Three Mile Island Reactor Accident: Recovery, Cleanup, Lessons, & Future

IRID Symposium
Tokyo

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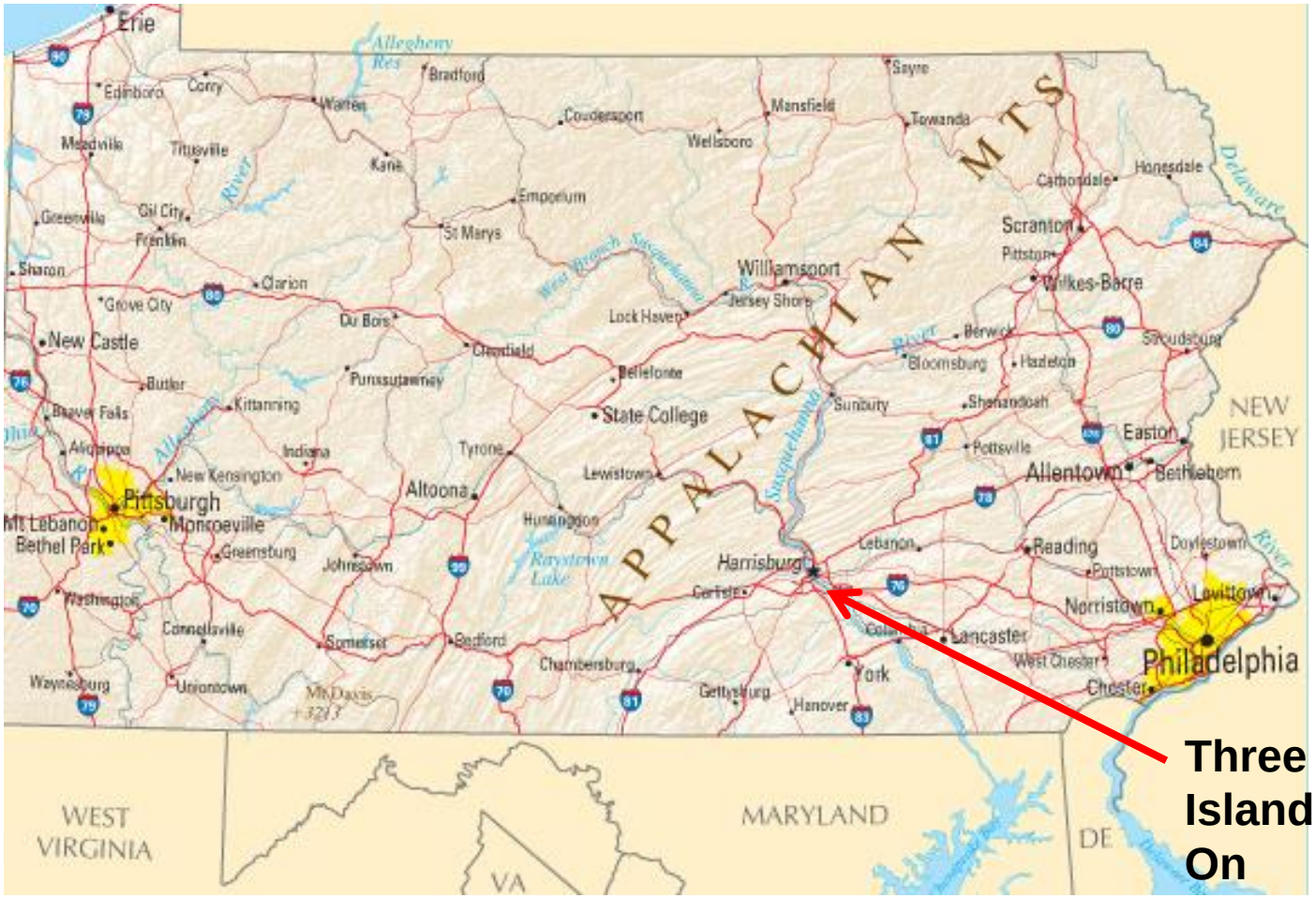
Three Mile Island

- **Light Water Power Reactor Core Melt Accident**
  - **1979: 35 Years ago**
- **Similar & Different Than Fukushima Daiichi (1F)**
- **TMI Major but Less Technically Severe Accident**
- **Similar Cleanup Challenges**
- **Many Lessons Are Applicable**
- **TMI Was Safely Cleaned Up & 1F Can Be Also**

TMI: US/Pennsylvania

Pennsylvania
Harrisburg-Middletown



Three Mile Island Units 1 &2

Susquehanna River

Three Mile Island Units 1 &2

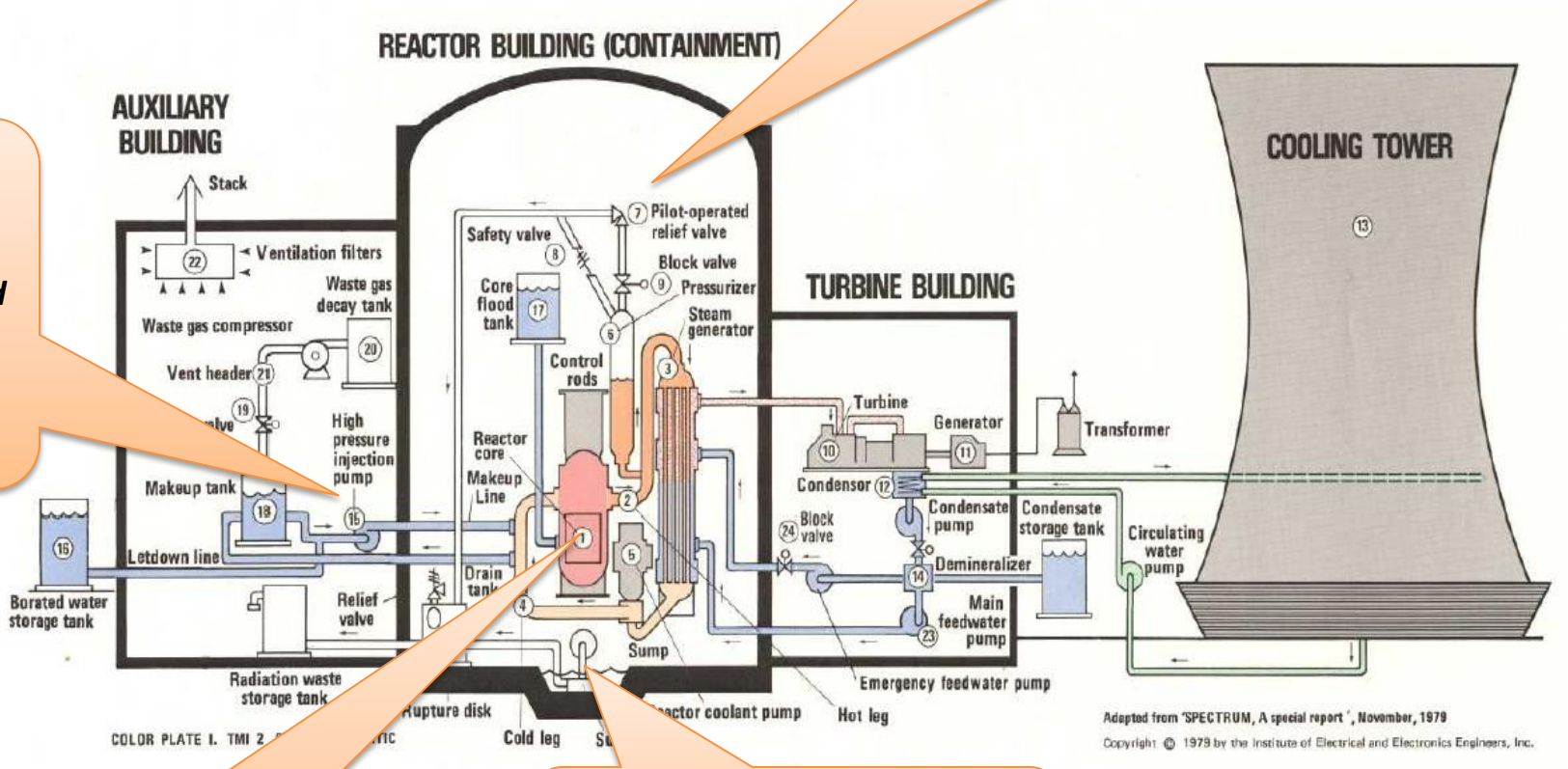
March 28, 1979

Three Mile Island Unit-2 Accident

March 28, 1979

04:00 Relief Valve fails to close

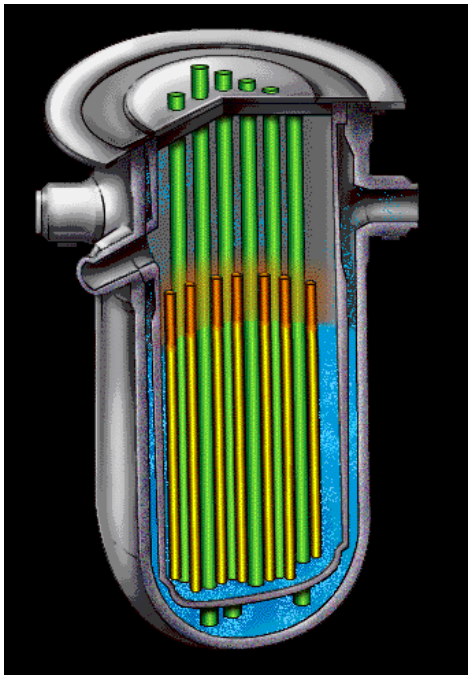
Operators Believe Reactor Overfilled and Turn Off Injection Pumps



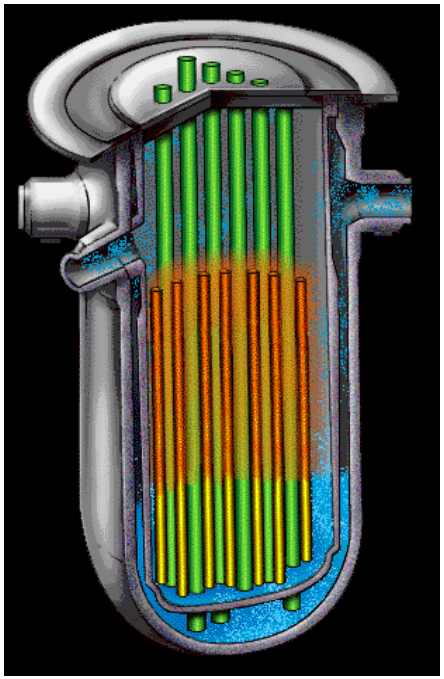
Core is uncovered Fuel overheats/fails/~50% Melt

650,000 gallons of highly radioactive water collects

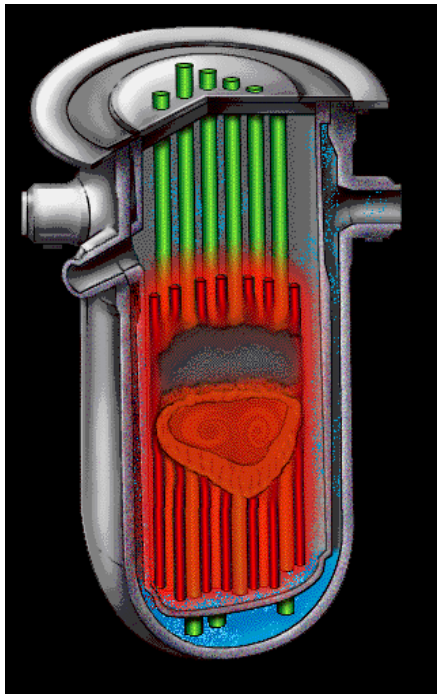
TMI Core Damage Sequence



~120 Min Core Uncovers-Damage Starts 800C Burst (~06:00)



~150Min Core Cladding Oxidize ~1800C (~06:30)



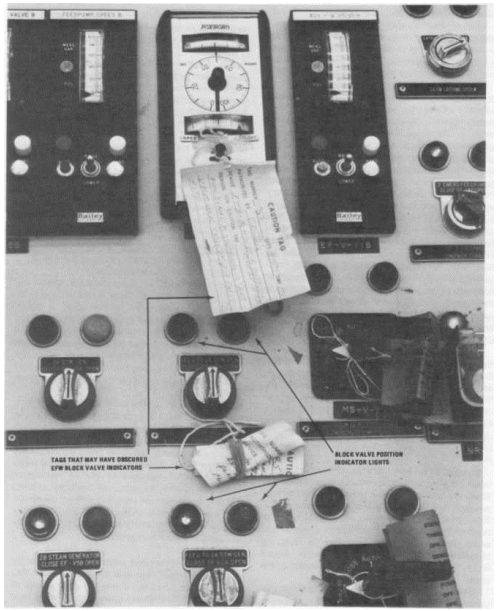
~226 Min Core Melted ~2700C (~07:30)

