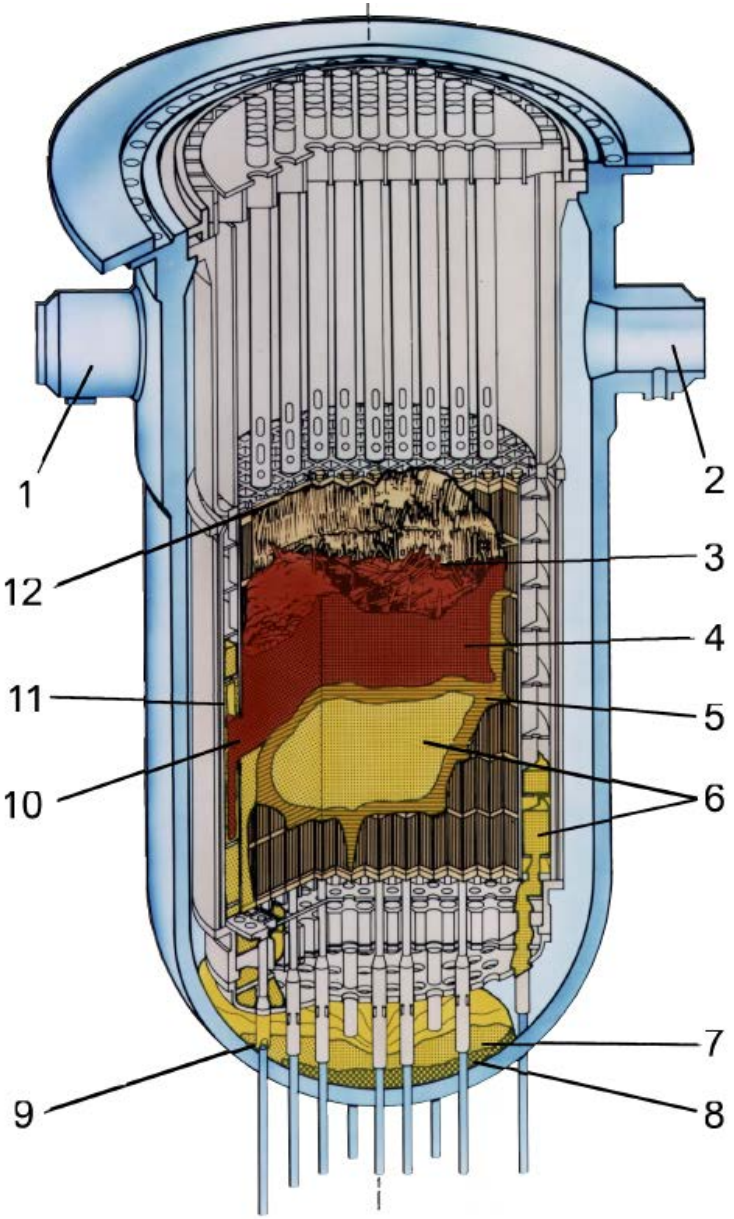
1. Cold leg Loop 2B inlet
2. Cold leg Loop 1A inlet
3. Cavity
4. Loose core debris
5. Crust
6. Previously molten material
7. Lower plenum debris
8. Hard layer debris
9. Damaged in-core instrument guide
10. Hole in baffle plate
11. Coating of previously molten material on bypass region interior surfaces
12. Upper grid damage



# Technical Issues/Challenges

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**Decontamination of intermediate-level contaminated water** (defined as less than 3.7 MBq/mL [100 µCi/mL]) in the auxiliary building

- Environmental Assessment issued and approval granted to use the Epicor-II filtration system

**Purging of the reactor building atmosphere**

- Environmental Assessment and evaluation completed
- Controlled and filtered purge accomplished over a 14 day period, per NRC approved procedures
- The maximum cumulative radiation dose and the maximum dose rate measured at off-site locations were a fraction of the limits allowed under NRC regulations

