1 INTRODUCTION

LIST OF FIGURES

LIST OF PHOTOS

2 MANAGEMENT

LIST OF FIGURES

LIST OF TABLES

3 STABLIZATION

LISTOF FIGURES

LIST OF PHOTOS

4 PERSONNEL PROTECTION

LIST OF FIGURES

LIST OF TABLES

5 DATA ACQUISITION AND ANALYSIS

LIST OF FIGURES

LIST OF PHOTOS

6 WASTE MANAGEMENT

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

7 DECONTLAMINATION

LISTOF FIGURES

LIST OF TABLES

LIST OF PHOTOS

8 DEFUELING

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

Appendices

EPRI Logo

Topics:
Reactor accidents
Source term
Degraded core accidents
Radioactive waste management
Decontamination

EPRI NP-6931
Project 2558-8
Final Report
September 1990

The Cleanup of Three Mile Island Unit 2

A Technical History: 1979 to 1990

Prepared by Grove Engineering, Inc.
Rockville, Maryland

R E P O R T   S U M M A R Y

SUBJECTS	Light water reactor safety / Risk analysis, management, and assessment / Radiation source term / Radioactive waste management
TOPICS	Reactor accidents Source term Degraded core accidents Radioactive waste management Decontamination
AUDIENCE	Nuclear utility managers and engineers

The Cleanup of Three Mile Island Unit 2

A Technical History: 1979 to 1990

The fuel damage and the release of fission products after the Three Mile Island unit 2 (TMI-2) accident required unprecedented decisions regarding the enormous cleanup operations. The rationale for those decisions will provide valuable information for other managers who may face similar situations. Planning and response procedures can benefit from the insights gained from the TMI-2 accident.

BACKGROUND Limited applicable experience hampers effective planning and response recovery operations in accidents involving fuel damage. TMI-2 demonstrated that effective cleanup responses remain unpredictable, determined largely by the specific situation. Managers must anticipate an extended period of plant recovery and cleanup following such an accident.

OBJECTIVE To describe the decision-making process during the TMI-2 cleanup, focusing on the project manager's area of responsibility and needs.

APPROACH Researchers gathered information by participating directly in the cleanup. Research by others and subsequent interviews with executives, managers, and workers supplemented their experience. The information collected was then analyzed, and substantive options, factors, and relevant decision-making data were identified and summarized.

RESULTS The report focuses on seven major aspects of the cleanup: cleanup management, stabilization, personnel protection, data acquisition and analysis, radioactive waste management, decontamination, and defueling. A chronological narrative identifies the major questions and challenges facing TMI-2 cleanup managers, describes the influencing factors and the options avail— able, and presents the final decisions and their consequences. An extensive bibliography provides sources for more-technical details.

EPRI PERSPECTIVE EPRI sponsored this technical history project to preserve the logic and COI sequences of decisions made during the TMI-2 cleanup.The results may help streamline recovery operations from similar accidents involving damaged fuel and fission-product release. The history will assist others in anticipating the consequences of a fuel damage event and in training managers accordingly. The, narrative also serves as a comprehensive source of information about the TMI-2 cleanup, providing a detailed chronology for those making a further study of the postaccident events.

PROJECT RP2558-8
EPRI Project Manager: R. W. Lambert
Nuclear Power Division
Contractor: Grove Engineering, Inc.

For further information on EPRI research programs, call
EPRI Technical information Specialists (415) 855-2411.

ABSTRACT

The Electric Power Re search Institute has sponsored a technical history project to ensure that the logic and consequences of decisions made during the Three Mile Island Unit 2 (TMI-2) cleanup are available for recovery from an accident involving damaged fuel and fission product release. The objectives of the history project are to identify the major questions and challenges facing management; describe the influencing factors and the options available; and present the final decisions and their consequences. This history of decision-making is intended to assist a project manager who must respond to a fuel damage accident, even if the scale is much smaller than TMI-2. The history has focused on decisions related to seven major aspects of the cleanup: cleanup management, postaccident stabilization, personnel protection, data acquisition, radioactive waste management, decontamination, and defueling. A detailed chronology and extensive bibliography accompany the text.

TABLE OF CONTENTS

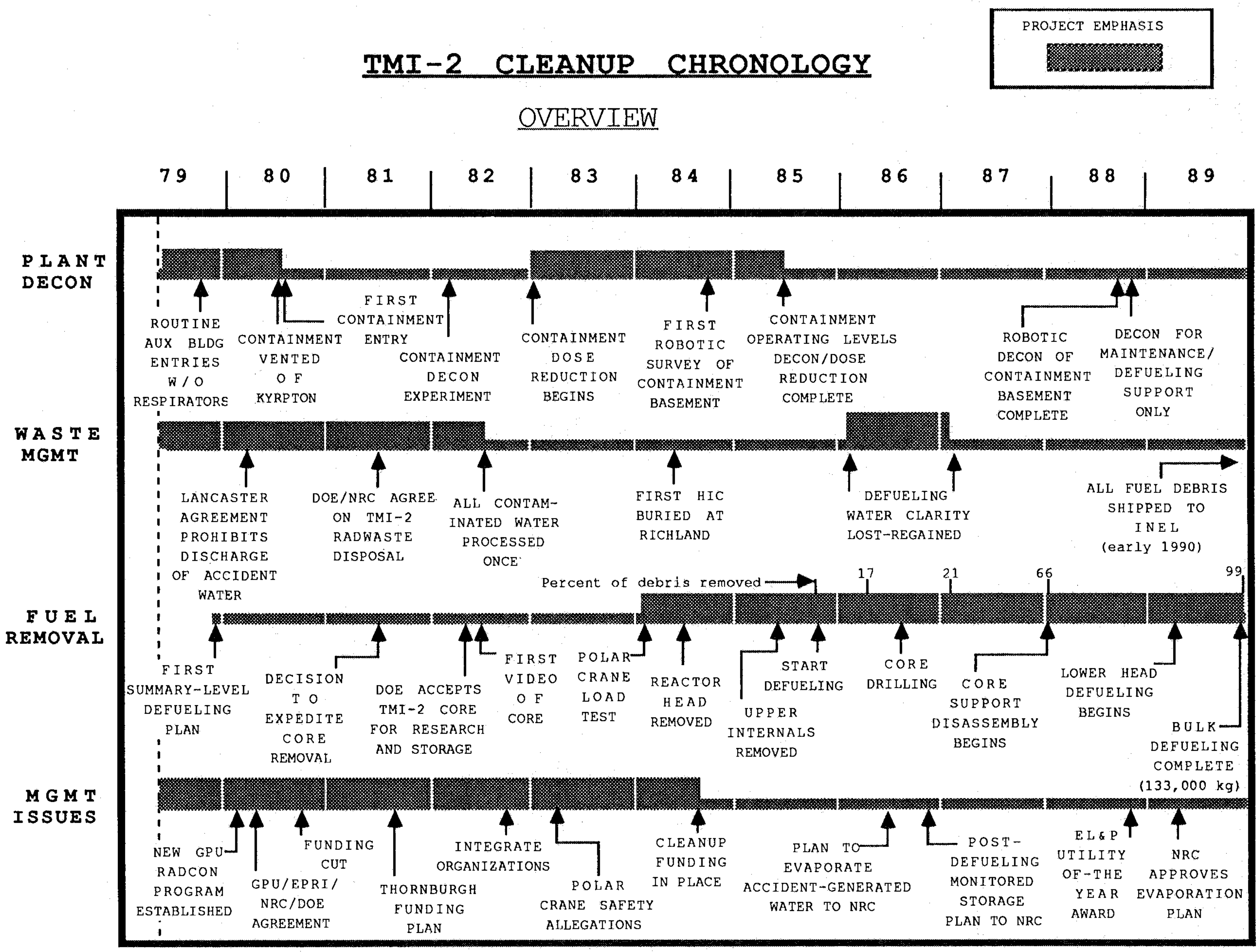


Figure 1-1. TMI-2 Timeline: Overview

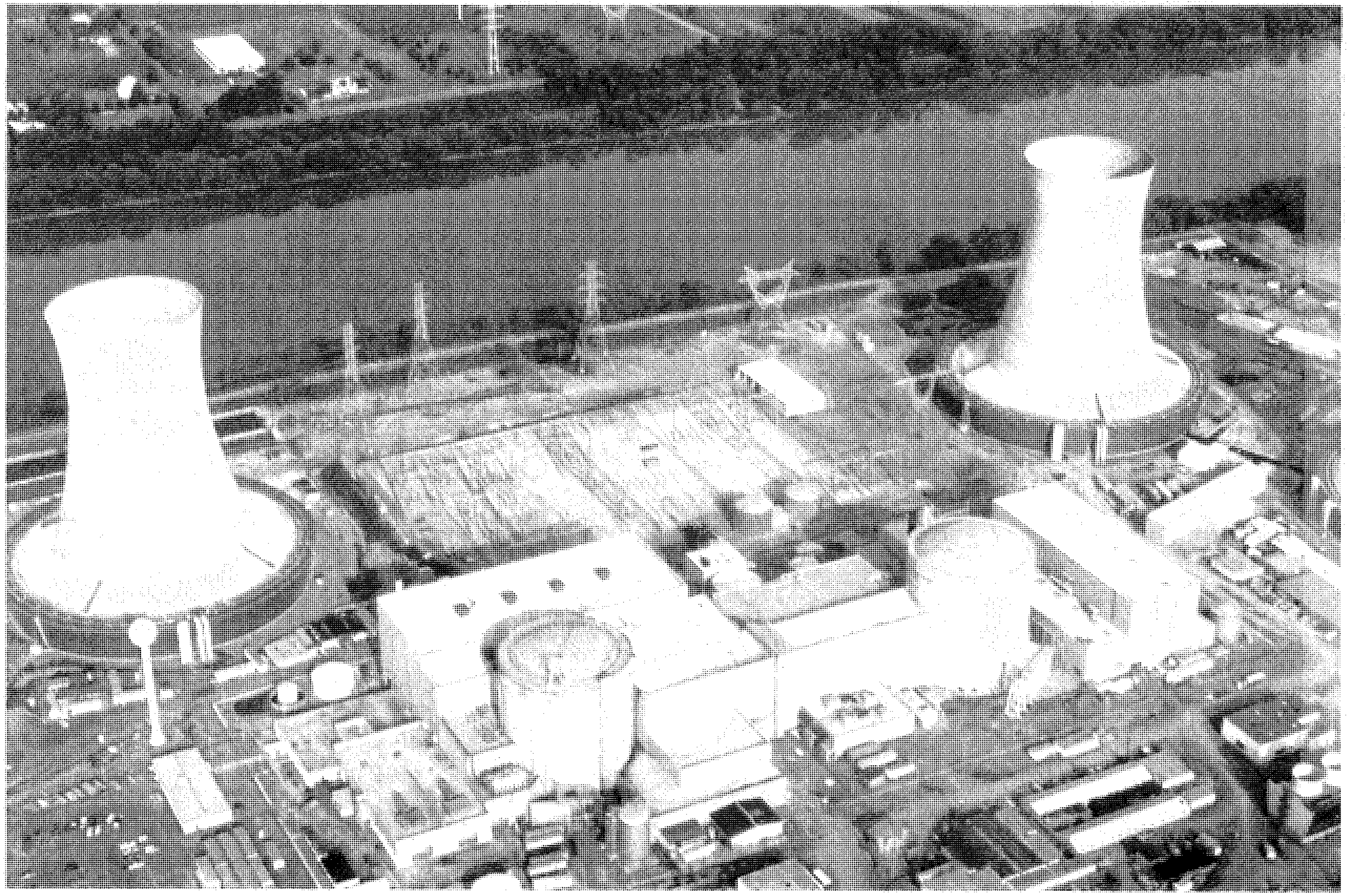


Photo 1-1. Three Mile Island (Looking East — Unit 2 on the Right)