Control Room Operators Confused

Not Recognize Plant Conditions

Untrained for Situation

Complex System
100+ Alarm Lights



Safety Tags Hid
Indicator Lights

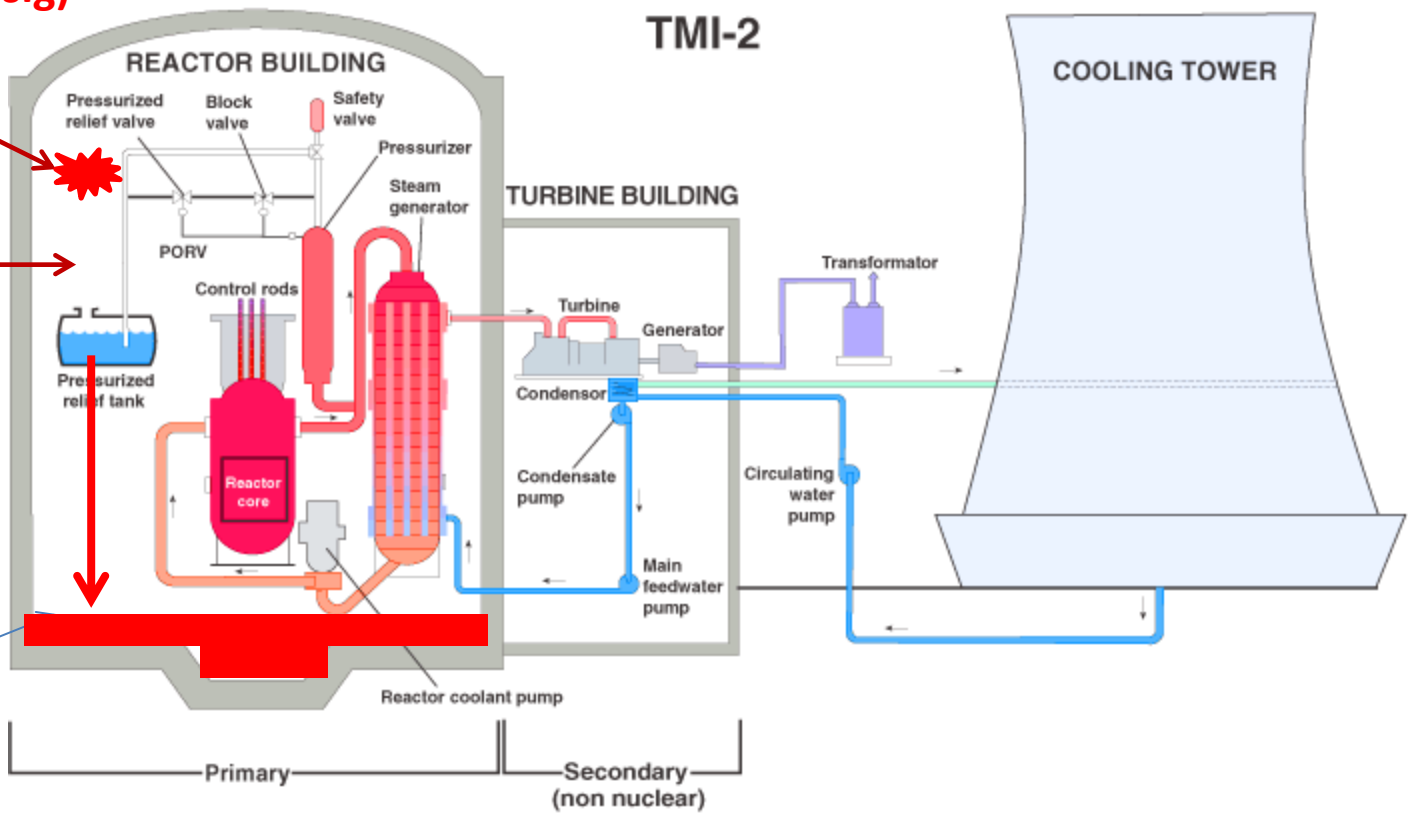
Difficult Environment to Think

Hydrogen Deflagrates 13:00
Containment Holds
Unknown for a Week

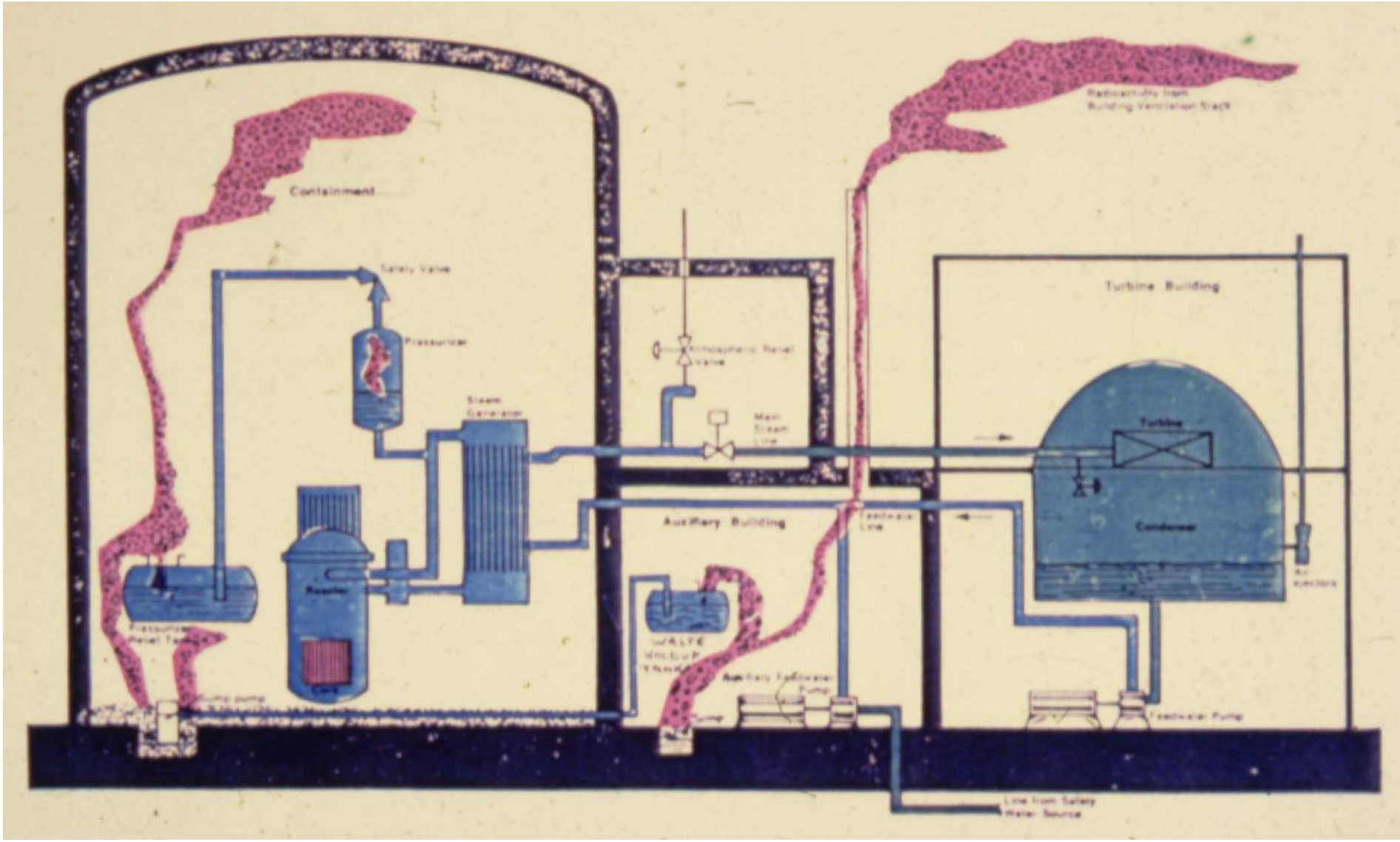
Hydrogen Deflagration 3MPa (28psig) 13:00

Radiation >200Sv/hr

~3M deep water

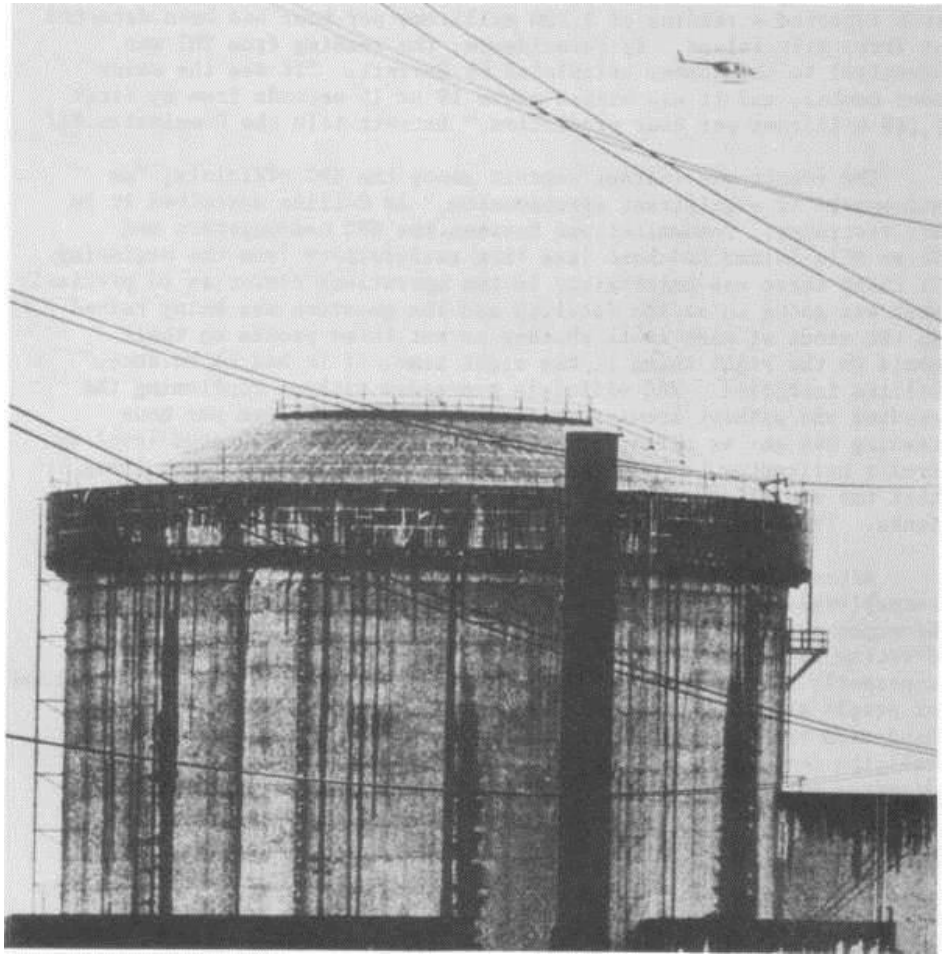


Radioactivity Release Pathways



Auxiliary Systems Needed to Run Main Coolant Pumps to Cool Melted Core

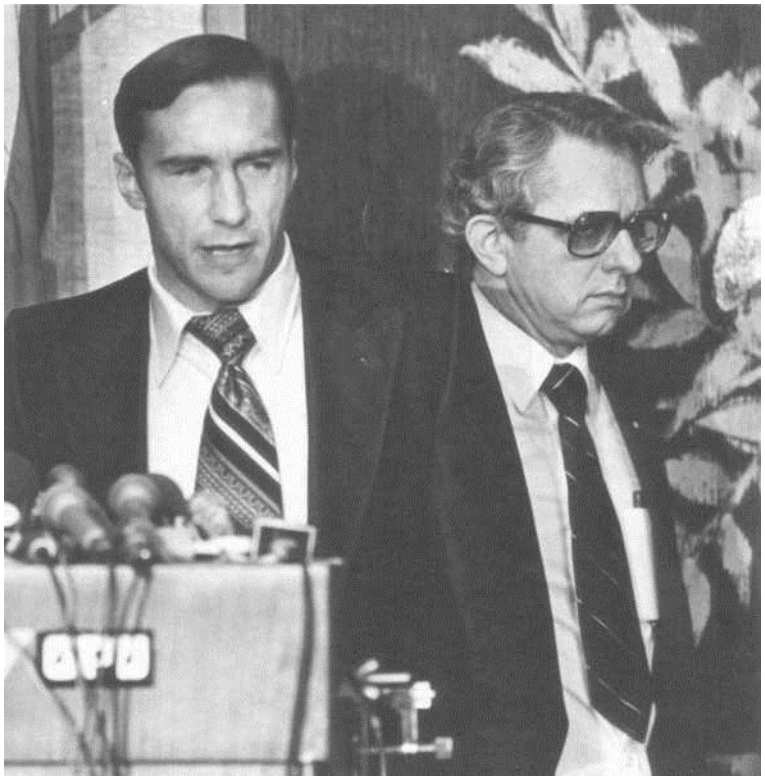
Offsite Releases Variable & Confused Readings 3/28-30



TMI Precautionary Evacuation March 30, 1979

- **Due To Uncertainties & Unknowns**
- **Advisory Evacuation for Pregnant Women & Children: lasted 10 days**
- **~140,000 People Left, most for Less than a Week**
  - **Cost $71M Paid by Owner Insurance**

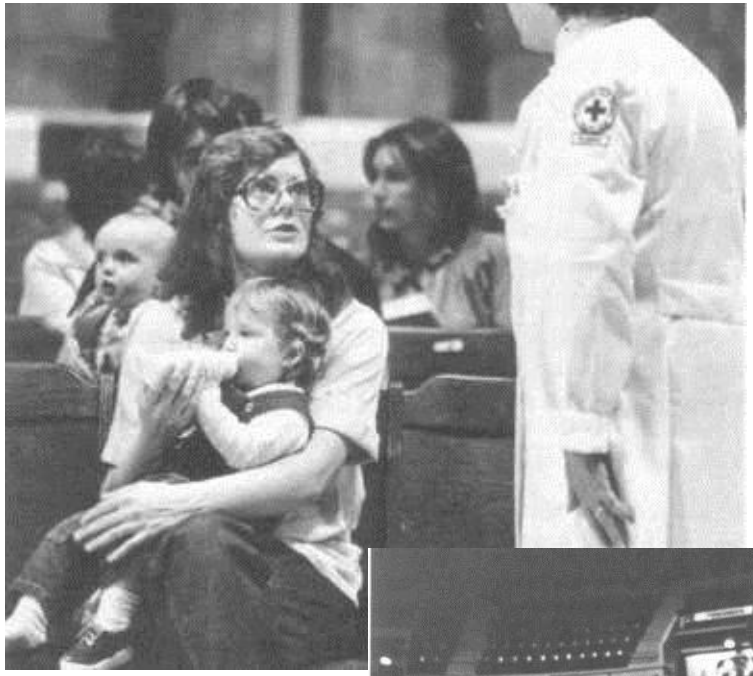
Public Confusion Due To Lack of Information & Distrust