# Technical Issues/Challenges

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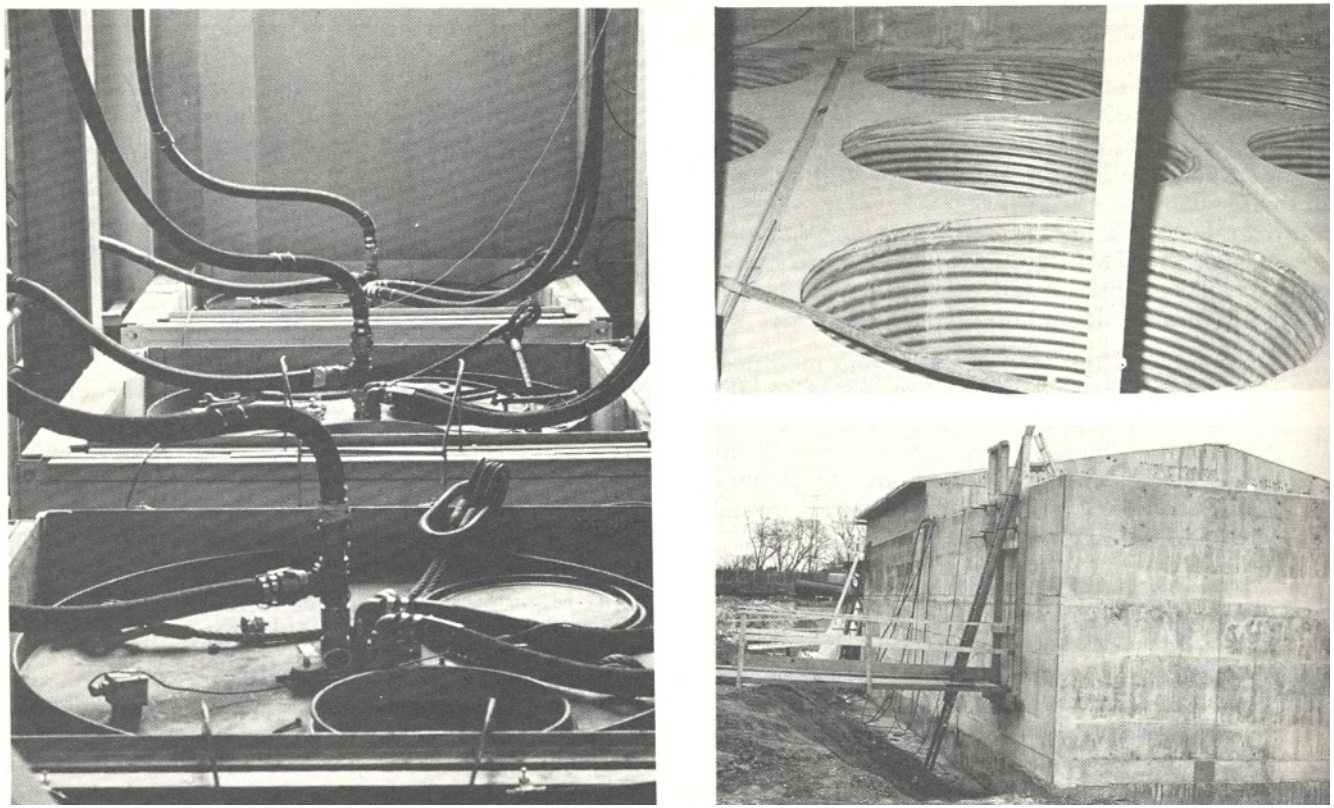

*EPICOR-II System*

# Technical Issues/Challenges

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**Decontamination of highly contaminated wastewater**

- The NRC Approved the use of the Submerged Demineralizer System (SDS)
- The SDS operated underwater, in one of the spent fuel pools of TMI Unit 2
- It consisted of a liquid waste treatment subsystem, a gaseous waste treatment subsystem, and a solid waste handling subsystem
- The approval to operate the SDS did not include water disposal

# Technical Issues/Challenges

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**Removal of fuel debris from the reactor**

- Operators removed damaged fuel and structural debris from the reactor vessel by “pick and place” defueling of loose core debris
- Workers performed defueling operations from a shielded defueling work platform (DWP) located nine feet above the reactor vessel flange
- The DWP had a rotating 17-foot diameter surface with six-inch steel shield plates, and was designed to provide access for defueling tools and equipment into the reactor vessel

# Technical Issues/Challenges

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*Shielded defueling work platform (DWP)*