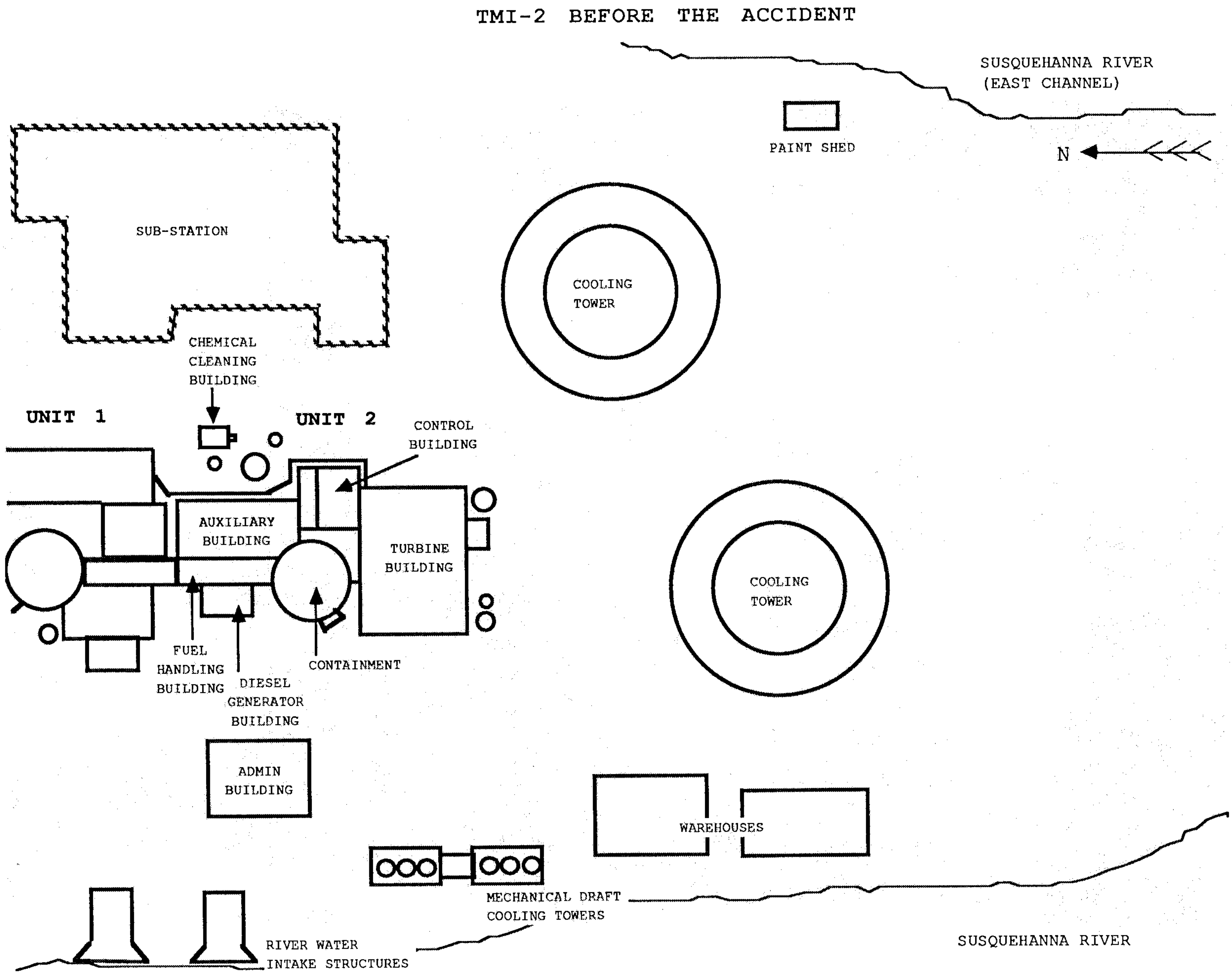


Figure 1-2. TMI-2 Before the Accident

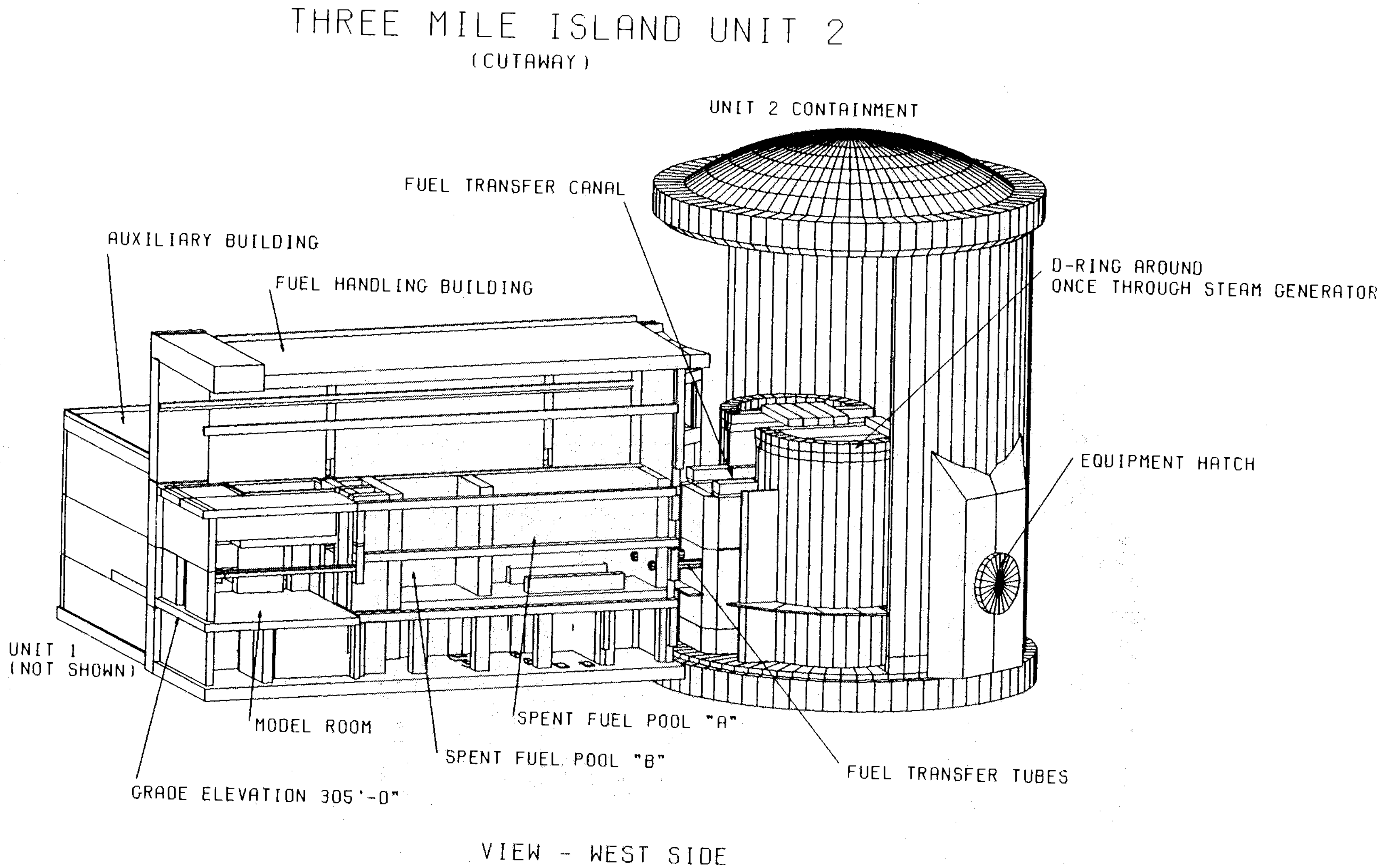


Figure 1-3. TMI-2 (View — West Side)

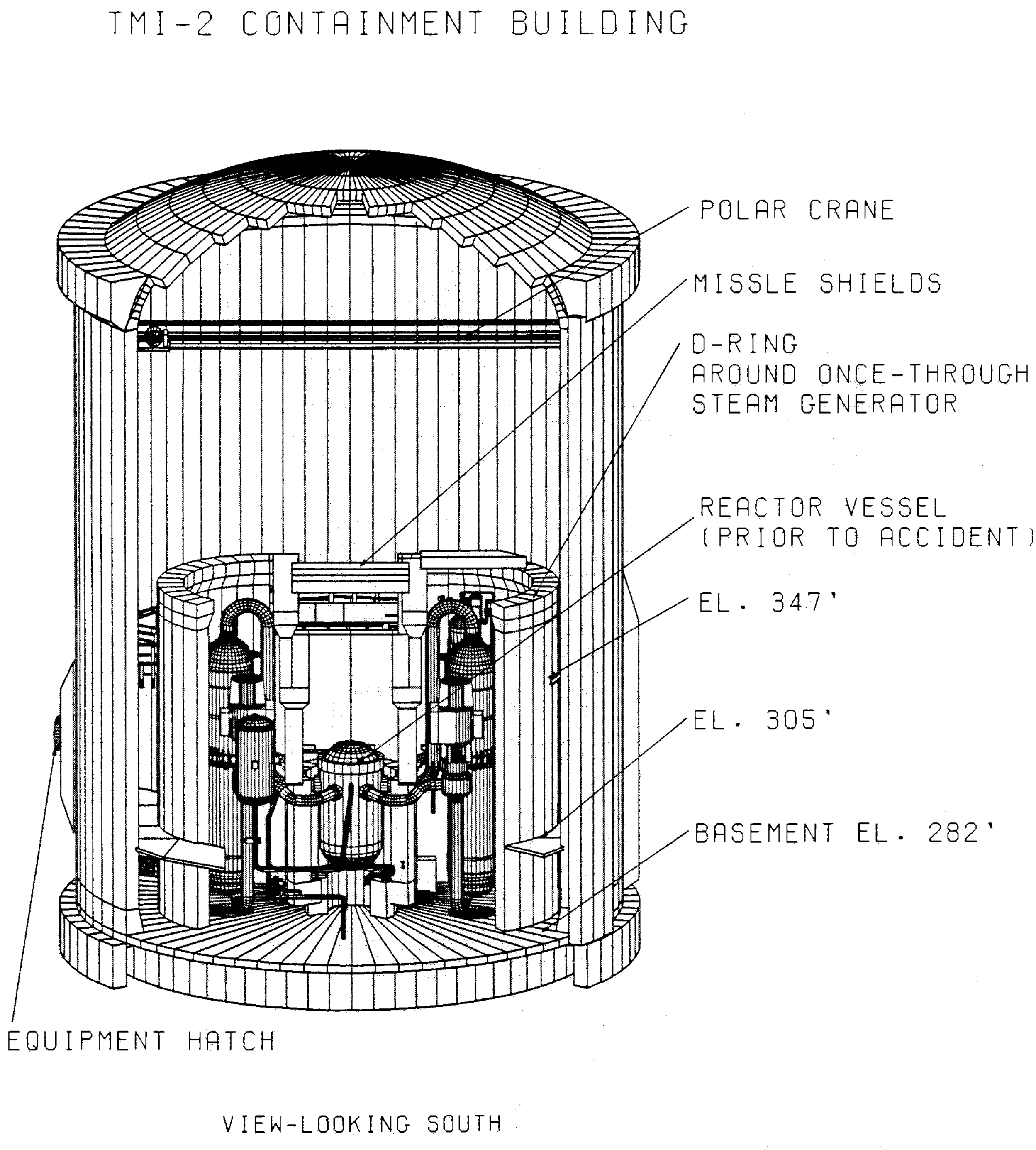


Figure 1-4. TMI-2 Containment Building (View — Looking South)