Company Not Believed

Government Distrusted
But NRC Single Spokesman
Denton Made Progress

Evacuation Sites



President Carter Arrives

April 1

Carter, Denton & PA Governor Thornburg

President Carter In Control Room

Initial Plant Stabilization

- **Core Cooling Established: 6 Hours**
- **Cold (<100C) Passive Shutdown:1 Month**
- **All Accident Water Retained**
- **Pre-accident Water Processed and Released to Make Room For Accident Water**
- **Accident Water Never Released to River**
- **Airborne Iodine Releases From Auxiliary Building Mitigated**

ACCIDENT RADIOLOGICAL CONSEQUENCES

- Ad Hoc Interagency Dose Assessment Group Findings
  - 2,000,000 Persons → 3300 Person-Rem
  - Average Population Dose: 15uSv (1.5 mrem)
  - Maximum "Fence-Post" Dose 830 uSv (83 mrem) (Estimated Actual Maximum Dose 37 mrem)
  - One Excess Cancer (Over 325,000 Bkgd)
  - Food Sampling - All Below FDA Limits

Severe Accident Recovery Prioritization Timing

- **Ancient Fundamentals: Fire, Wind, Water & Earth**
- **Nuclear Accident Recovery Fundamentals:**
  - **Fire: Energy- Cool Core**
  - **Wind: Control/Mitigate Airborne Release**
  - **Water: Control/Mitigate Water Release**
  - **Earth: Manage Solid Wastes Responsibly**

TMI Recovery-National Support

Visitor Center Command Station-1000+ people

New Accident Response/Cleanup Management Organization

- GPU Formed Integrated National Cleanup Team
  - Utility
    - Owner & Existing Operational Workforce
  - Nuclear Contractor Industry
    - Bridge Technology & Operational Support
  - National Defense Laboratories
    - Intellectual & Applied Knowledge
  - Navy Nuclear Culture
    - Disciplined Technological Operational Philosophy
  - Academia
    - Advanced Technology

New Accident Response/Cleanup Management Organization-2

- US Government Supported
  - Had Authority to Take Over, however Remained Private for Best National Interest
  - USNRC Became Lead Agency
  - USDOE Scientific Technical Support
    - Defense and Non-Defense
  - USEPA Active Local Environmental Monitoring
- Special USNRC Regulatory Program
  - Special Delegated Onsite Authority

New Accident Response/Cleanup Management Organization-3

- Active Public Communications/Involvement Programs
  - Rebuild Public Trust & Confidence
  - It's personal: Focus is on People, not Technology
- Extensive Congressional Oversight
- Extensive Pennsylvania State Involvement
- Extensive Local Government Involvement
- Extensive Nuclear Industry Involvement
  - Utilities (e.g. EPRI)
  - Contractors (e.g. Bechtel & NSSS)

Industry Government Teamwork

- Federal Government
  - DOE National Laboratories
    - High Radiation Reprocessing Experience
  - DOE R&D Support
    - Solid Waste Disposal
    - Spent Fuel Removal
- Other Utilities
  - EPRI Agreement
- Academia
  - Robotics Applied Science Center
    - PA Universities

Creation Of New Applied Cleanup Research & Development (R&D)Program

- **Couple DOE Laboratory Programs To On-Site Cleanup Task Problem Solution Activity**
  - **TMI On-Site DOE Technical Integration Office (TIO)**
  - **Coordinated All National Laboratory Efforts**
  - **Senior DOE Person Full Time at Site: Dr. Willis Bixby**
  - **Senior INEL (EG&G) Laboratory Lead Staff**
- **Bring Advanced Technology Research to Implementable Onsite Cleanup Actions**

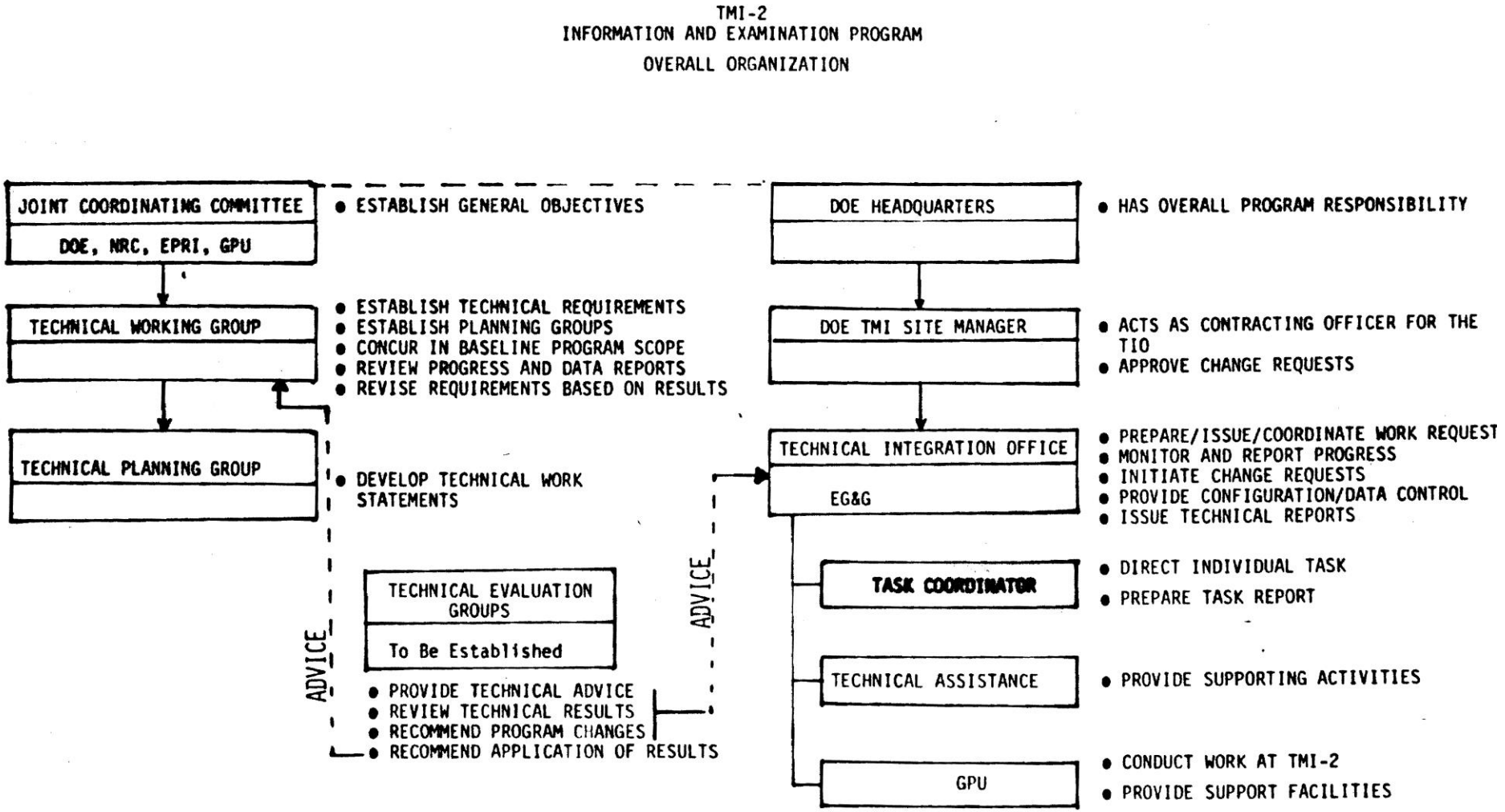
Formal TIO 'Teamwork" Applied Cleanup R&D Agreement

- **Integrated & Formalized Earlier Accident Response Science Efforts**
  - **Owner Utility: GPUN**
  - **DOE Laboratory Organizations**
  - **EPRI**
  - **NRC Research**
- **Signed and Implemented March 1980**

TIO Team Developments Utilized

- Advanced Water Treatment Systems for Processing & Defueling
- Degraded Core Investigation Instrumentation
- Defueling Tools
  - Core Boring Machine
- Waste Packaging & Safety Analyses
- Fission Product Transport Analysis
- Decontamination Processes

TMI-2 Cleanup
TIO Organization Functions



Cleanup Principles-1

- **Maintain Public Safety & Environmental Protection**
  - **Stable Cool Core & High Activity Waste**
  - **Clean, Control & Monitor all Airborne Releases**
  - **Clean, Recycle, Monitor & Store all Water**
  - **Manage Solid Radioactive Wastes For Disposal**
- **Maintain Worker Safety**
  - **Control Worker Exposures ALARA**
  - **Industrial & Rad Safety Factors**
- **Focus to Remove Damaged Fuel**

Cleanup Principles-2

- Cleanup Site To Status Similar to a Normal Shutdown Reactor
- Properly Disposition Fuel & Radioactive Wastes
  - Technically
  - Socially
- Open & Transparent & Inclusive Process
  - Understandable to Outside People
  - Responsive to Needs
  - Maintain Social/Political Support

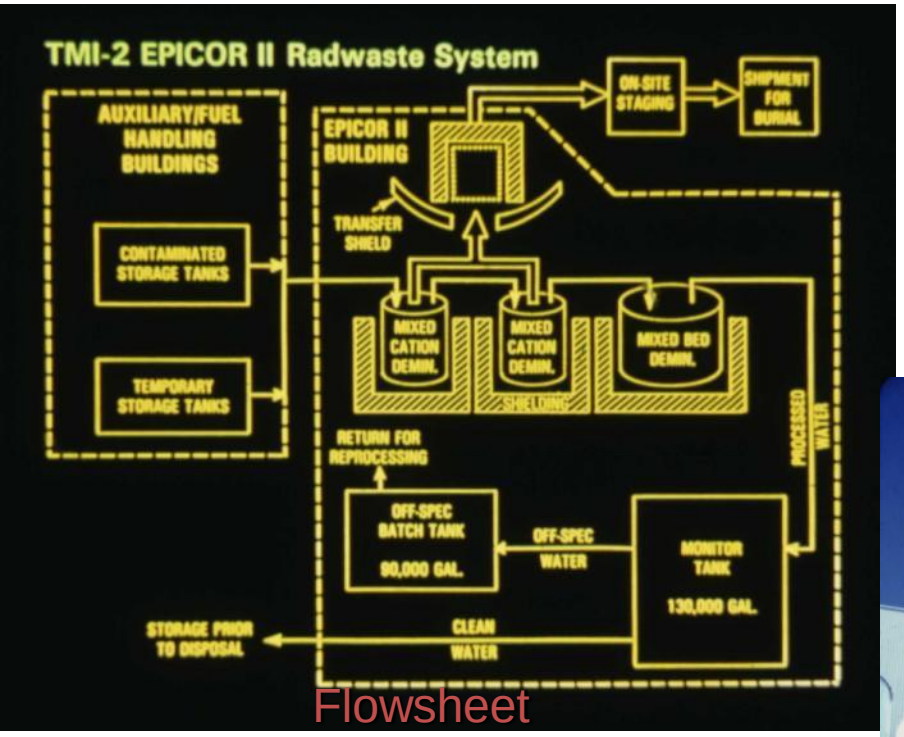
Cleanup Approach

- **Prompt Safe & Cost Effective Cleanup**
  - **Reduce Risks, Contain, Stabilize**
- **Clear End State Focus**
- **Expect Surprises**
  - **Monitor, Self-Learn, Adapt, Succeed**
- **Keep Simple**
  - **Adapt Proven Technologies As Much As Possible**
- **Work Safely From Outside In**