# Technical Issues/Challenges

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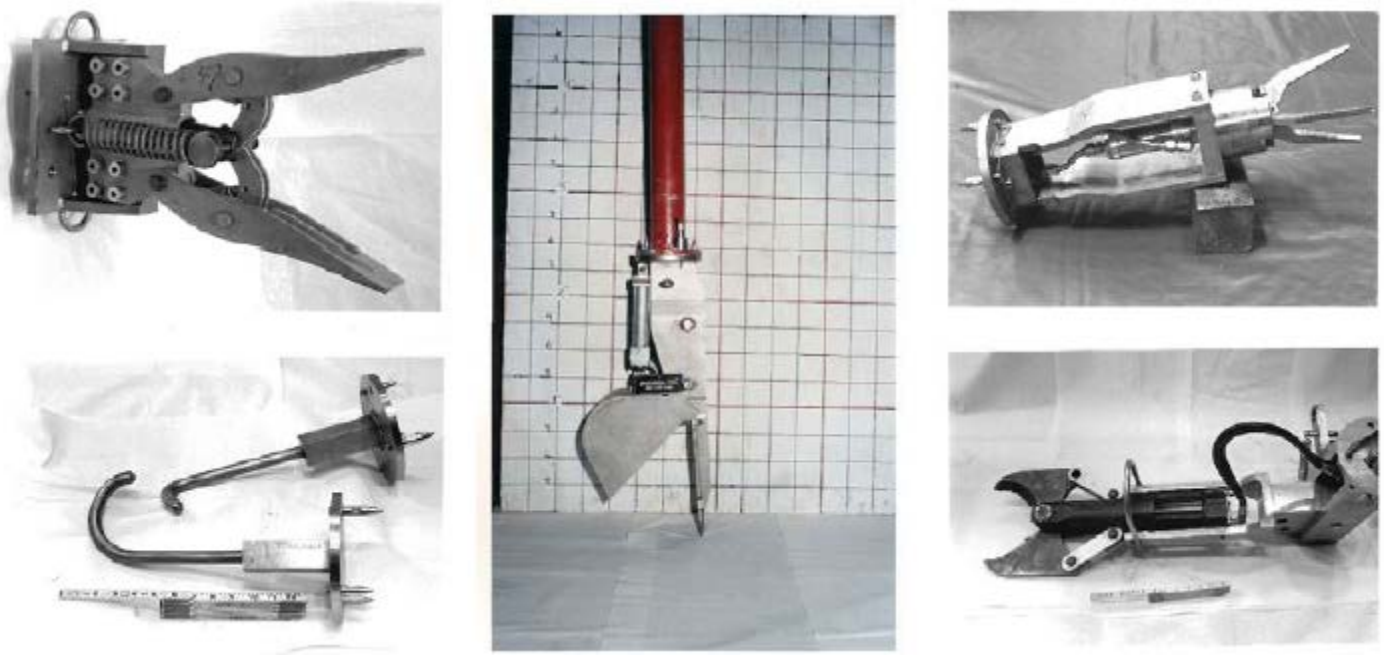

*Numerous manual and hydraulically powered long-handled tools were used to perform a variety of functions, such as pulling, grappling, cutting, scooping, and breaking up the core debris. These tools were used to load debris into defueling canisters positioned underwater in the reactor vessel.*

# Technical Issues/Challenges

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**Robotic Technologies**

- Remote robotic technologies played a role in the remediation of TMI-2
- Used extensively to perform work in the reactor building's basement, the makeup demineralizer room in the auxiliary building, the reactor coolant pump seal injection valve room in the fuel handling building, and the reactor vessel
- Both versatile and productive, and proved useful in many different tasks, including video camera inspections, radiation monitoring, sediment sampling, acquisition of concrete core samples, high pressure water flushing, concrete scabbling and scarification, and debris pickup and removal

# Technical Issues/Challenges

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**Microorganisms inside the reactor vessel**

- A large population of microorganisms developed in the reactor coolant system (RCS), clogging cleanup system filters and hindering the view of defueling activities
- Licensee conducted a multi-phase program to restore water clarity consisting of high-pressure hydrolancing, the addition of hydrogen peroxide, and the use of a high-pressure positive displacement pump
- A diatomaceous earth (swimming pool-type) filter was operated in conjunction with the letdown and makeup of batches of reactor coolant, to remove the organic material and improve the clarity of the RCS water

# Technical Issues/Challenges

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**NRC and DOE signed Memorandum of Understanding (MOU) on waste disposal**

- The MOU formalized the working relationship between the two agencies with respect to the removal and disposal of solid nuclear waste generated during the cleanup of TMI-2
- Significant step toward ensuring the TMI site would not become a long-term waste disposal facility
- The MOU covered only solid nuclear waste, and did not cover liquid waste resulting from cleanup activities
- DOE also agreed to accept fuel and highly radioactive resins from the water purification system

# Technical Issues/Challenges

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**NRC and DOE signed Memorandum of Understanding**