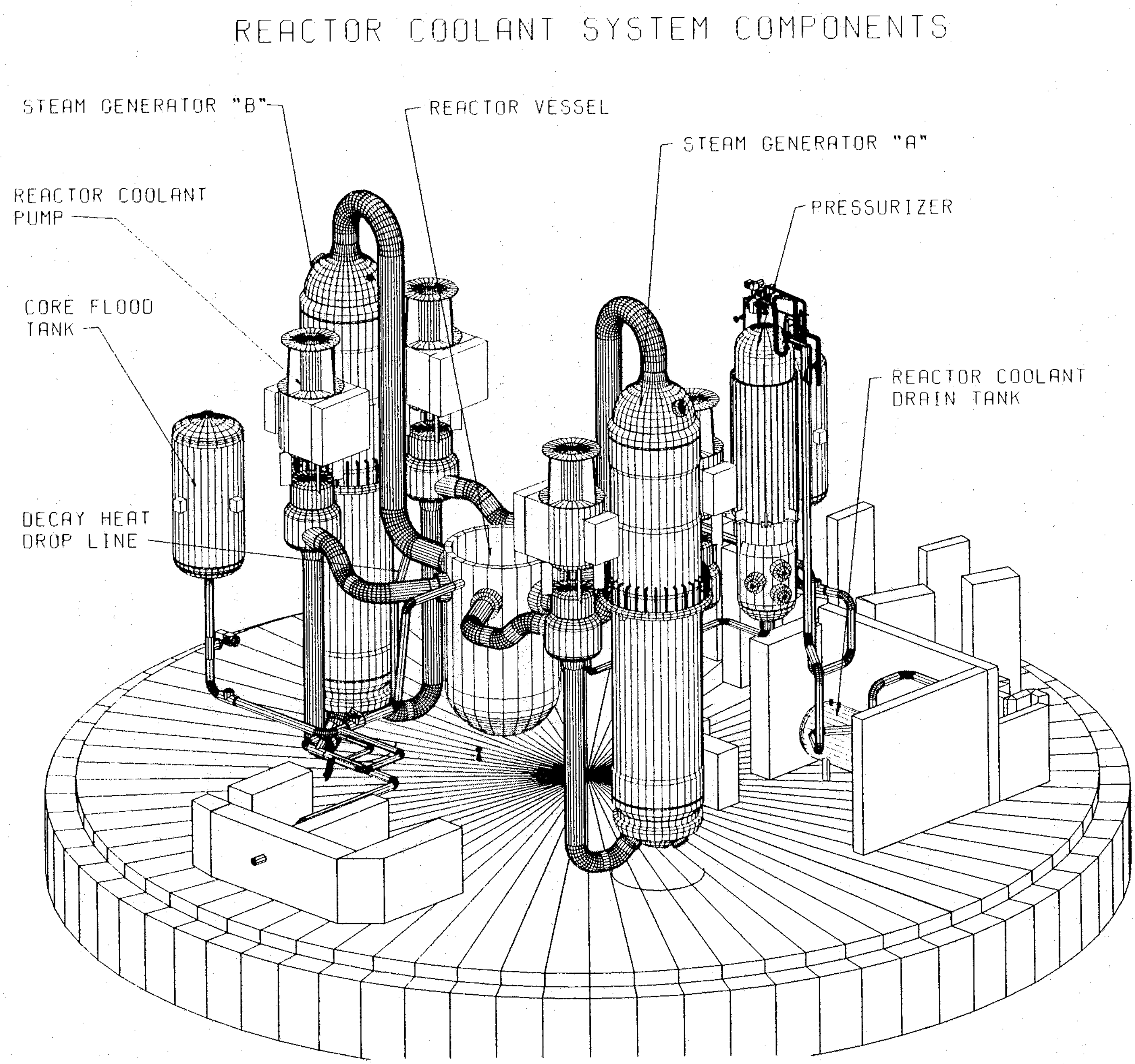


Figure 1-5. TMI-2 Reactor Coolant System

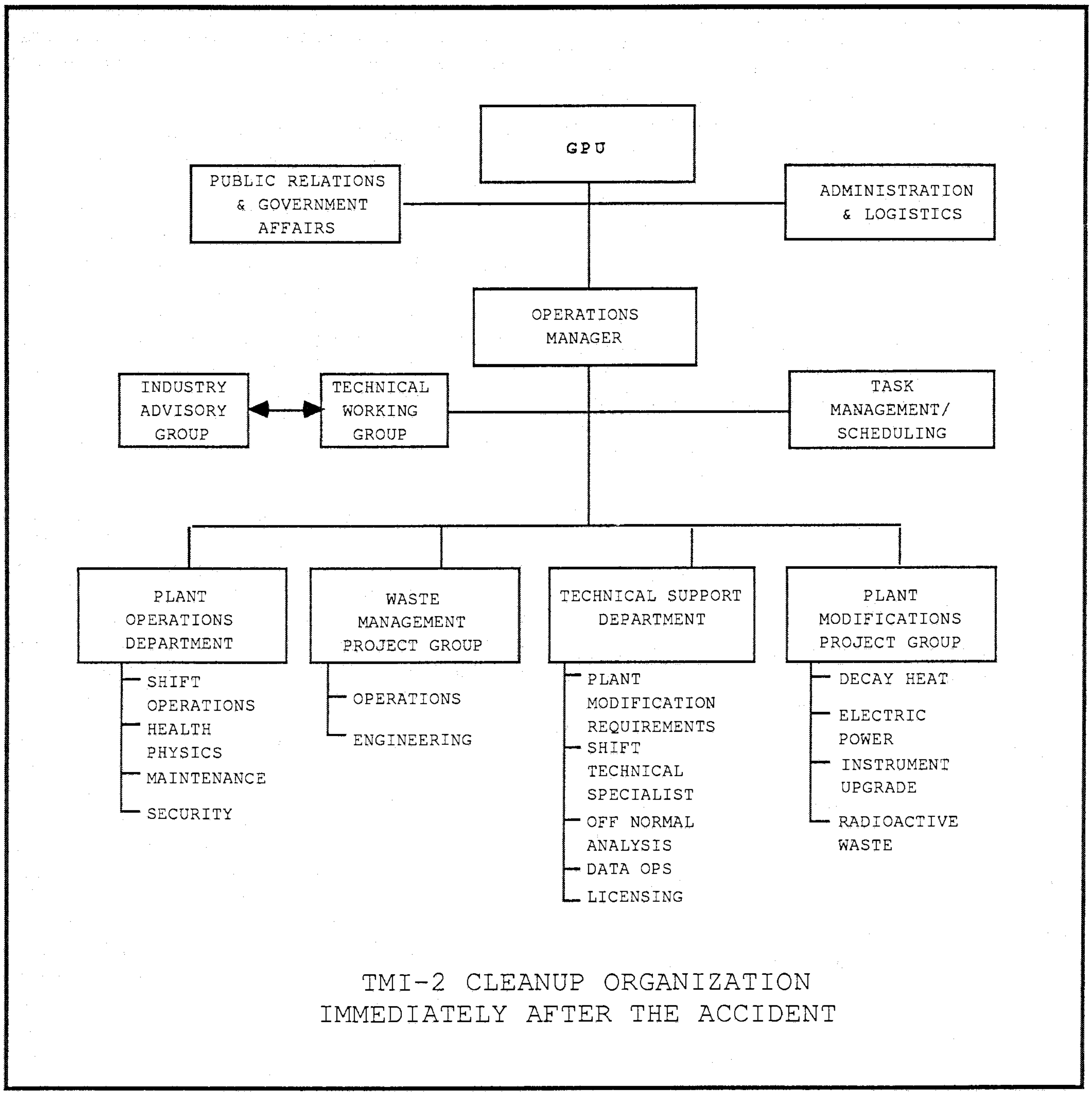


Figure 2-1. TMI-2 Cleanup Organization Immediately after the Accident

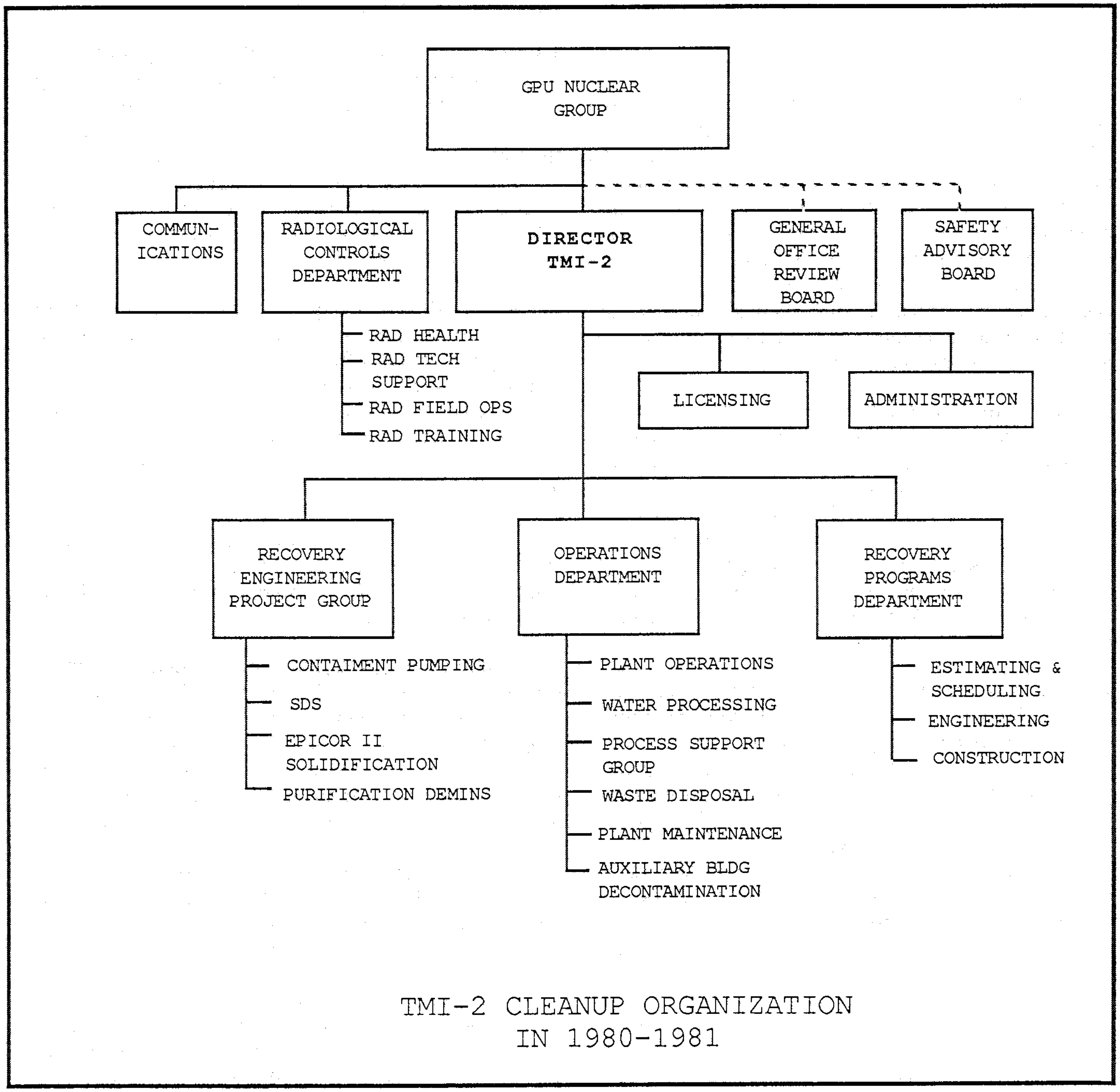


Figure 2-2. TMI-2 Cleanup Organization in 1980–1981

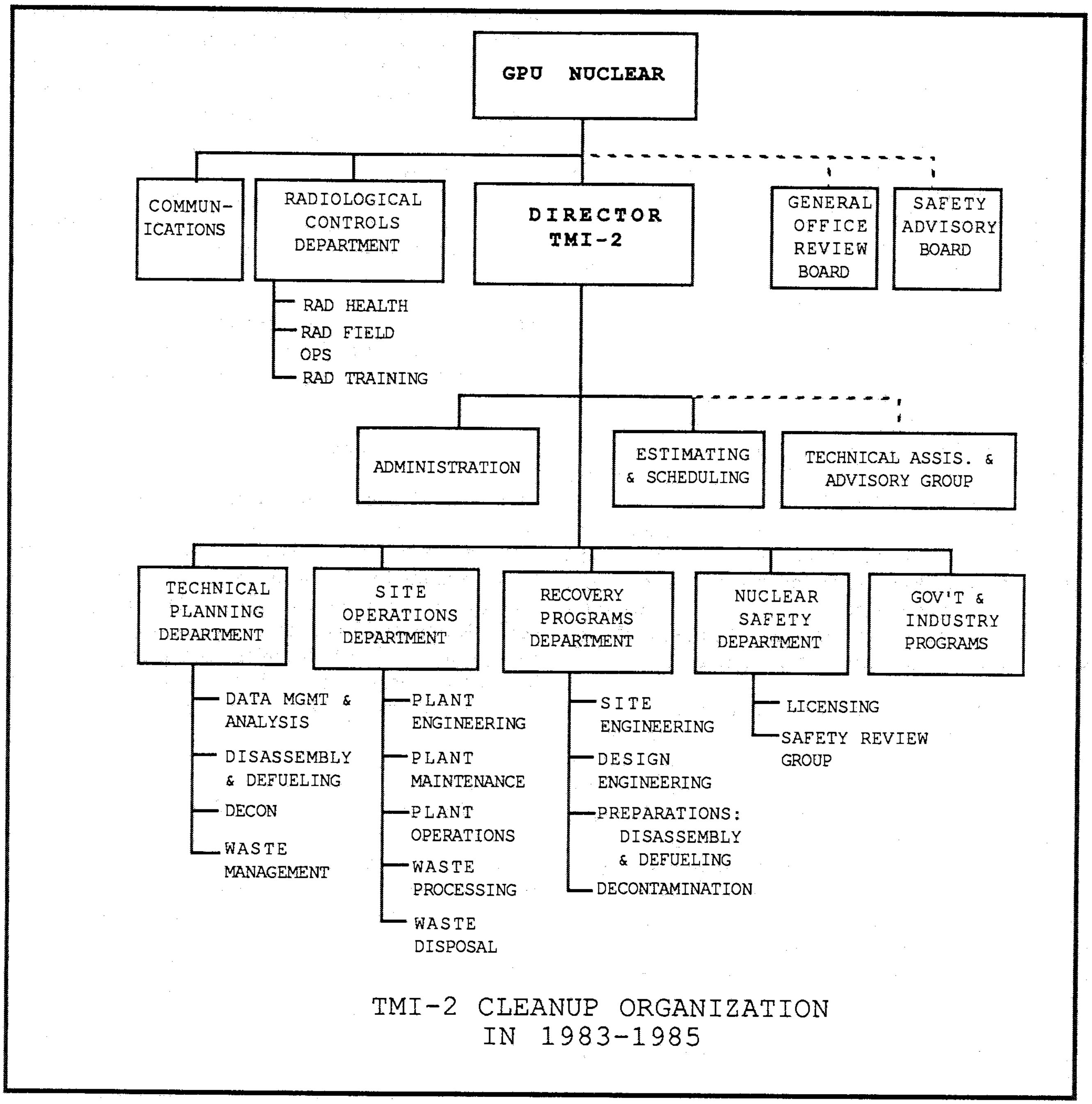


Figure 2-3. TMI-2 Organization in 1982–1985

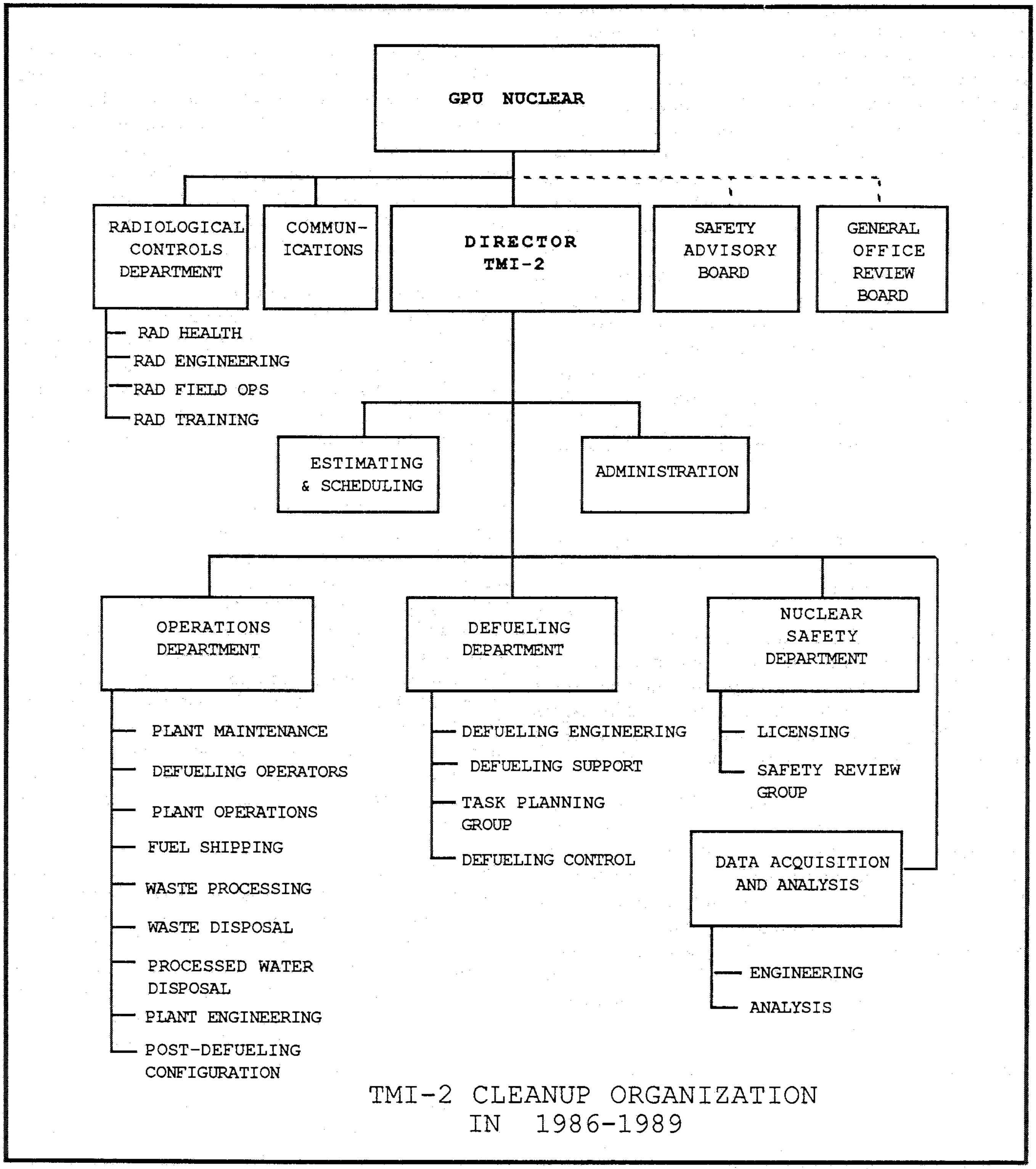


Figure 2-4. TMI-2 Cleanup Organization in 1986–1989

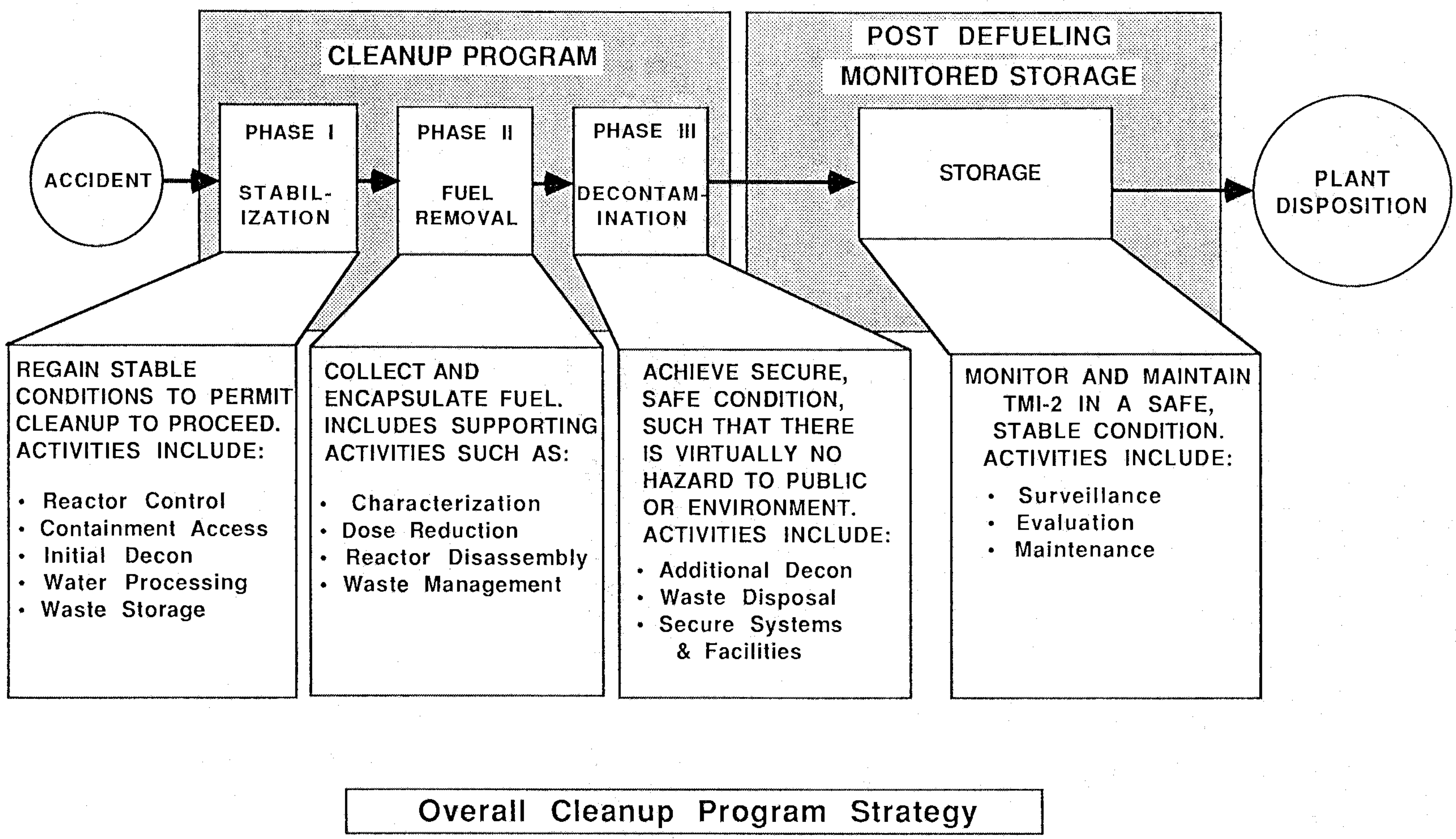


Figure 2-5. Overall Cleanup Project Strategy

agreement that recognized the importance of recovery from the accident to the entire nuclear power industry and the Nation. The agreement recognized that the work was specialized and highly demanding, requiring large-scale capital outlays, and exacting measures to protect public and worker health and safety. The unions also recognized that the company's existence was at risk because of its fragile financial health.

Consequently, the unions and management agreed to a cooperative relationship. This included a mutual ban on any form of work stoppage or lockout, and a high standard of radiological safety practices (Arnold and Georgine 1980). As a result of this agreement, labor problems were resolved by arbitration—technical progress was not affected by either labor grievances or the necessity of planning for them.

2.4.2 *Cost and Schedule*

Estimating the cost of the cleanup while it was in progress was as elusive as pinning down its technical scope. The cost estimates varied in direct relationship with the uncertainty and novelty surrounding the work. They were plagued by a lack of data and uncertainty in the regulatory environment within which the cleanup activities were to take place (Comptroller General 1981). The scope of work for each estimate varied much more than the dollar figures as project management learned the condition of the plant, conducted work, and defined a reasonable stopping point. Many estimates were made, and the following discussion shows only the general course of that process.

The American Nuclear Insurers had estimated $140 million of damaged insured property in April 1979. Another preliminary estimate in July 1979 reckoned that the plant could be returned to power in four years for approximately $430 million. As the real scale of the undertaking was revealed, a series of formal program estimates was made (GPUN 1985). In August 1980, after one containment entry, $855 million was the estimated total cost. The projected work scope envisioned defueling complete in March 1983, and then cleanup through reconstruction to pre-accident conditions, refueling, testing, and commercial operation, which was to have begun in late 1985.