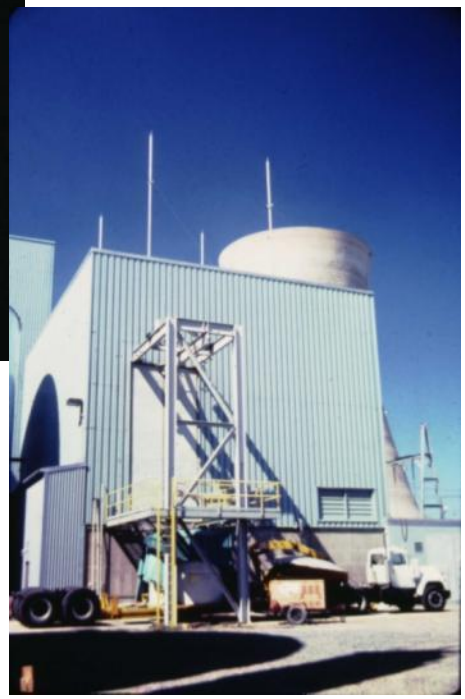
Auxiliary Building Decon
1979

Process Auxiliary Building Water

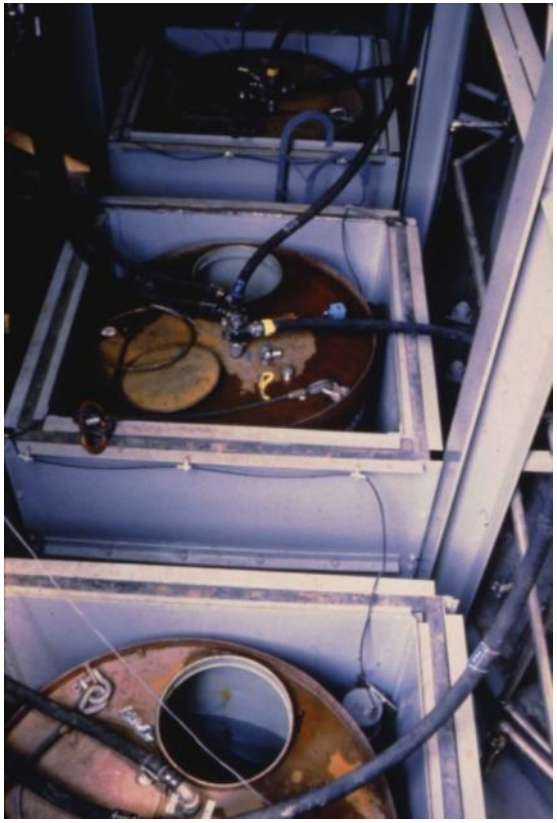
EPICOR Radwaste System



Flowsheet



Building



Resin Canisters

High Activity Aux Bldg Wastes Shipped & Disposed

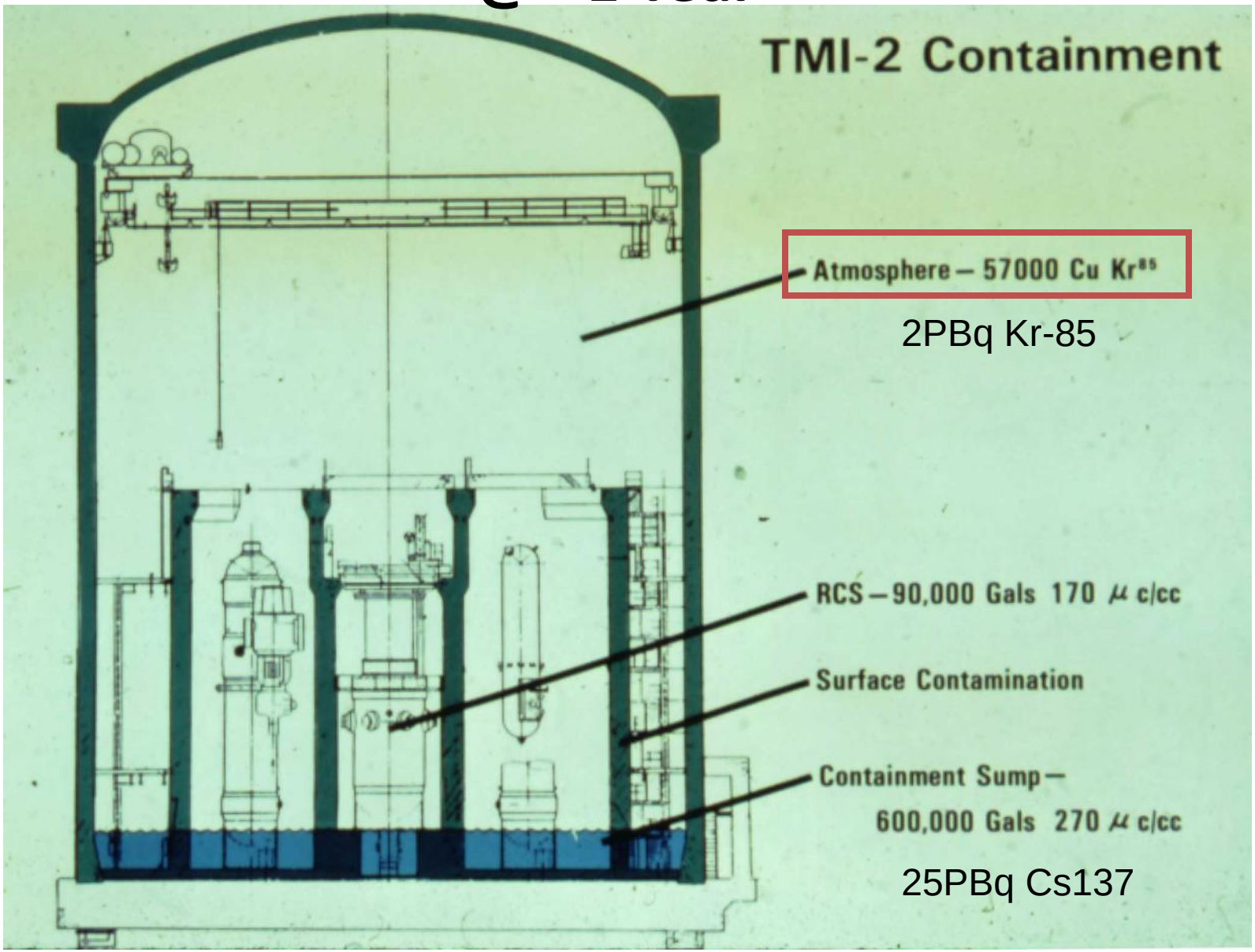
Resin Liners Stored at TMI

Loaded In Transport Cask

Disposed In High Integrity Container in Disposal Site in Washington

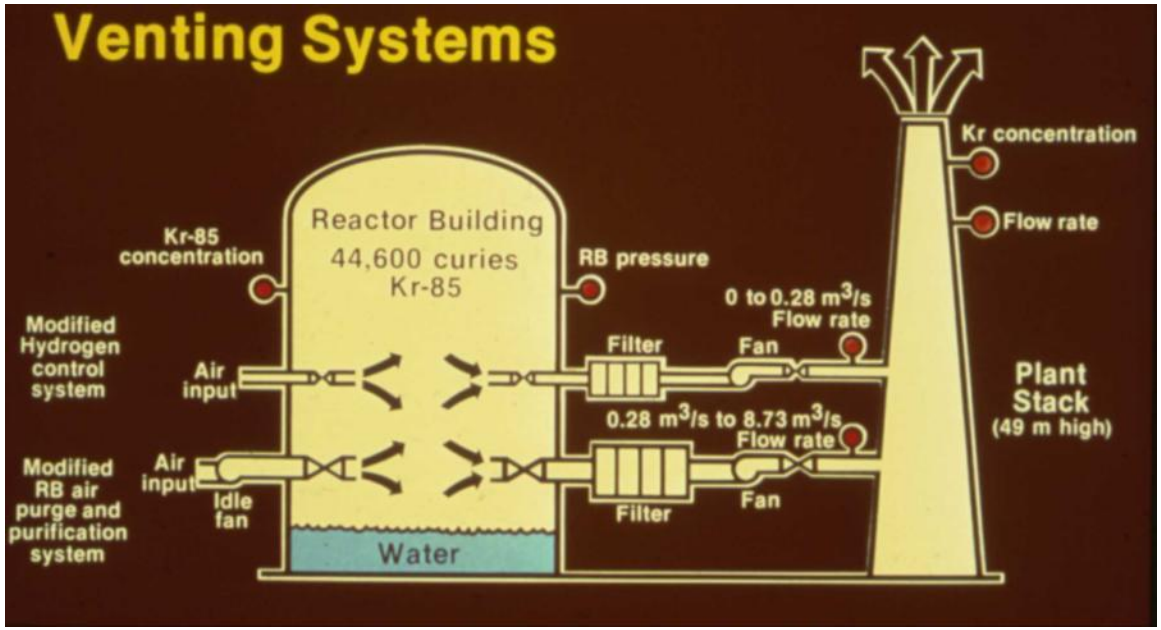
Containment Access Necessary

@ +1 Year

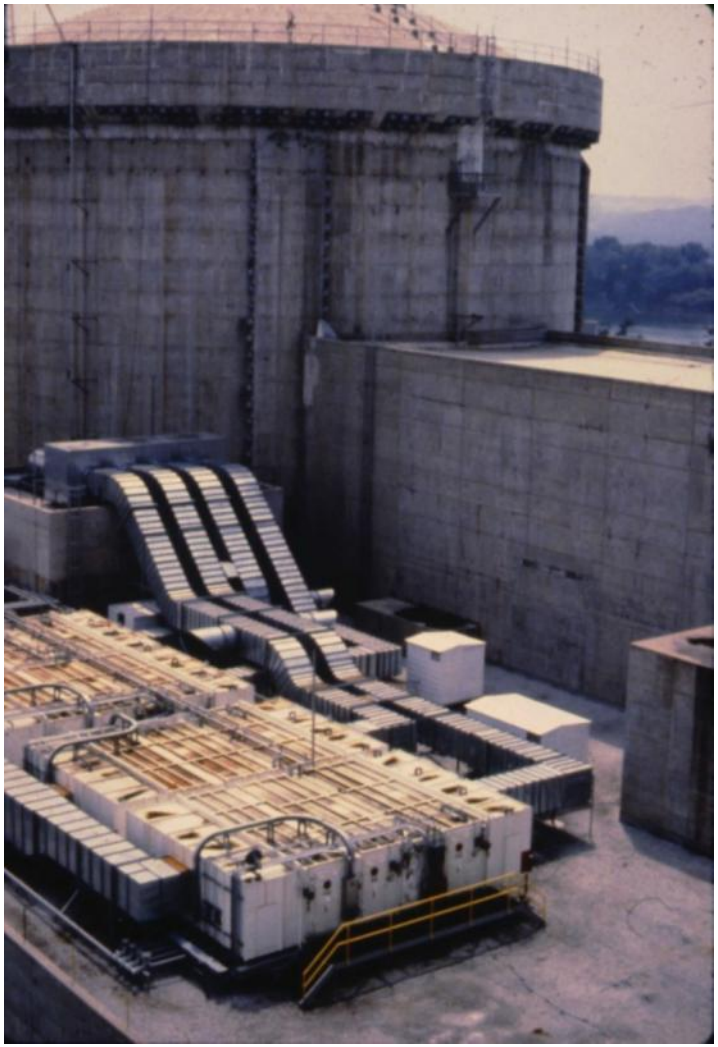


^{85}Kr Venting

June 28, 1980



Concept



Filtration System

Public Emotional Issue
External Advisory Committee

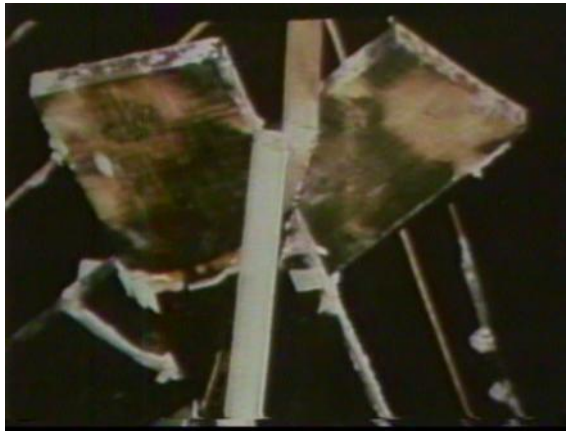
Containment Conditions