- MOU addressed three basic categories of TMI-2 waste:
  1) waste determined by DOE to be of generic value in terms of beneficial information to be obtained from further research and development activities
  2) waste determined to be unsuitable for commercial land disposal because of high levels of contamination, but which DOE may also undertake to remove, store, and dispose of on a reimbursable basis from the licensee
  3) waste considered suitable for shallow land burial, to be disposed of by the licensee in licensed, commercial low-level waste burial facilities

# Technical Issues/Challenges

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**Epicor resin waste disposal**

- The NRC approved the licensee's request to dispose of Epicor resin liners via shallow land disposal, as they were similar to typical reactor resin wastes
- Several shipments were also made to various laboratories for testing purposes

**Submerged Demineralizer System resin waste disposal**

- Submerged Demineralizer System liners were sent to DOE
- DOE conducted research on glass vitrification (solidification) of this type of solid waste at Hanford

# Technical Issues/Challenges

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## Disposal of slightly contaminated water

- The licensee was approved for a treatment/disposal method involving the forced evaporation of the water contaminated during the accident and used in subsequent cleanup operations at the TMI site - to be completed over a 2.5 year period
- Residue from this operation, containing small amounts of the radioactive isotopes cesium-137 and strontium-90, and large volumes of boric acid and sodium hydroxide, would require solidification and disposal as low-level waste

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# Institutional Framework and Strategic Planning

# Institutional Framework

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**Regulatory Organizational Changes**

- Organizational arrangements/structures shifted from operational NRC oversight prior to the accident, to an augmented on and off-site emergency response structure during the emergency phase, and to a new structure enhanced by lessons learned after the emergency

- Changes to the NRC's organizational framework occurred in the establishment of a TMI Program Office and a TMI-2 Project Directorate, and an Office for Analysis and Evaluation of Operational Data (AEOD)

# Institutional Framework

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**Regulatory Organizational Changes**

- The NRC formed a 12 member Public Advisory Panel including local citizens, local and state governmental officials, and scientists, meeting regularly with both the public and NRC Commissioners

- Local citizens, local and state governmental officials, and scientists
- Held 78 meetings over 13 years

# Institutional Framework

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## Licensee Organizational Changes

- Electric Power Research Institute (EPRI), discusses organizational changes and resource requirements in their document titled “The Cleanup of Three Mile Island Unit 2, A Technical History: 1979 to 1990, EPRI NP-6931, (1991)”

- Four different organizational structures which evolved over the life of the recovery and remediation projects

# Institutional Framework

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## Licensee Organizational Changes

- The initial organization included a staff of nearly 2000 people onsite focused on the immediate effects of the accident

- The second organization, in place by 1980, was described as being more “departmental in structure,” with additional focus on radiological controls as personnel protection required much more attention than in a normally operating power plant

# Institutional Framework

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**Licensee Organizational Changes**

- Third organizational structure focused more on the enhanced project management in terms of
  - Recovery
  - The overwhelming organizational need to make the project work efficiently, and
  - The fact that, with the plant in effective cold shutdown, the need for redundant organizations was eliminated

- The fourth organization, established around 1985, was mostly focused on defueling operations

# Institutional Framework

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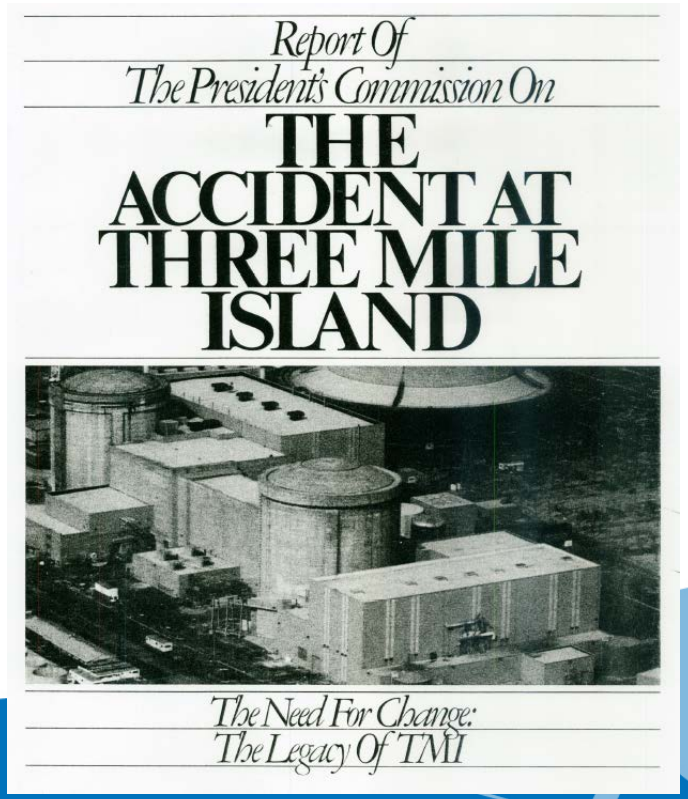
## Industry Changes