An estimate in August 1981—for $1034 million—stressed the need for significantly more data and did not include the costs of restart. The cleanup experience of the past year was reflected in the increased estimate, as was the temporarily reduced level of effort resulting from the

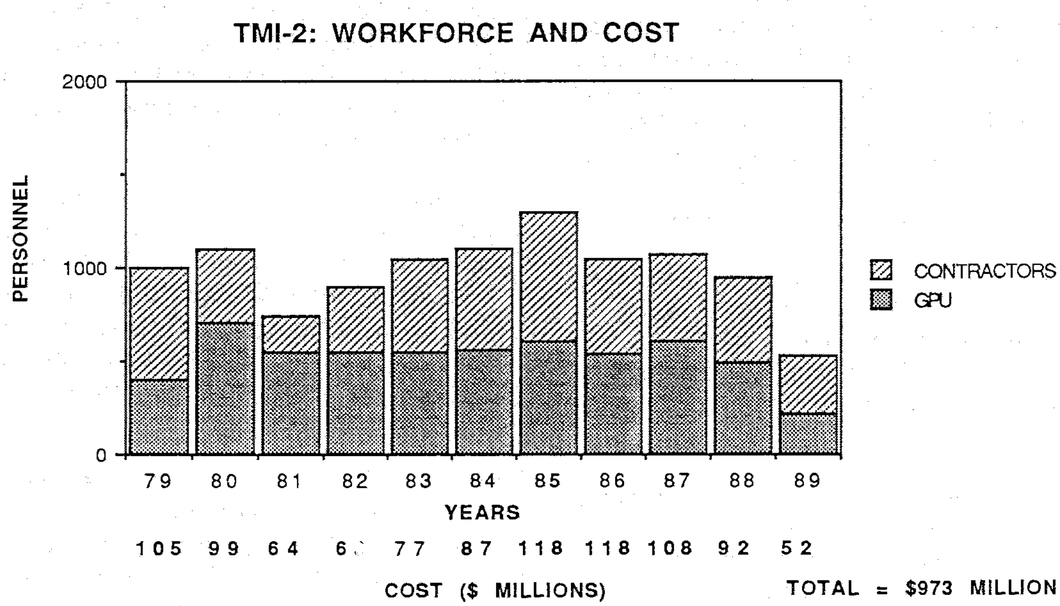


Figure 2-6. TMI-2: Workforce and Costs

Figure 2-7 shows the funding sources for the cleanup.

In addition to the funding shown in the figure, considerable research funding was committed that could not be considered as being of direct benefit to the cleanup (e.g., laboratory work). EPRI provided approximately $11 million in funds to the cleanup and to technology transfer activities. (This does not include the R&D funds spent by the Source Term Program or in-house costs such as NSAC work.)

2.5 Other Administrative Issues

Several other issues are worthy of discussion because of their unique roles in the postaccident situation.

2.5.1 Emergency Materials Management

Ensuring a steady flow of equipment and supplies was, of course, an intrinsic part of the cleanup. The initial effort at mobilizing procurement to support the cleanup was outstanding and contributed greatly to the early successes. The day of the accident, the plant purchasing staff reverted to an "Emergency Procurement Mode" that had previously been used during outages and weather-related emergencies. A temporary warehouse was set up at the Crawford Station plant, about five miles from TMI. This operation was staffed 24 hours a day to handle requests for supplies, equipment, and services, and to act as a marshalling area to receive material and equipment.

The day after the accident a Materials Management Task Force was also established. The task force combined the existing personnel at the Crawford Warehouse with TMI contract administration and added a home office team consisting of buyers, contract personnel, and transportation personnel. An interface with corporate procurement was also established. The task force pursued water storage and processing equipment and services, boration and decontamination equipment, and facilities for support personnel; e.g., setting up "Trailer City" at the observation center, about one-half mile from the plant. Several days later, Burns & Roe purchasing personnel were sent to Crawford to coordinate receipt of material specified by Burns & Roe and to otherwise assist as needed.