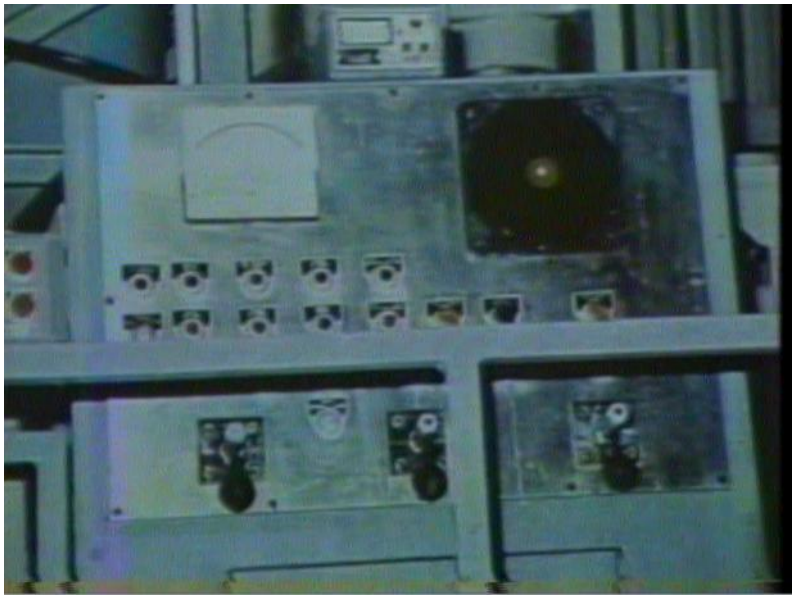
Closed Environment With Rain

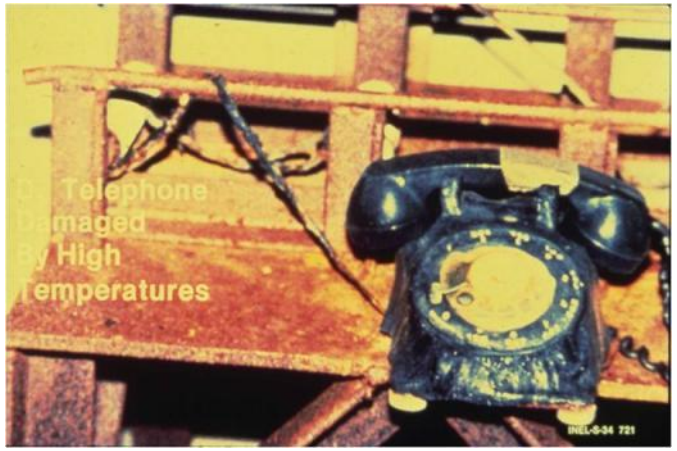
Closed Environment With Rain

3 M Deep 10Sv/hr Warm Water

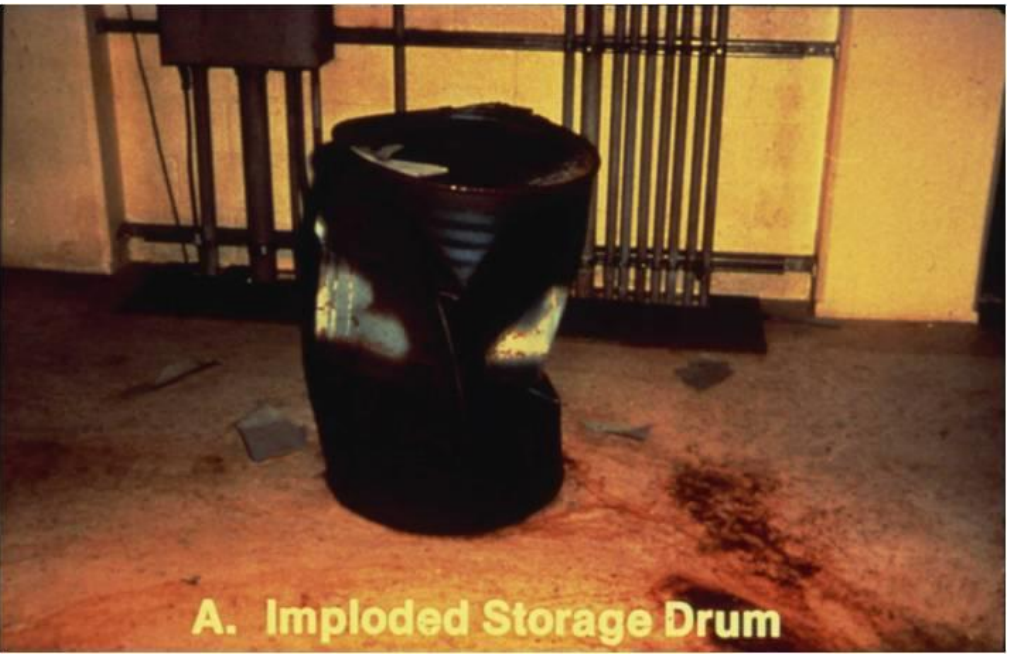
Radiation Heat Damage

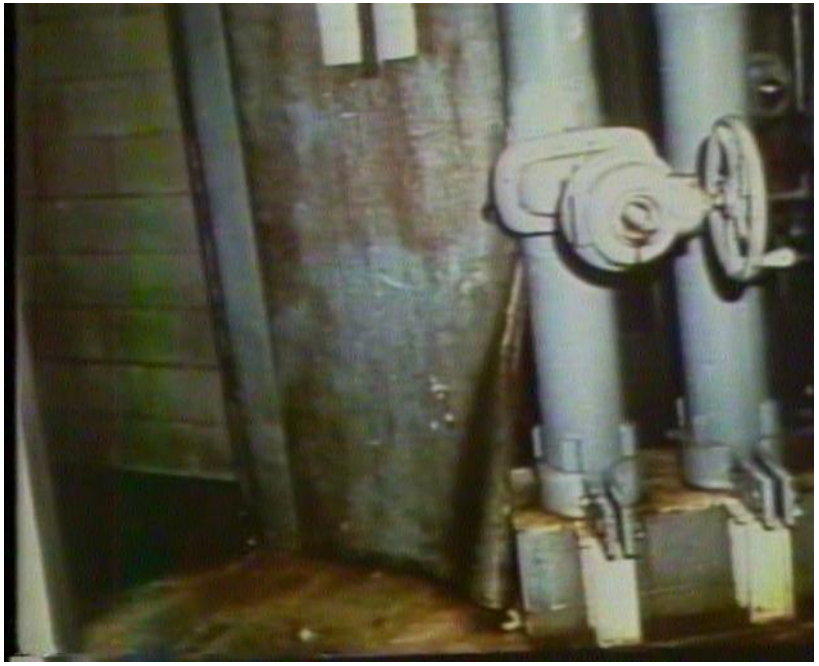




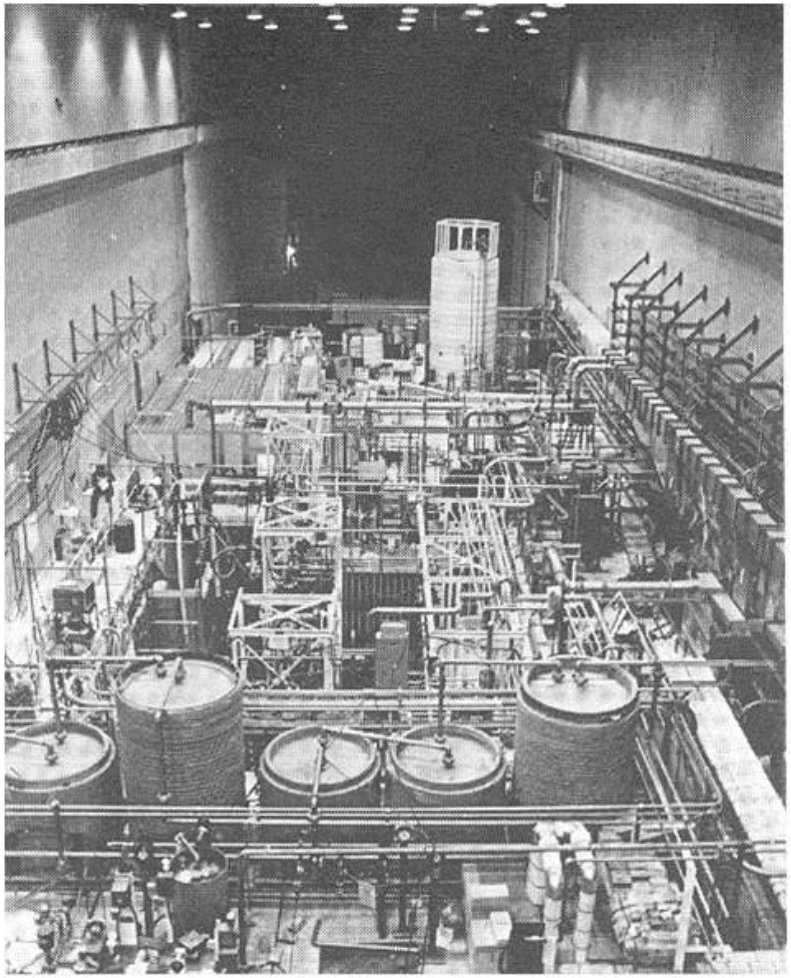


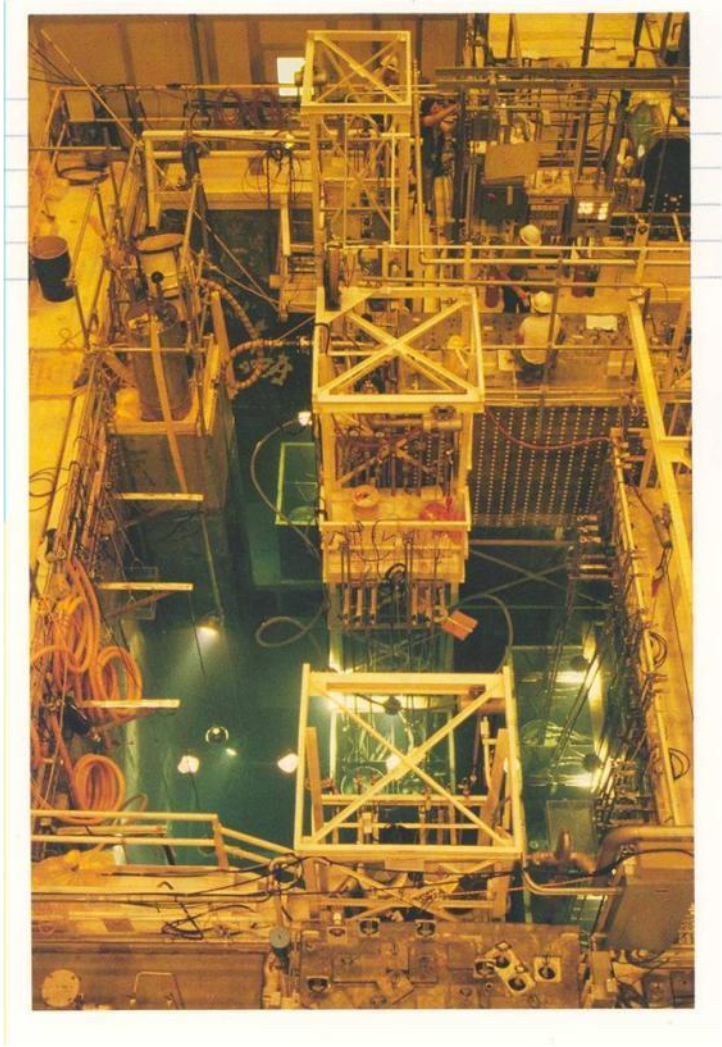
H2 Pressure Wave Damage



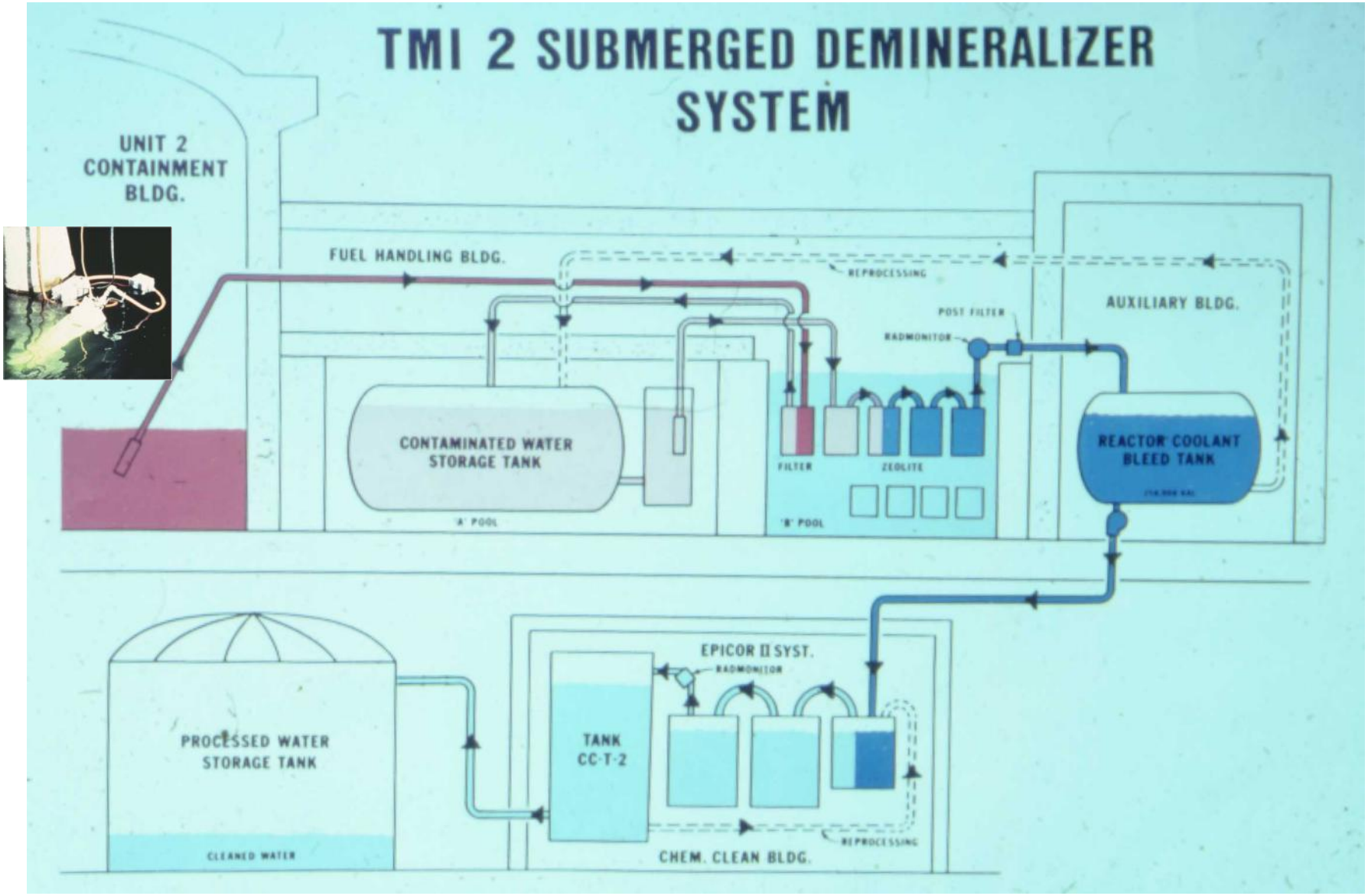


Process 2.5M L of Water From Containment Basement





Phased Water Cleanup Systems Created Based on Best Available Technology Submerged Demineralizer System (SDS)



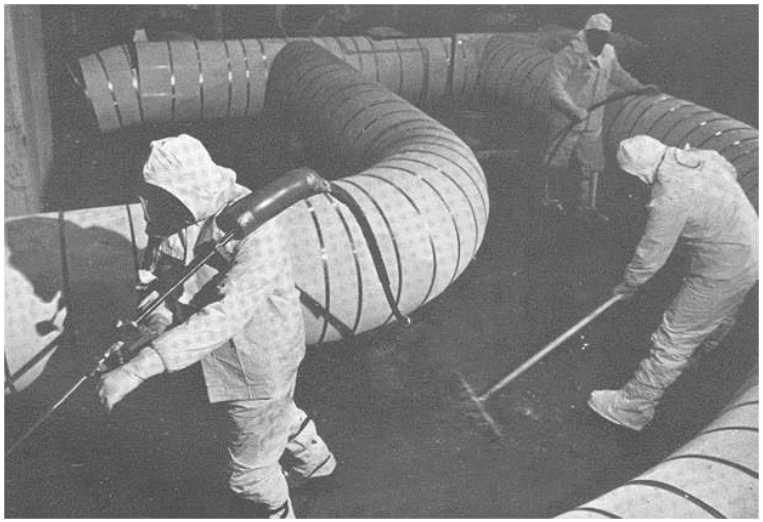
Closely Coupled Design-Operations Team for Successful Developmental System