- Organizational changes were made to the nuclear industry as a whole based upon recommendations of the Kemeny Commission (a 12-member commission appointed by President Jimmy Carter to investigate the TMI-2 accident)



# Institutional Framework

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**Industry Changes**

- Specifically related to industry, the Kemeny Commission recommended the following:
  - The (nuclear power) industry should establish a program that specifies appropriate safety standards including those for management, quality assurance, and operating procedures and practices, and that conducts independent evaluations
  - There must be a systematic gathering, review and analysis of operating experience at all nuclear power plants, coupled with an industrywide international communications network to facilitate the speedy flow of this information to affected parties

# Institutional Framework

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**Industry Changes**

- To address these recommendations, the Institute of Nuclear Power Operations (INPO) was established by industry in December 1979, as a not-for-profit organization with a mission:

  "*to promote the highest levels of safety and reliability – to promote excellence – in the operation of commercial nuclear power plants*"

# Funding

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**Accident Remediation Funding**

- Early estimate of $500 to 600 million to "decontaminate and repair the damaged nuclear reactor and related facilities" - Actual cost to remediate TMI-2 was around $1 billion
  - Approximately 2/3 covered by the licensee (via utility's shareholders, customers, and insurance underwriters)
  - Remaining, covered by the U.S. DOE, the electric power industry, the States of Pennsylvania and New Jersey, and the Japanese government /nuclear industry (approximately $18 million - for research, knowledge management, and training purposes)

# Funding

## Final Decommissioning Funding

- A decommissioning fund is maintained by the licensee to complete the final decommissioning of the site

- An annual funding status report is provided to the NRC, and the latest report indicates that the site-specific TMI-2 radiological decommissioning cost estimate is $1,180,928,000 (escalated to 2014 dollars)

# Strategic Planning

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## GEND

- Collaborative effort between the Government and nuclear industry organizations to foster post-accident research to inform a prompt and safe remediation

- In 1980, four organizations - the **G**eneral Public Utilities (GPU), the **E**lectric Power Research Institute (EPRI), the **N**RC, and the **D**epartment of Energy (DOE) - formed a group known as "**GEND**"

- 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

# Strategic Planning

- Several investigation committees were formed shortly after the accident, which influenced organizational/structure changes
  - 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 NRC sponsored both internal and external investigations, and asked the independent Special Inquiry Group, known as the “Rogovin Committee” to perform an investigation

# Strategic Planning

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- Many 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
  - The NRC's Advisory Committee on Reactor Safeguards

# Strategic Planning

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## Decommissioning and Waste Management Strategy

- TMI-2 license was amended to a “possession-only” license after accident remediation
- Facility entered a post-defueling monitored storage (PDMS) state until eventual site decommissioning after TMI-1 ceases operations
- PDMS represents a unique licensing strategy that is currently held only by TMI-2

# Strategic Planning

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## Decommissioning and Waste Management Strategy

- Unique strategies were also required to address portions of the TMI-2 accident waste
  - A Memorandum of Understanding was required between the U.S. NRC and DOE to address certain types of wastes
  - NRC and DOE Revised Memorandum of Understanding to Accept Fuel and Resins

# Three Mile Island Unit 2 Status

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- TMI-2 remains in Post Defueling Monitored Storage (PDMS) status
- U.S. NRC inspections occur annually and containment entry occurs every 5 years, last visit was June 2017
- D&D activities at TMI-2 are planned to occur after expiration of the TMI-1 license, independently from TMI-1 decommissioning
- TMI-1 has announced it will shutdown by 2019

# Knowledge Management

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- **Continued efforts on knowledge management**
  - Supplement 1 to "Three Mile Island Accident of 1979 Knowledge Management Digest (NUREG/KM-0001, Revision 1)" published
  - 4 supplemental DVDs of historical reports and regulatory guidance

- **Plans for a Volume 3 of NUREG/KM-0001**
  - Will focus on safety reviews of recovery and cleanup activities