Within a week, project management realized that this arrangement was insufficient for the situation and the role was essentially turned over to GPU Service Corp., which had been responsible for construction of the plant and had until recently been responsible for purchases. The procurement organization processed over 1,000 purchase orders within approximately 40 days.

A few highlights of this initial effort:

- A diesel generator was delivered to the site in two days, with the cooperation of four railroad companies who flagged the shipment as an emergency.
- A large-system HEPA and charcoal filters were provided for use on the roof of the auxiliary building. These were transported from a western utility by the U.S. Air Force in six C141s and one C5A.

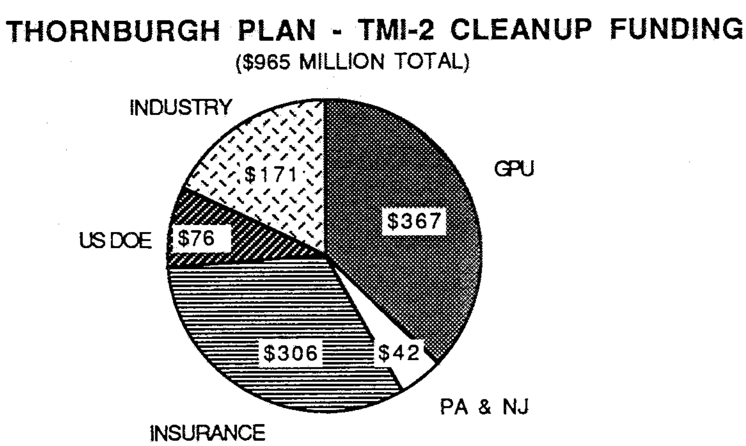


Figure 2-7. Thornburgh Plan — TMI-2 Cleanup Funding

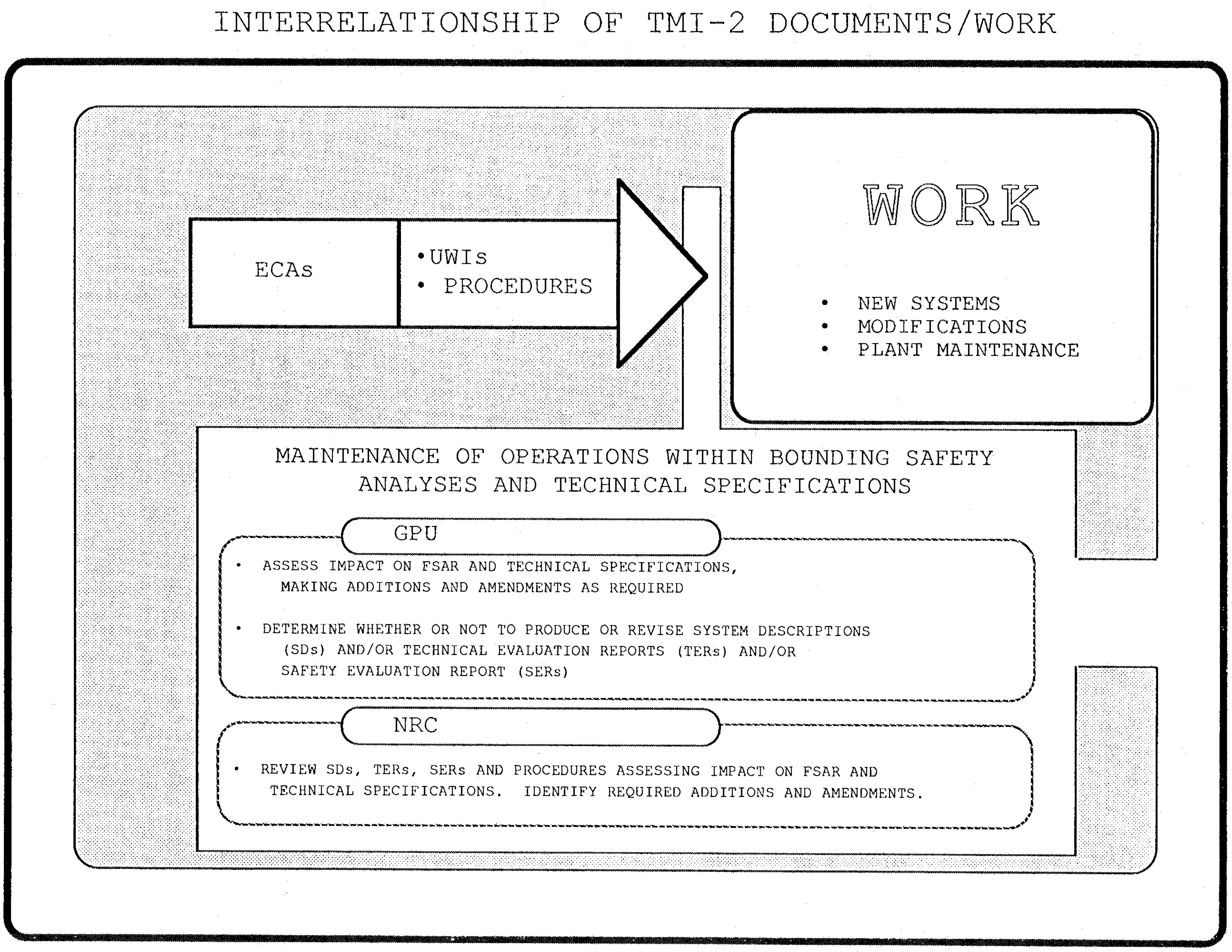


Figure 2-8. Interrelationship of TMI-2 Documents/Work

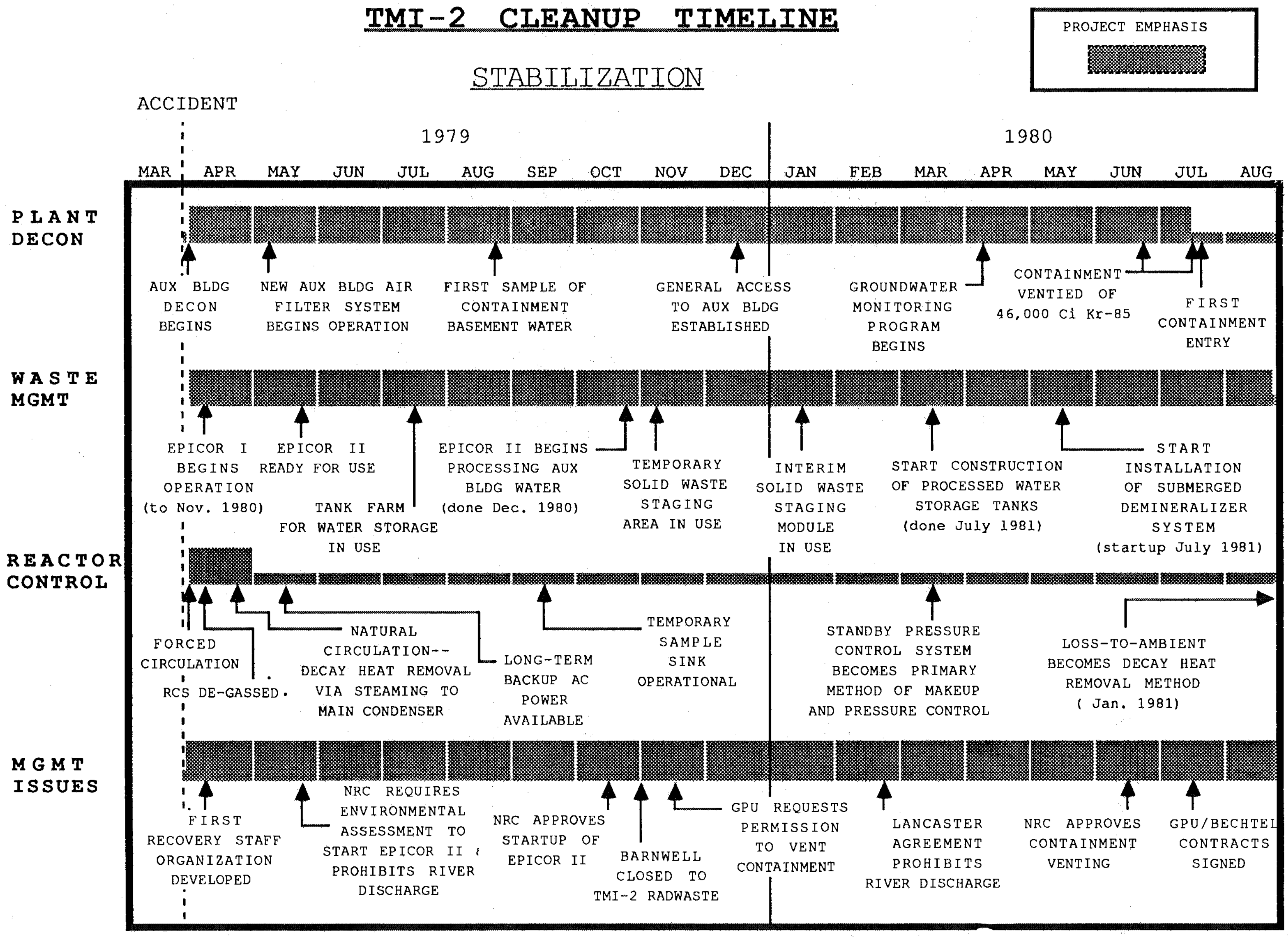


Figure 3-1. TMI-2 Cleanup Timeline — Stabilization