SDS High Active Waste
1PBq (E15 Bq or 30KCi) of Cs/Can

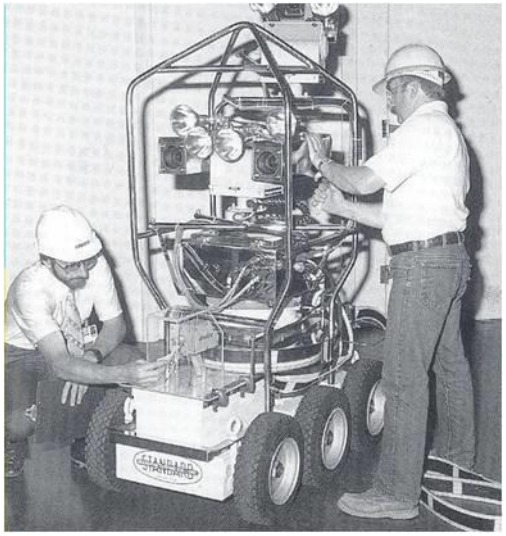
Loading SDS Shipping Cask

SDS Shipping Cask

Containment Decontamination

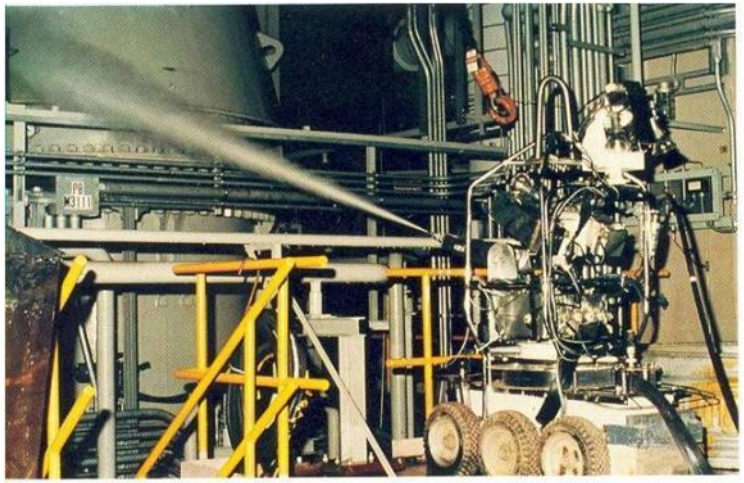


High Pressure Washing



Robots Developed

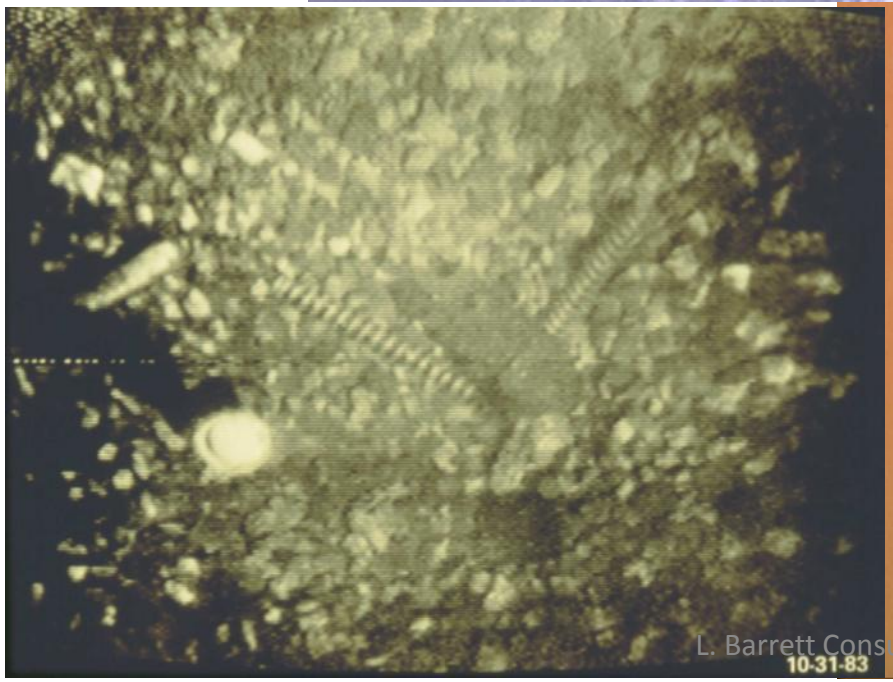
Radioactive Sludge on Floor

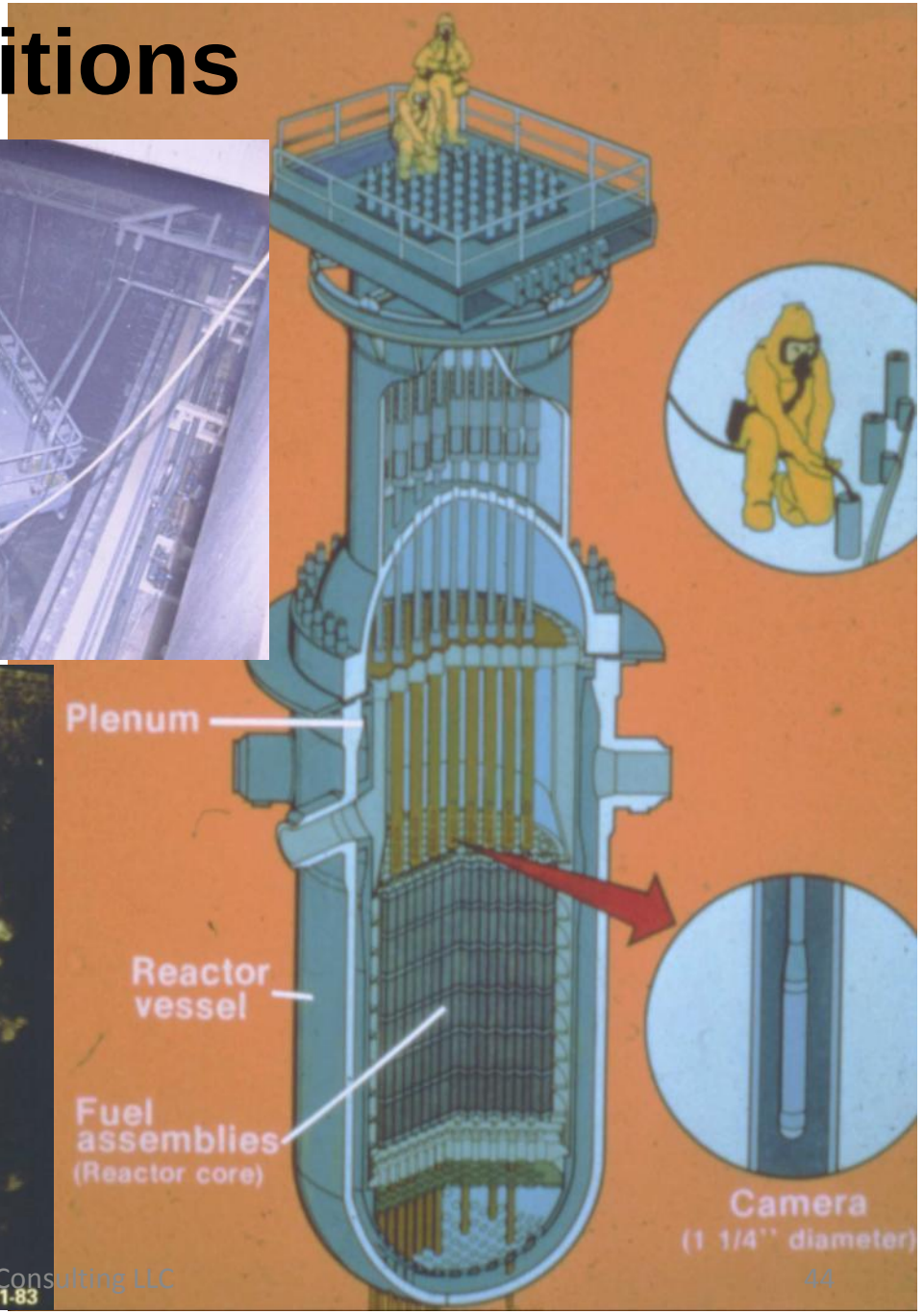


Robotic HP Washing

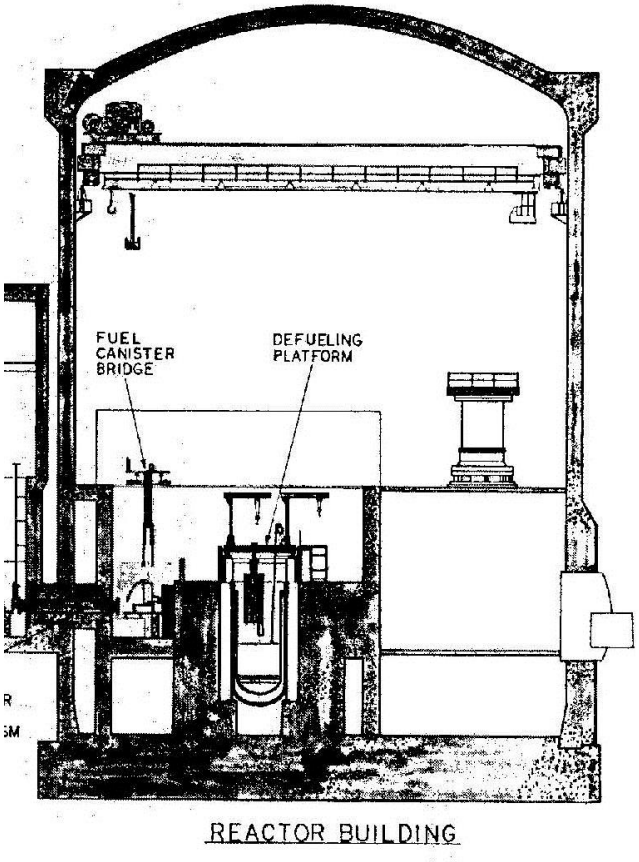
Evaluate Core Conditions

Quick Look





Restore 100Ton Polar Crane



REACTOR BUILDING

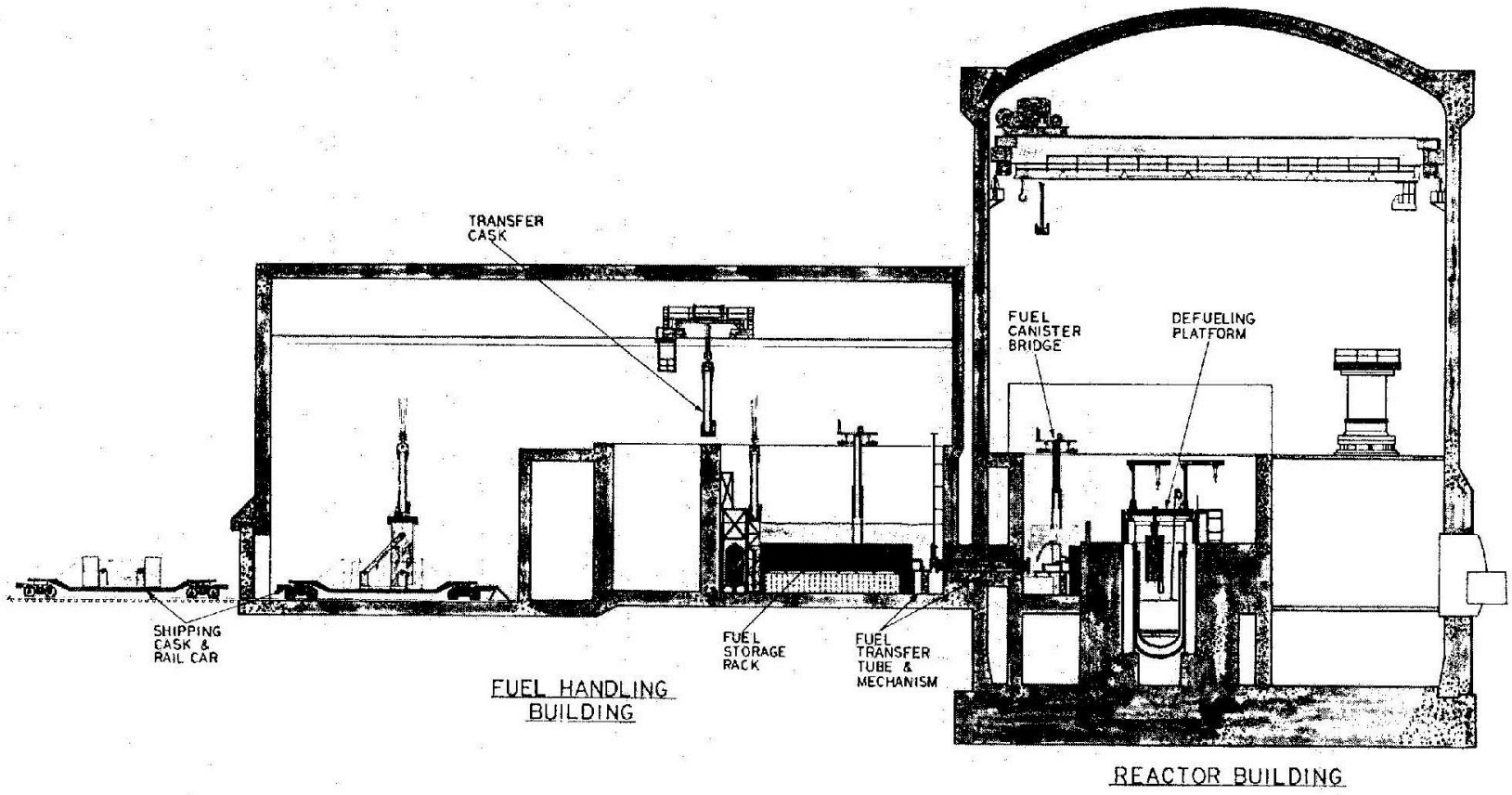
Gain Access to Reactor Internals

Building Remediation to Gain Core Access (Barrett Entry)