# Knowledge Management

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**TMI Knowledge Transfer Workshop at Idaho National Laboratory**

- October 2016 workshop that presented many lessons learned from the TMI accident in the interest of informing remediation at Fukushima
- Collaborative meeting between U.S. NRC, DOE, and industry representatives along with Japanese regulatory and industry representatives (e.g., Japan's NRA, METI, NDF, TEPCO, and IRID)
- INL has also hosted NUREG/KM-0001: https://tmi2kml.inl.gov/

**TMI 38th Anniversary Seminar**

- March 28, 2017 at NRC

# Knowledge Management

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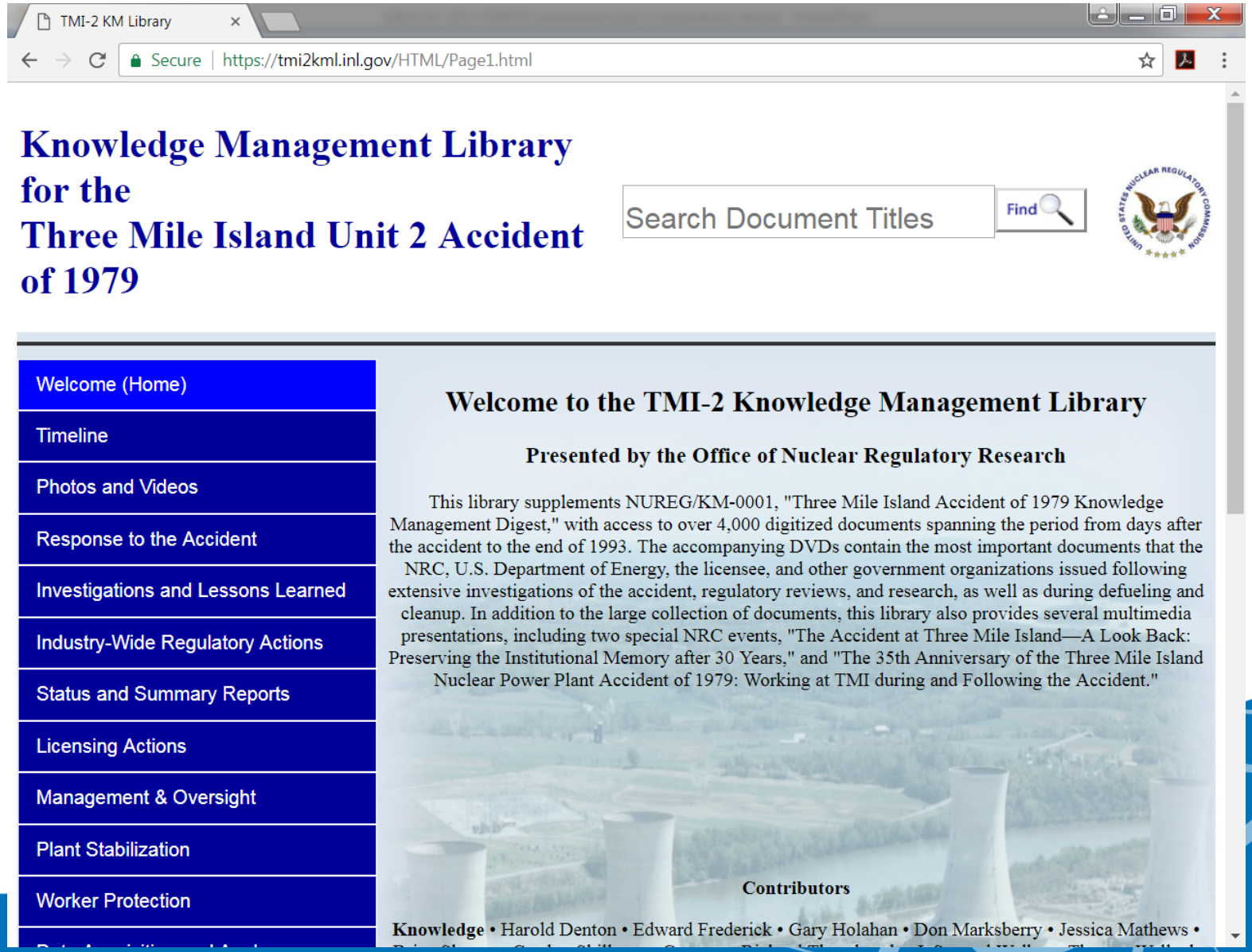

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# Questions/Comments?

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**Thank You!**