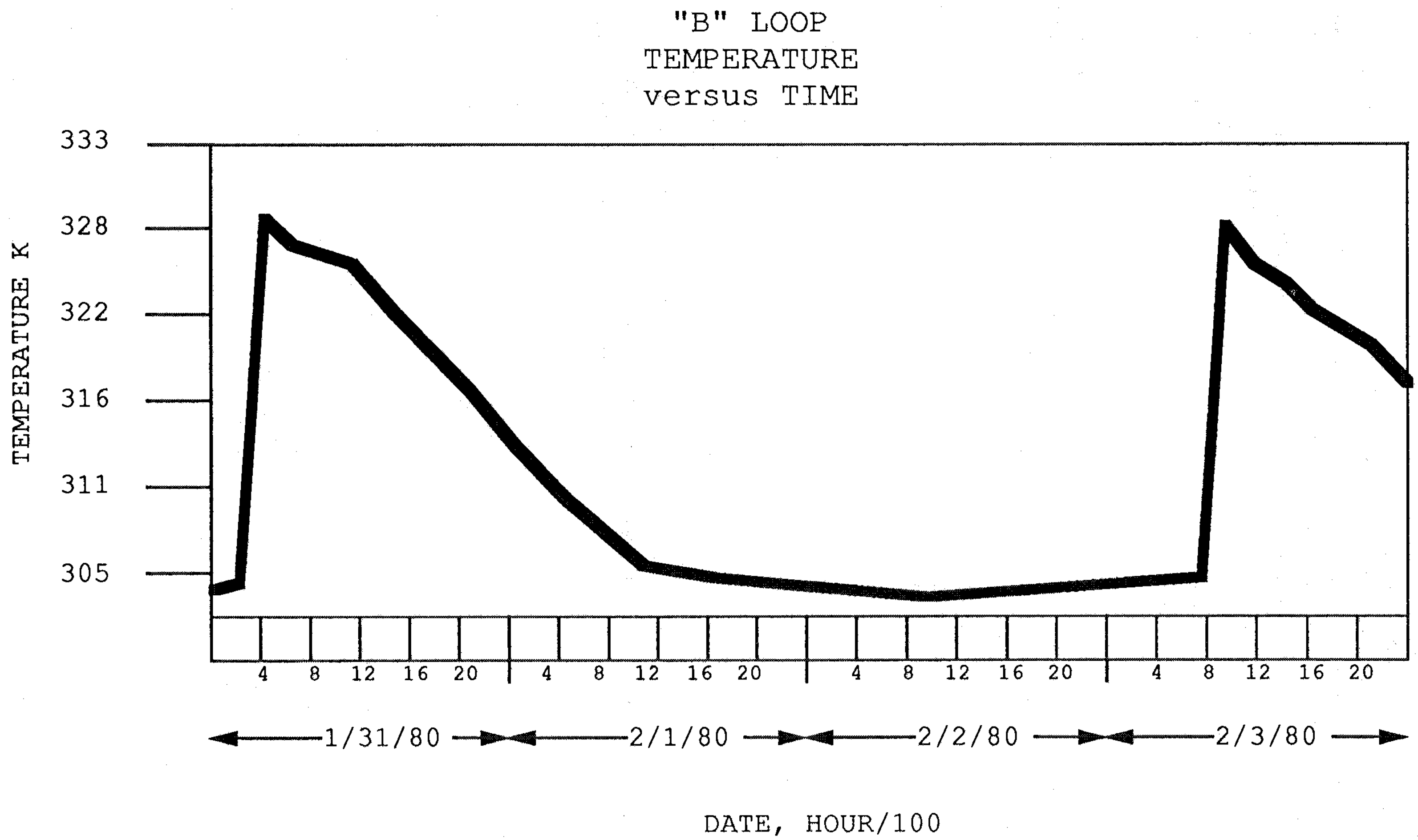


Figure 3-2. "B" Loop Temperature versus Time

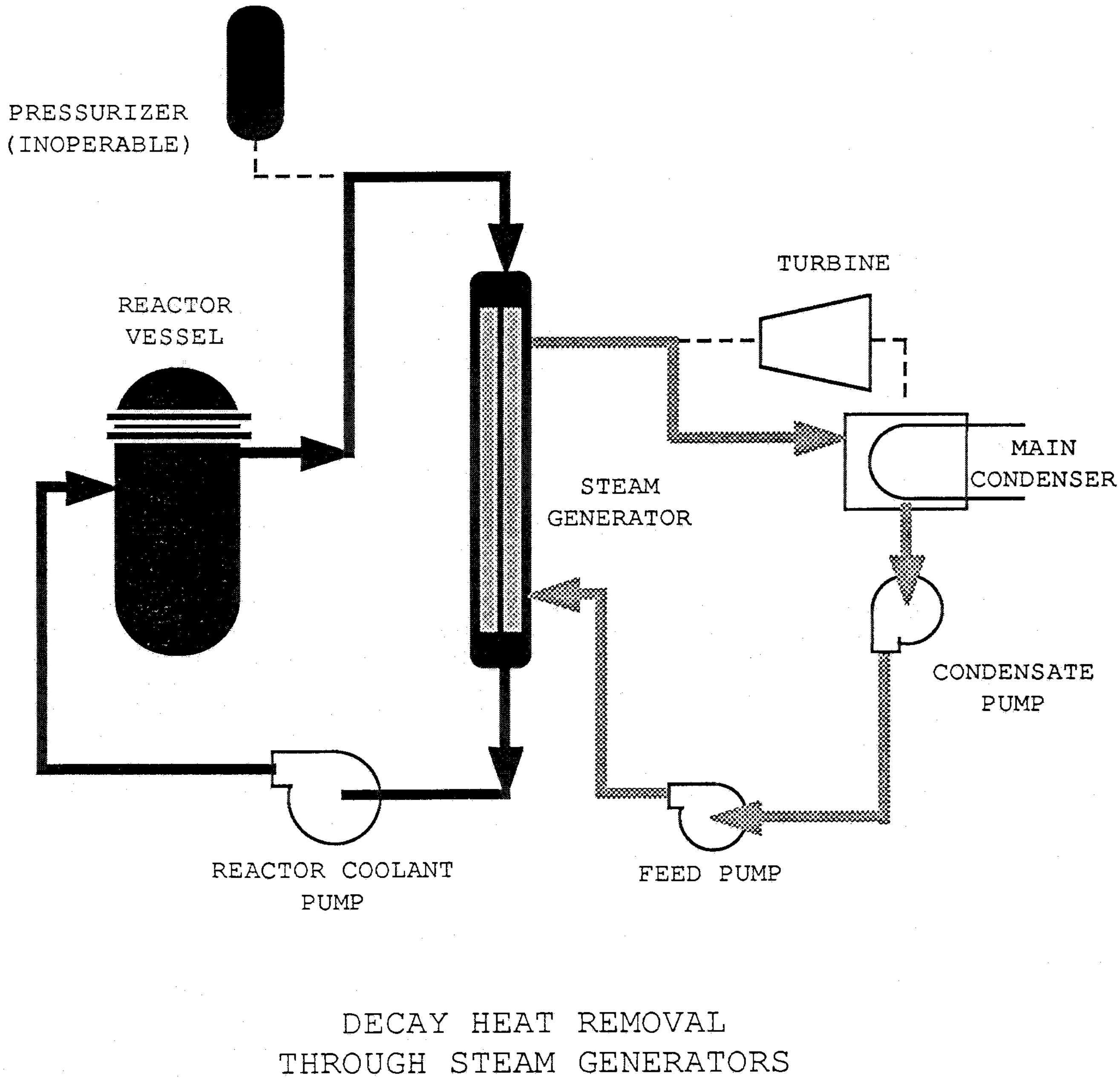


Figure 3-3. Decay Heat Removal through Steam Generators

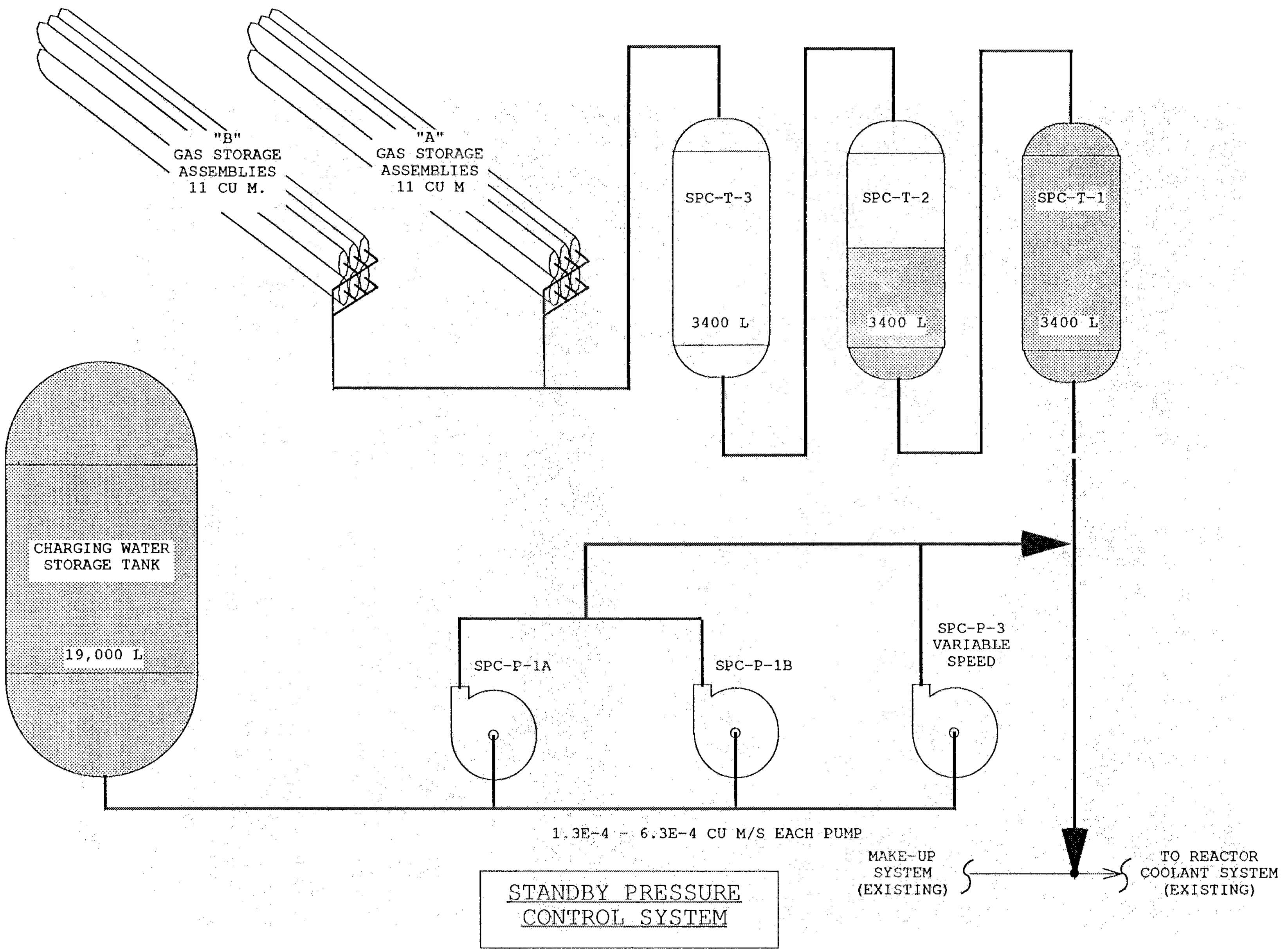


Figure 3-4. Standby Pressure Control System

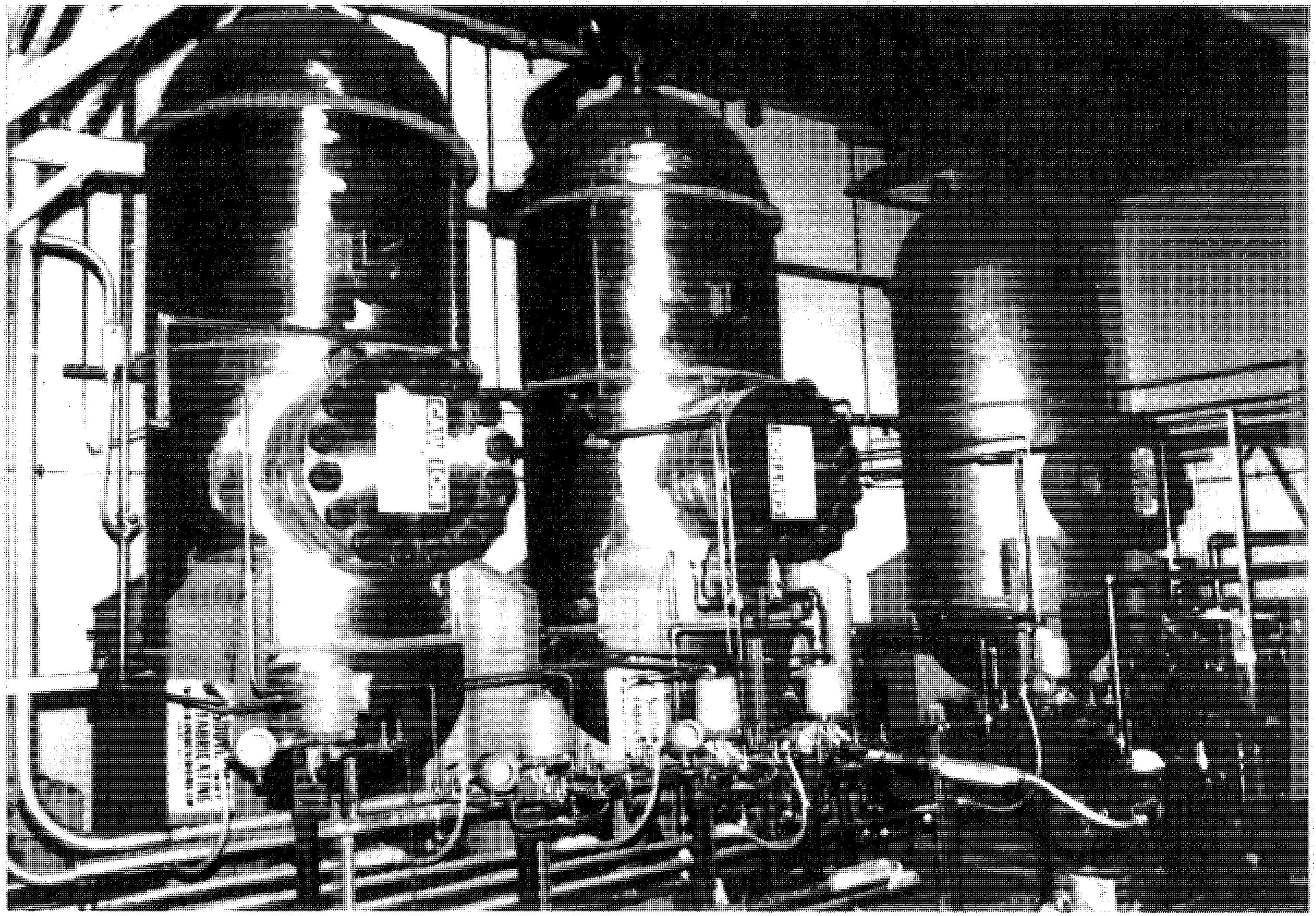


Photo 3-1. SPCS Pressure Control Vessels

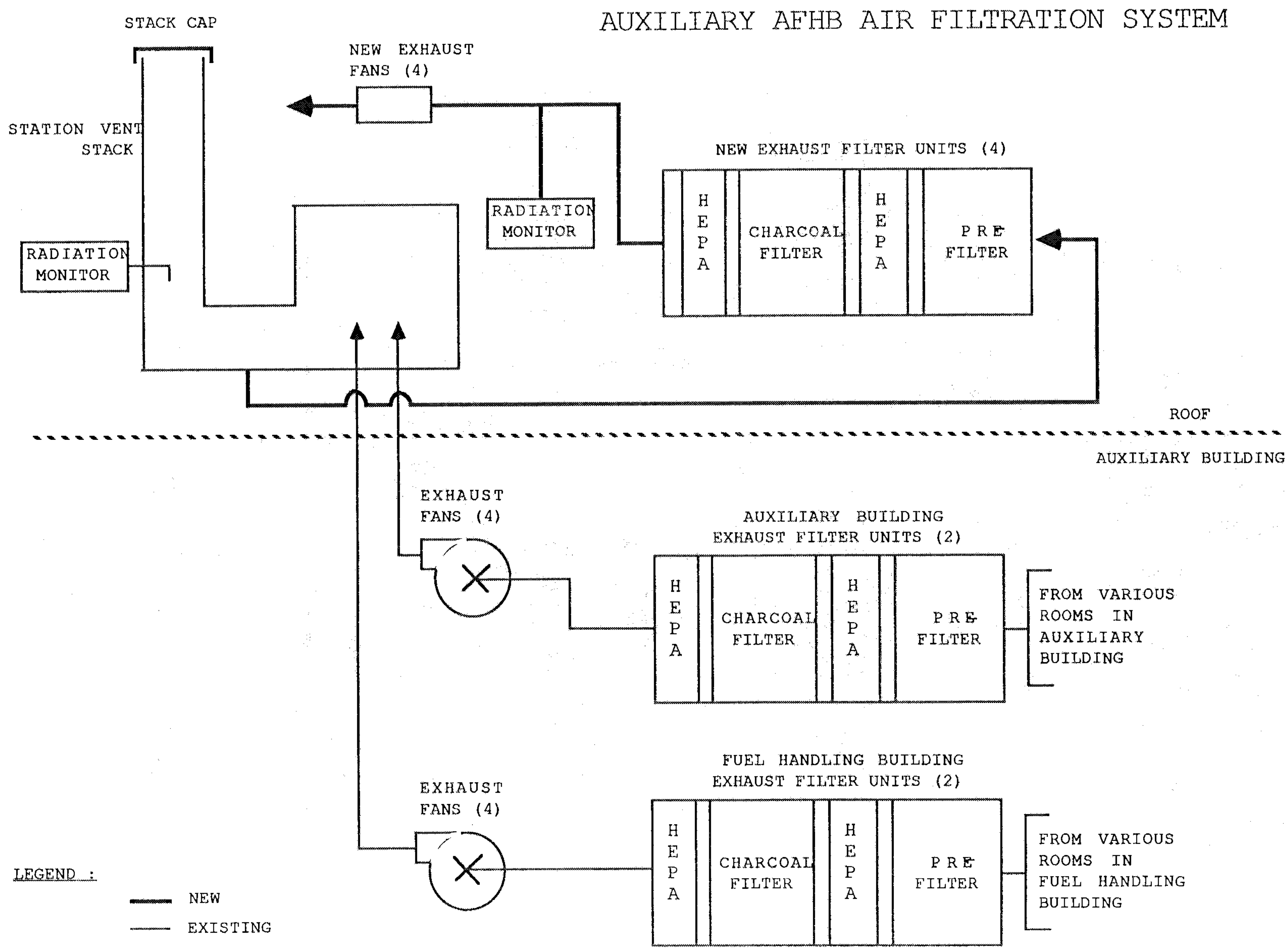


Figure 3-5. Auxiliary AFHB Air Filtration System

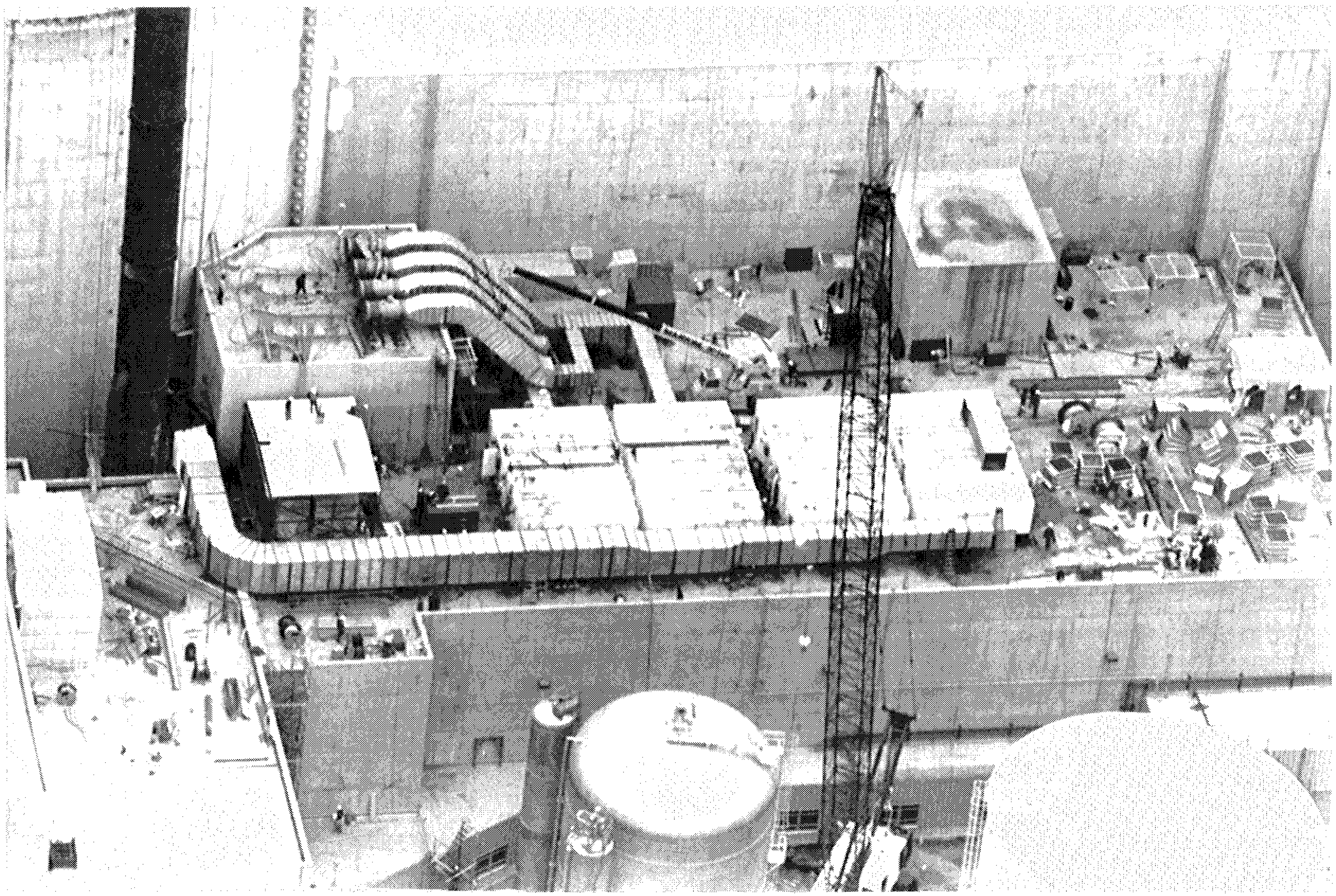