Lifting 40 Ton Missile Shield Blocks

Reactor Head Lift

Defueling Plan



Internal Surface Decontamination

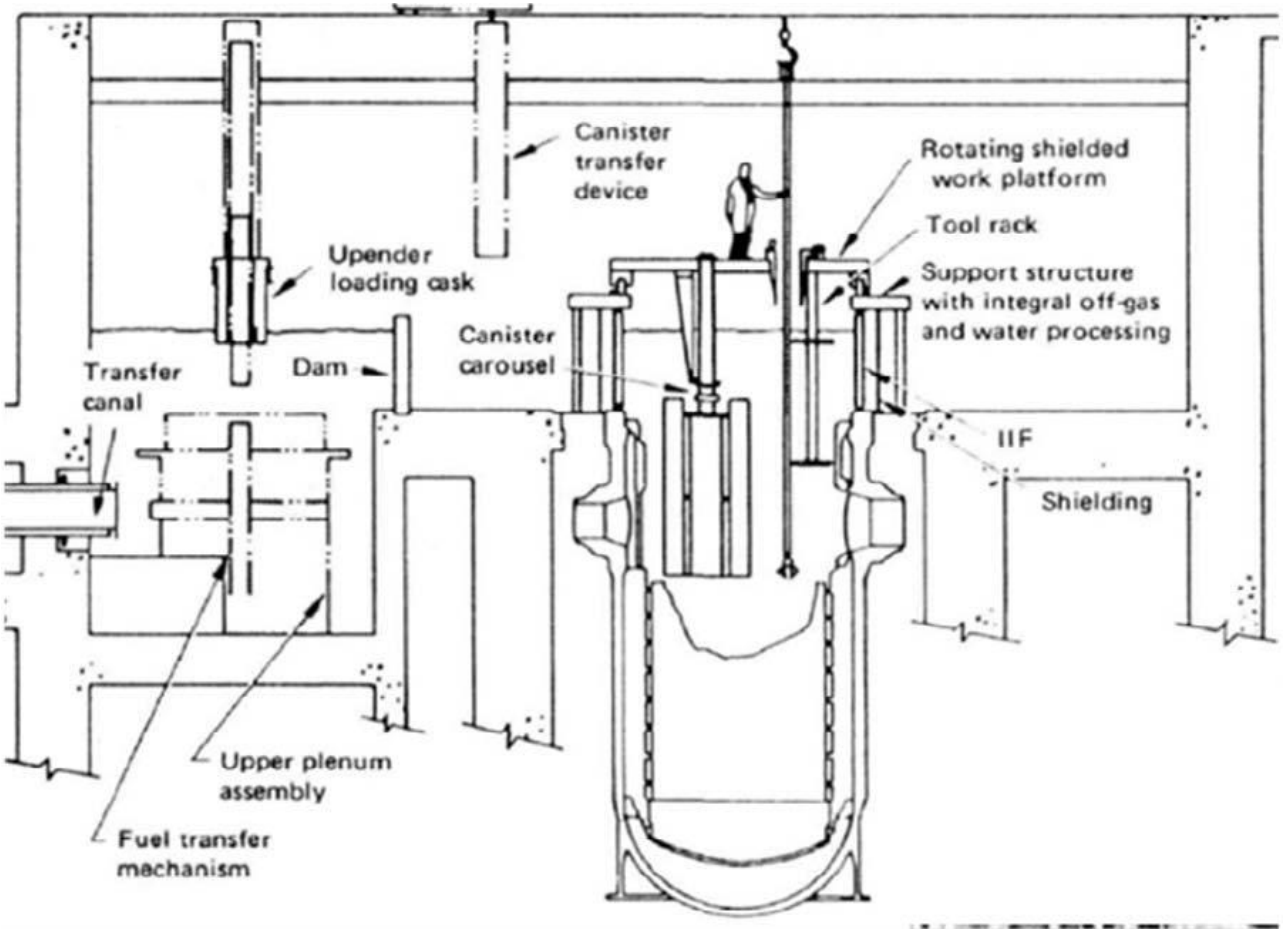
Evolutionary Process

Manual Surface Scabbling

Scabble Machine

Scabble Robot Vacuum

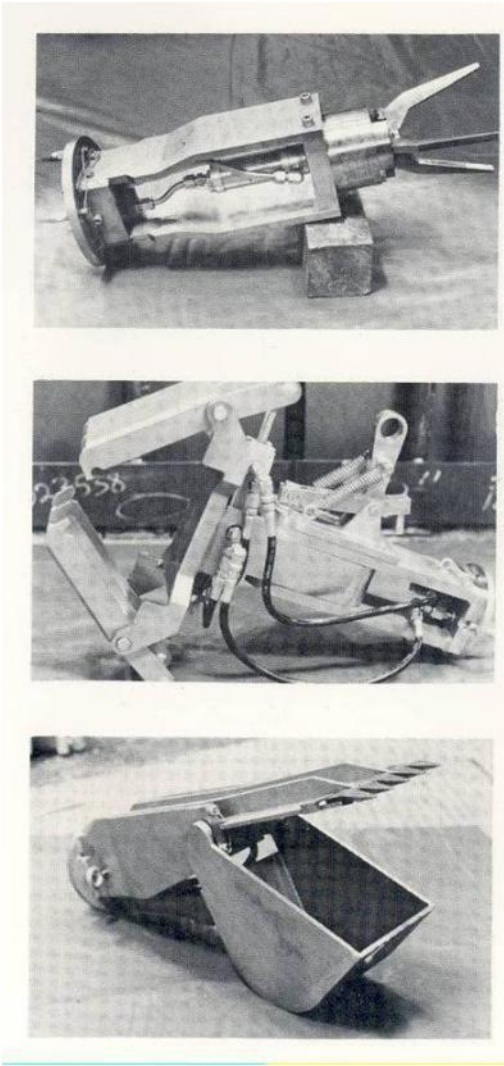
Defueling Work Platform



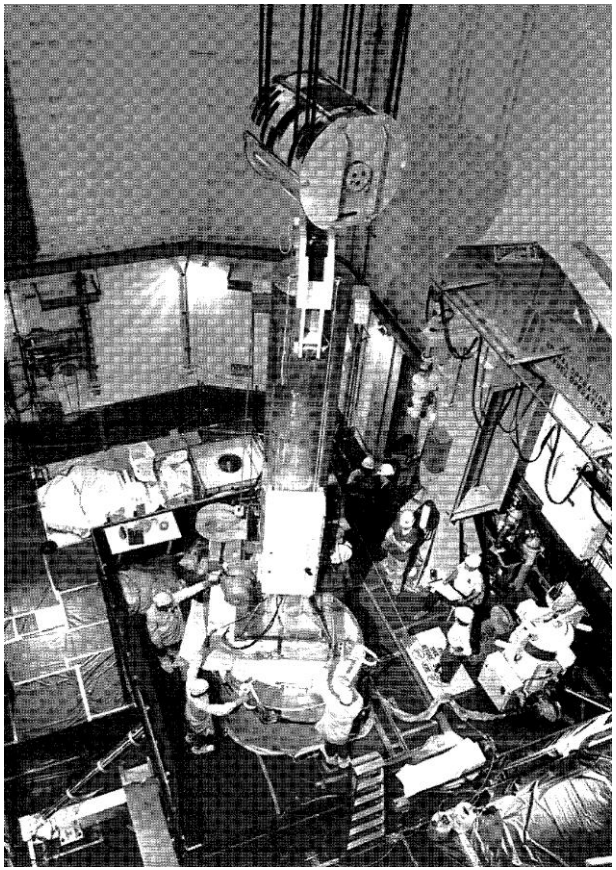
TMI Damaged Core Removal

~1985-1990

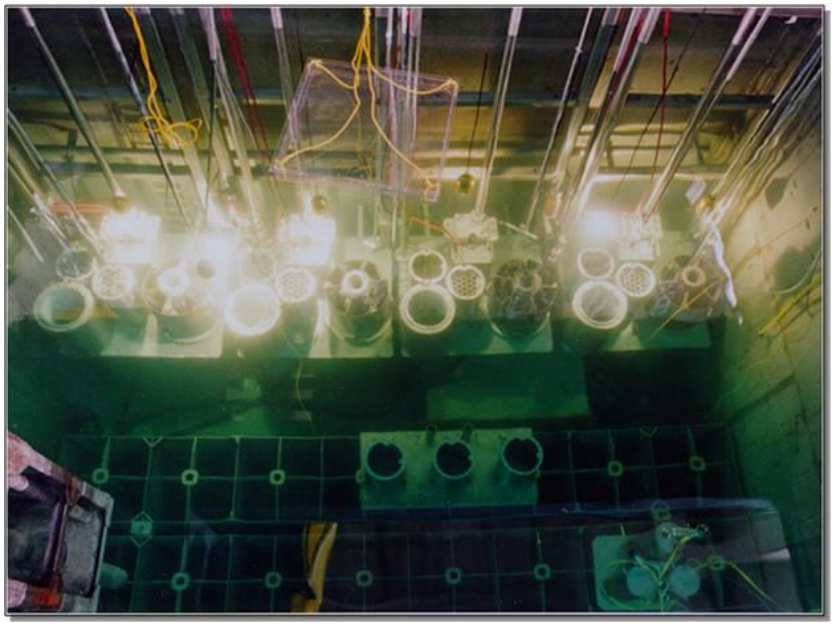
Defueling Tools



Transfer Load Spent Fuel Cans

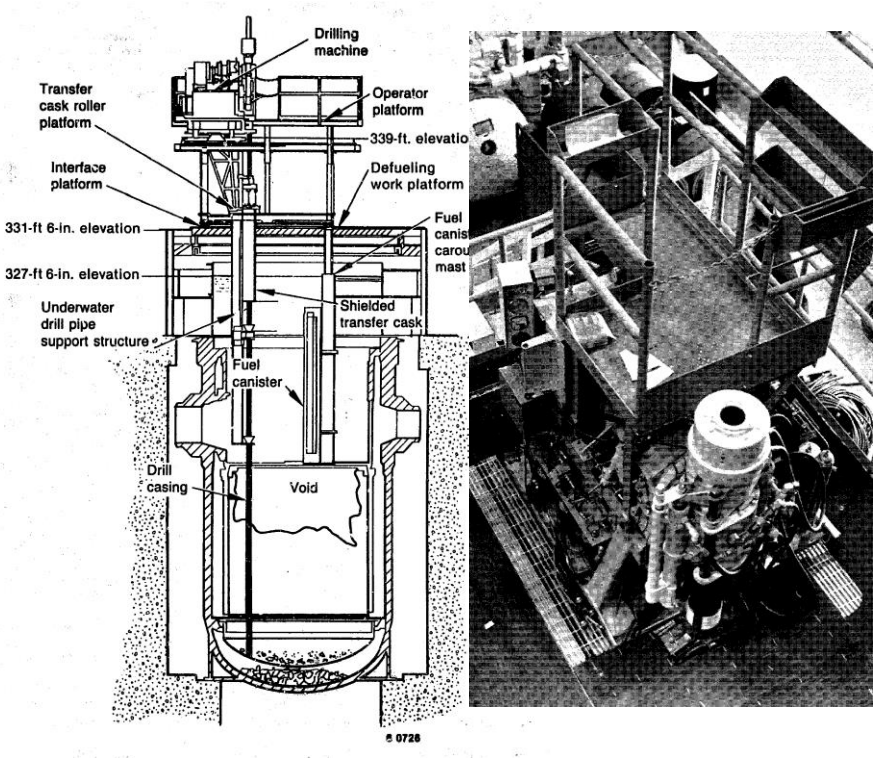


Shielded Transfer Bell



Spent Fuel Cans In Pool for Transport cask loading
344 cans loaded

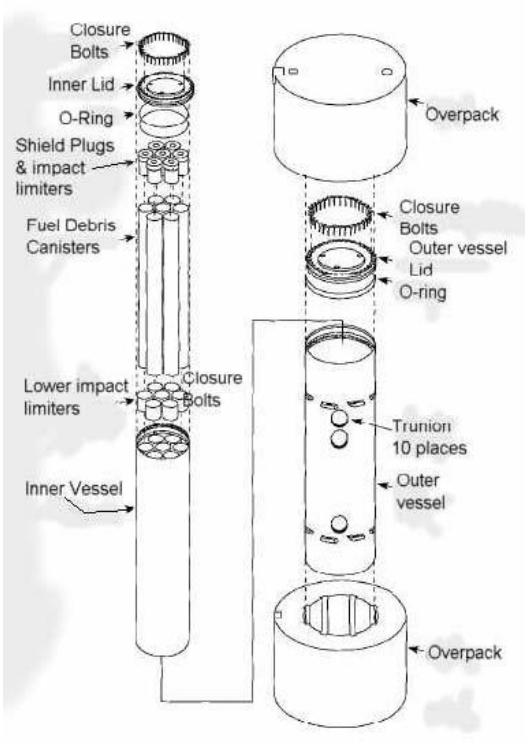
TMI Defueling



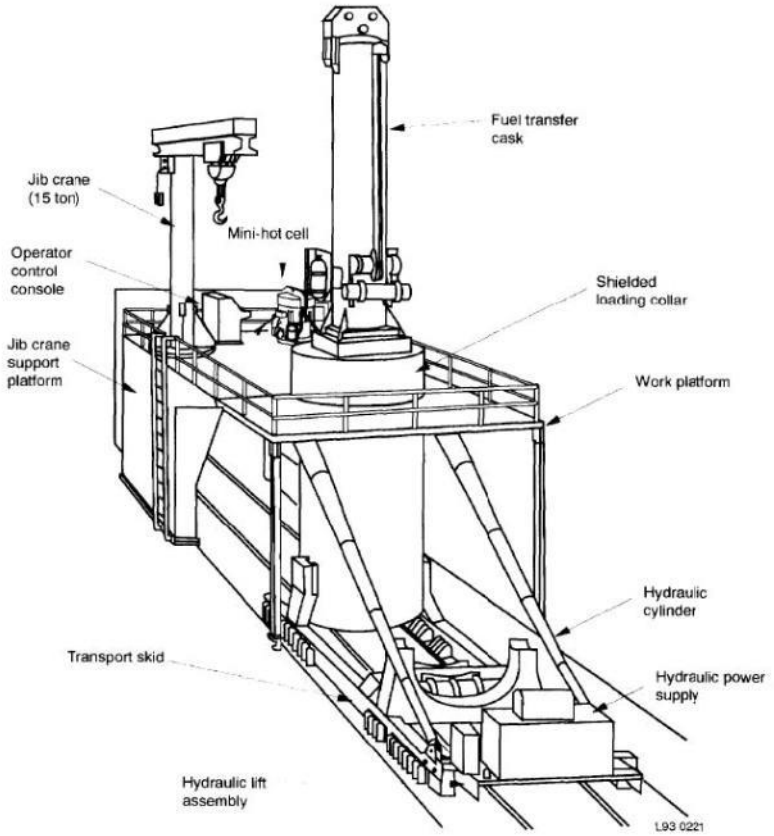
Core Bore Machine

Defuel Can Loading

Transportation Cask Developed, Licensed & Constructed



Hold Seven Fuel Cans



Dry Loading System

Spent Fuel Shipping

Transport Cask

Last Fuel 125B Casks
Leaving TMI To Idaho
1990

Rail Route to Idaho

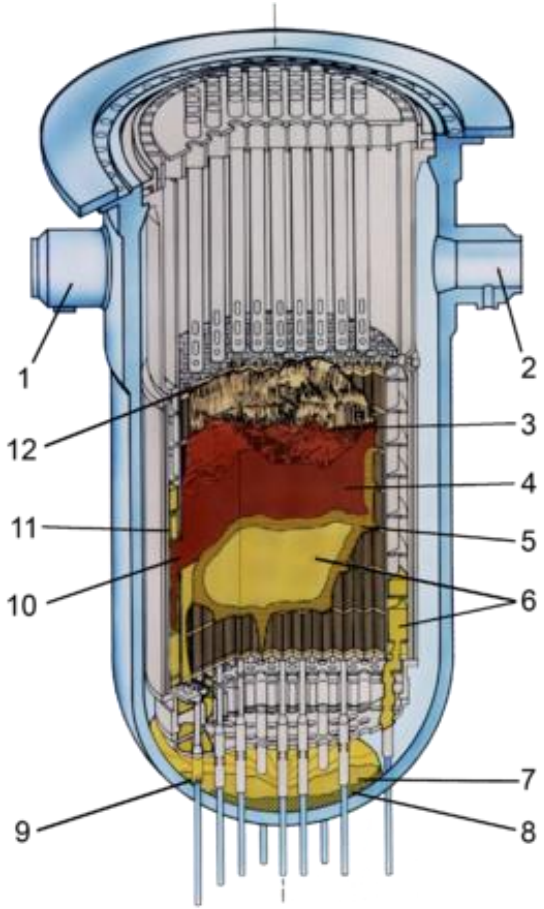
Figure 17. Map of shipment route of TMI-2 wastes to Idaho National Engineering Laboratory.

5-15

Cask Unloading At Idaho INEL

Fuel Can Unloading For R&D

Fuel To Hot Cell for Analysis



Core Material & Vessel Analyses

INEL Nuclear R&D/Storage Program Cask Transfers In Idaho

INEL Nuclear R&D/Storage Program

TMI Fuel In Dry Storage Today

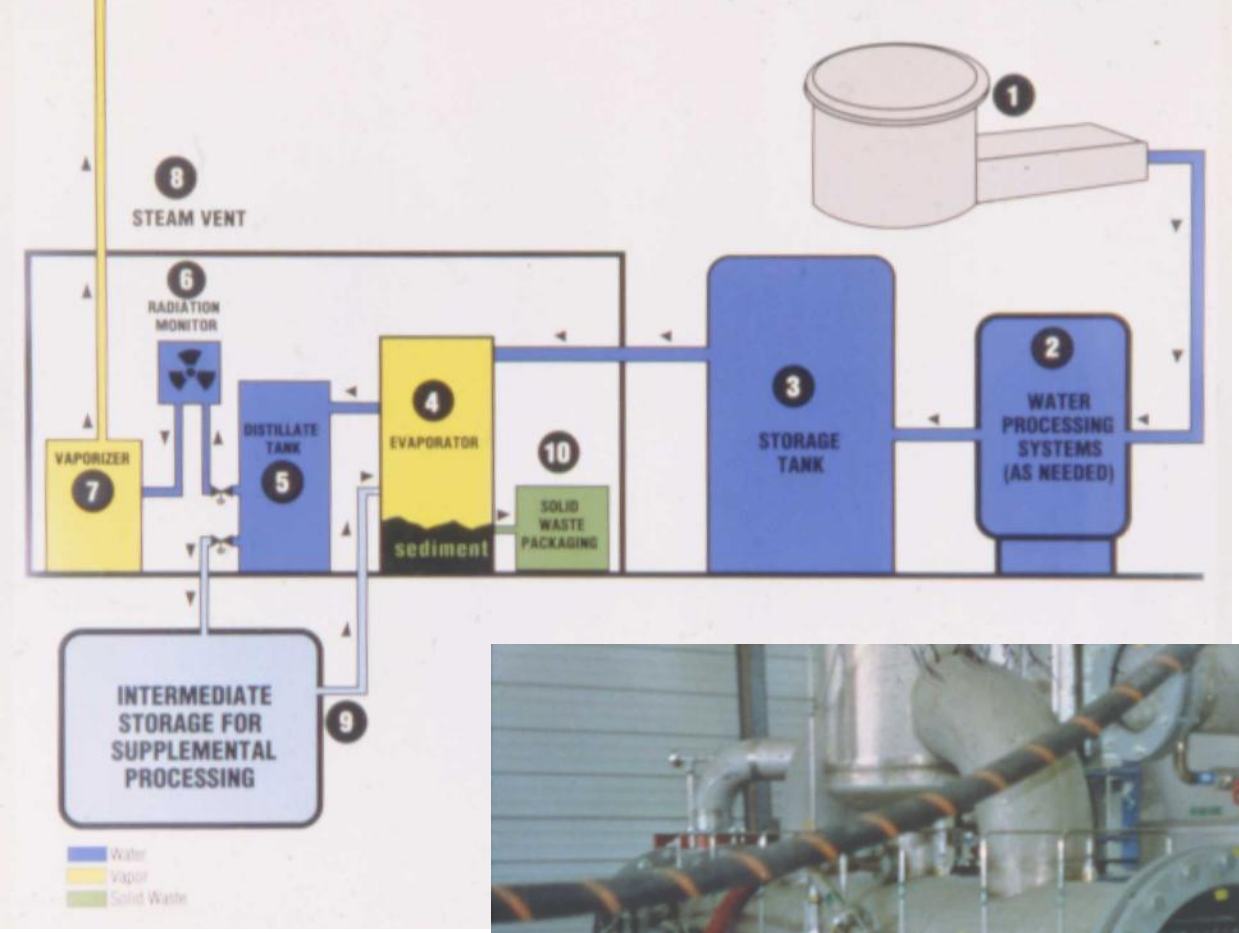
Accident Water Storage Tanks

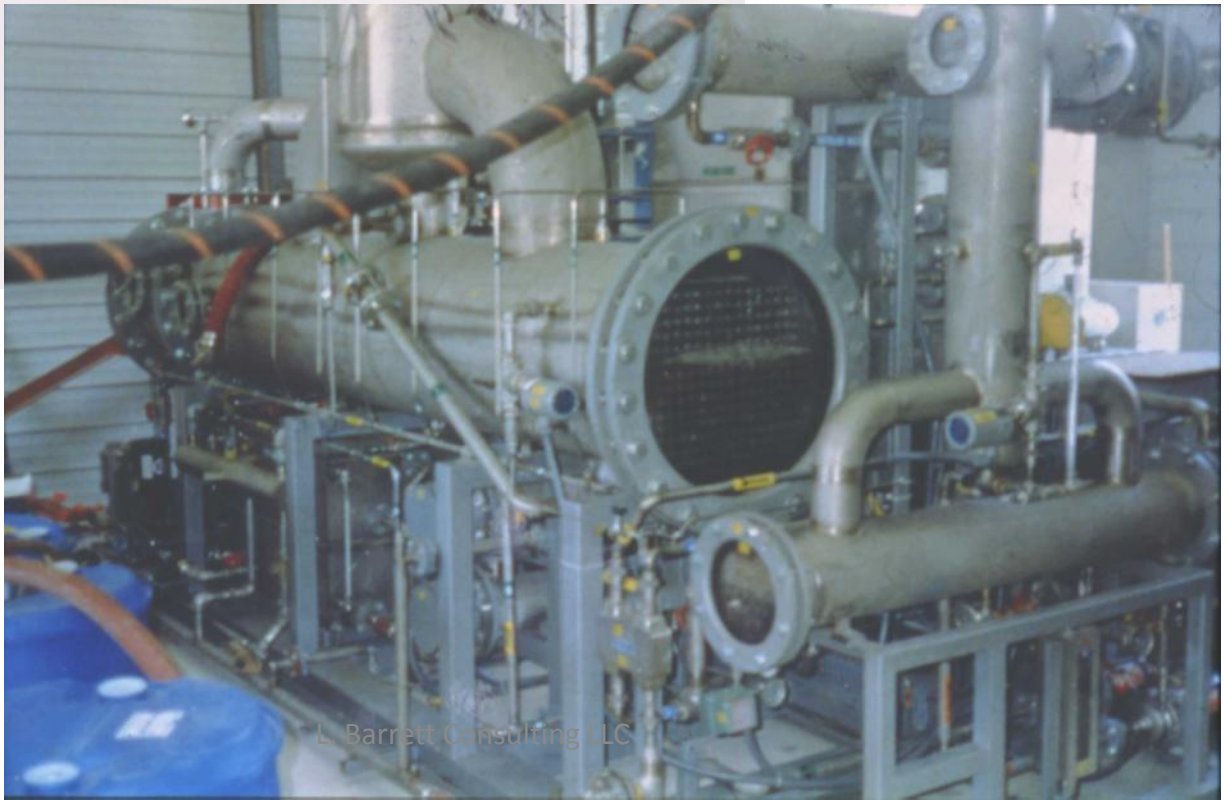
Downstream Drinking Water Cities Objected

~9 Milllon L of Tritiated (24TBq) Accident Water Met Release Standards,

BUT STONG EMOTIONS

Processed H3 Water Evaporation 9,000 Tons 1991-93





Three Mile Island Units 1 &2 Today

1993- Current

Unit 1 Operating Until 2034 Then Decommission Both Units Together

Three Mile Island History

- Reactor Scram: 04:00 3/28/79
- Core melt and relocation: ~ 05:00 – 07:30 3/28/79
- Hydrogen Deflagration: 13:00 3/28/79
- Recirculation Cooling: Late 3/28/79
- Phased Water Processing: 1979-1993:Removed ~1.2MCi Cs137
- Containment Venting 43KCi Kr-85: July 1980
- Containment Entry: July 1980
- Reactor Head removed and core melt found: July 1984
- Start Defuel: October 1985
- Shipping Spent Fuel: 1988-1990
- Finish Defuel: Jan 1990
- Evaporate 9,000 Tons Processed Water: 1991-93
- Cost: ~$1 Billion ($2.3B in 2012$)

TMI Unit 1 Restarted

- Separated GPU Organization From Unit 2
- Restarted September 18, 1985
  - Six and Half Year Process
  - Extensive Operator Training
  - Plant Modifications
  - Extensive Public Regulatory Hearing Process
- One of Best Operating Reactors Today in US

TMI SUMMARY

- Most Serious U.S. Reactor Accident
- Reactor Core Melted (Not Known at Time)
- Large Releases to Containment Building
- Only Minor Environmental Releases & Consequences
- Cleanup Accomplished
- Profound Effects-MADE US NUCLEAR STONGER
  - Utility
  - Nuclear Industry
  - Regulatory Authorities

TMI Became Model For Future Growing US Cleanup Industry

- Growth Of Defense Cleanup Programs
  - Creation of DOE Environmental Management Organization
  - Technology Development
  - Technology Application
  - Effective Management Practices Evolution
- Growth of Commercial Cleanup Programs
  - Commercial Power Reactor D&D Programs

Peace On The River

Most Painful Experiences Are the Most Teachable

Most Stress is Gone- All are Wiser
Nuclear Power is Safer
Nuclear Power is More Productive

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Lake Barrett is a part time independent consultant in the energy field. He has worked in the nuclear energy and nuclear materials management areas for over 4 decades, most recently as the former head of the US Department of Energy's Office of Civilian Nuclear Waste Management which is responsible for implementing the United Sates' programs for spent nuclear fuel and high-level radioactive waste, as mandated by the Nuclear Waste Policy Act. In that capacity, he led the complex scientific Yucca Mountain Geologic Repository program through the statutory site selection process culminating with the Presidential site designation and following successful House and Senate votes.

He also served at U. S. Nuclear Regulatory Commission, where he was directly involved with the early response to the Three Mile Island reactor accident and became the Site Director, responsible for regulatory programs during the stabilization, recovery, and cleanup of the damaged reactor. He also has had extensive managerial and engineering experiences in DOE's Defence Programs and private industry at both Bechtel Power Corporation, with commercial nuclear power plants, and Electric Boat Division of General Dynamics with nuclear reactor and submarine systems design, operation, and decommissioning.