Photo 3-2. Installation of the Auxiliary AFHB Air Filtration System

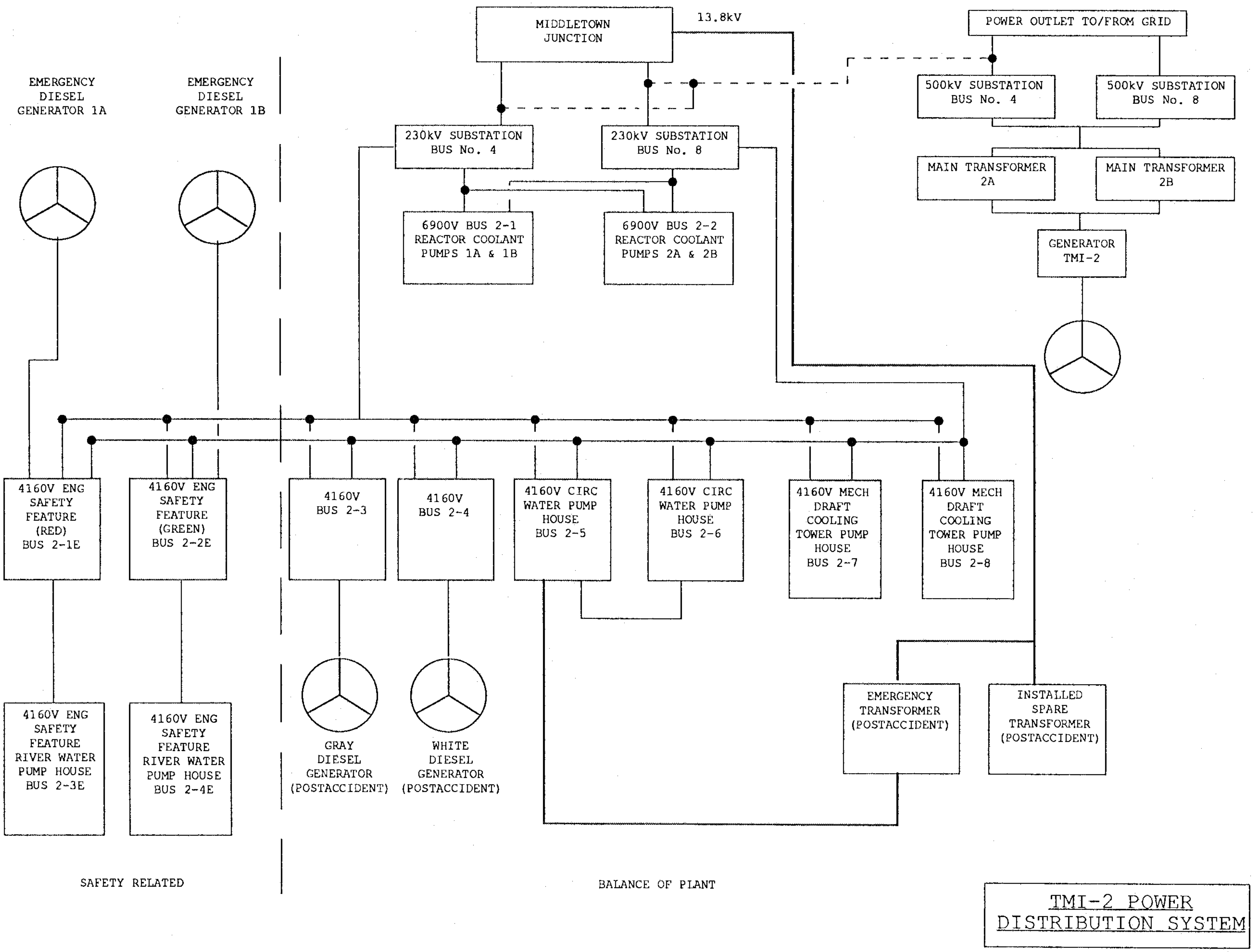


Figure 3-6. TMI-2 Power Distribution System

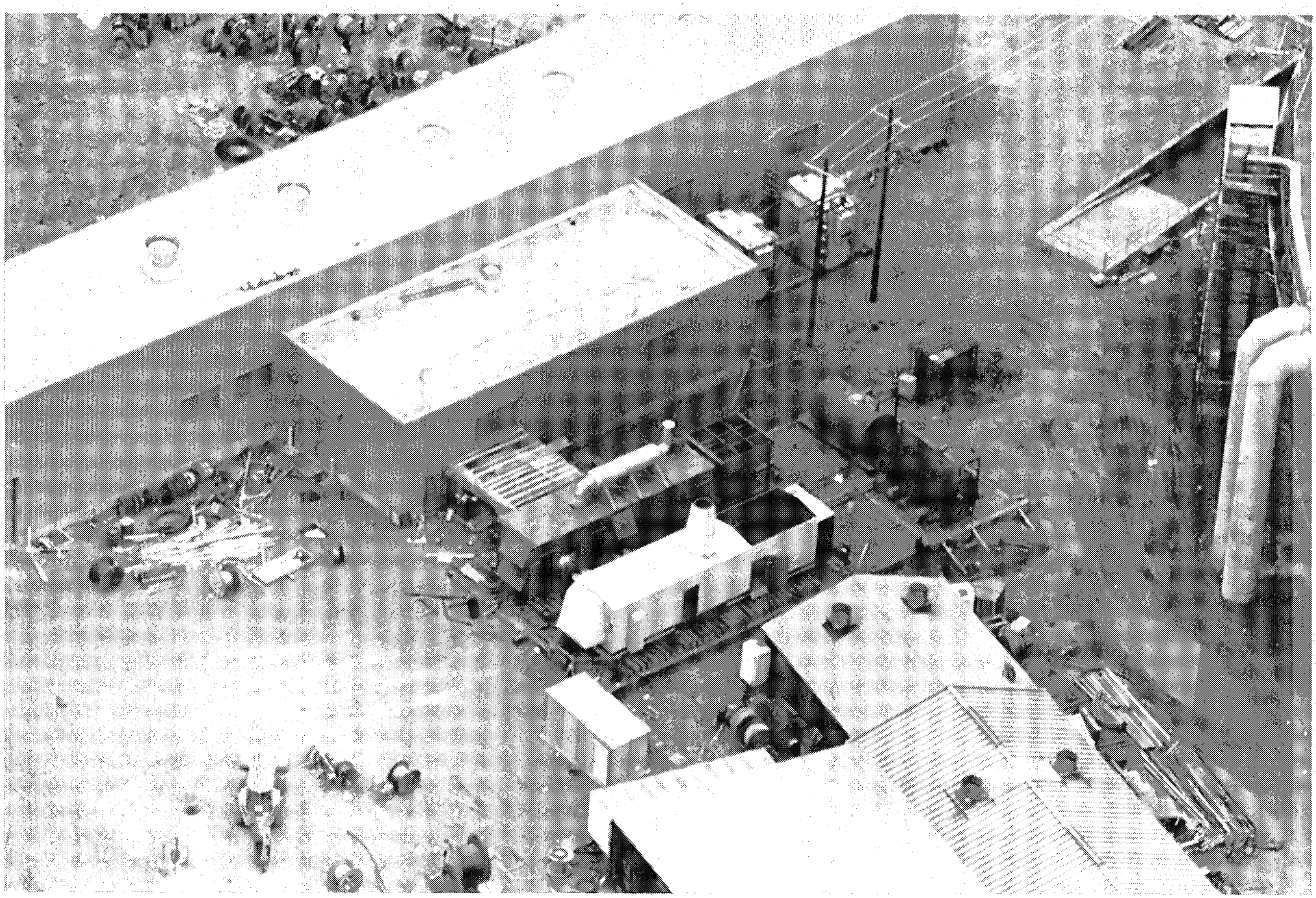


Photo 3-3. Gray and White Backup Diesels

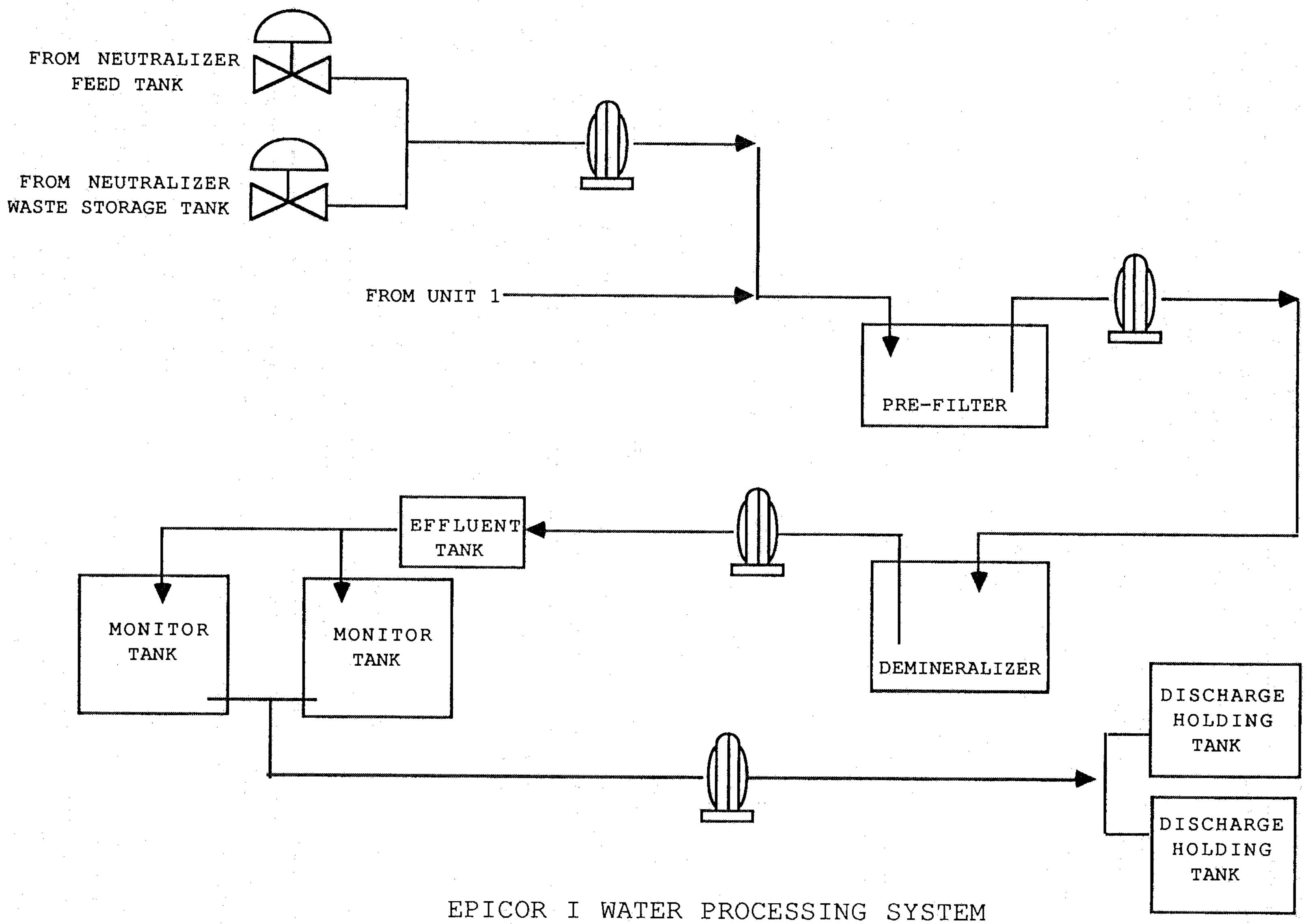


Figure 3-7. EPICOR I Water Processing System

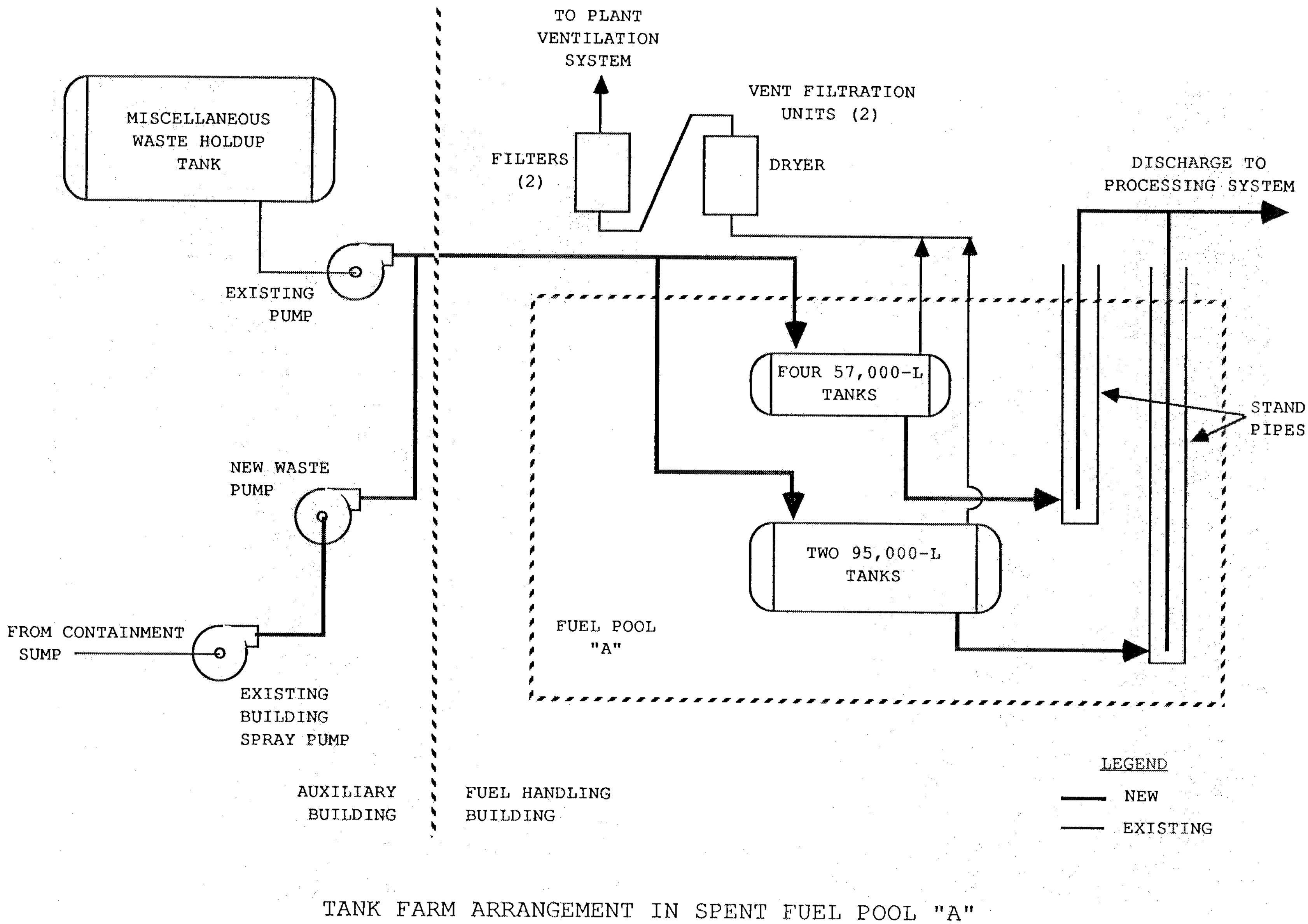


Figure 3-8. Tank Farm Arrangement in Spent Fuel Pool "A"

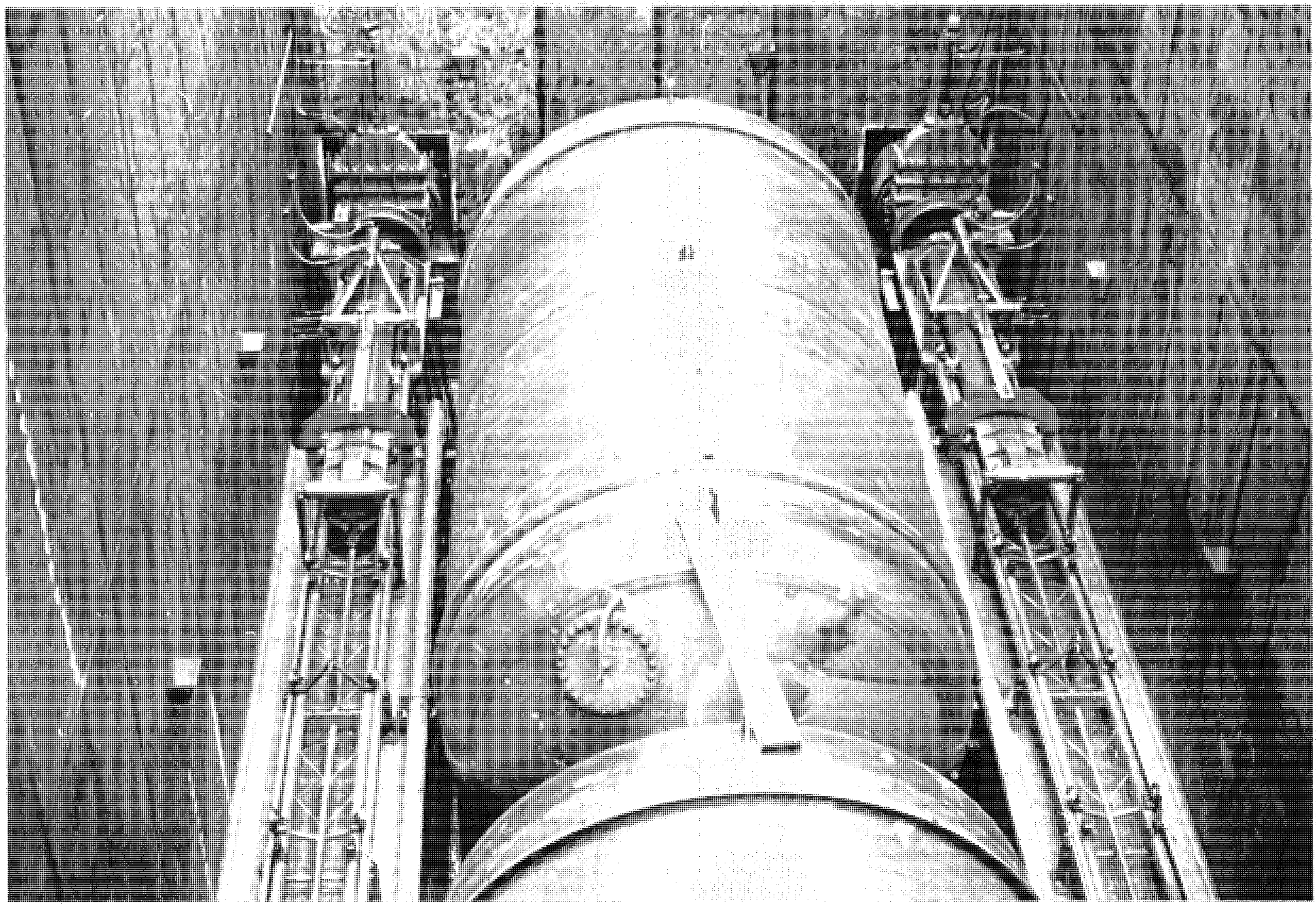


Photo 3-4. Tank Farm in Spent Fuel Pool "A"

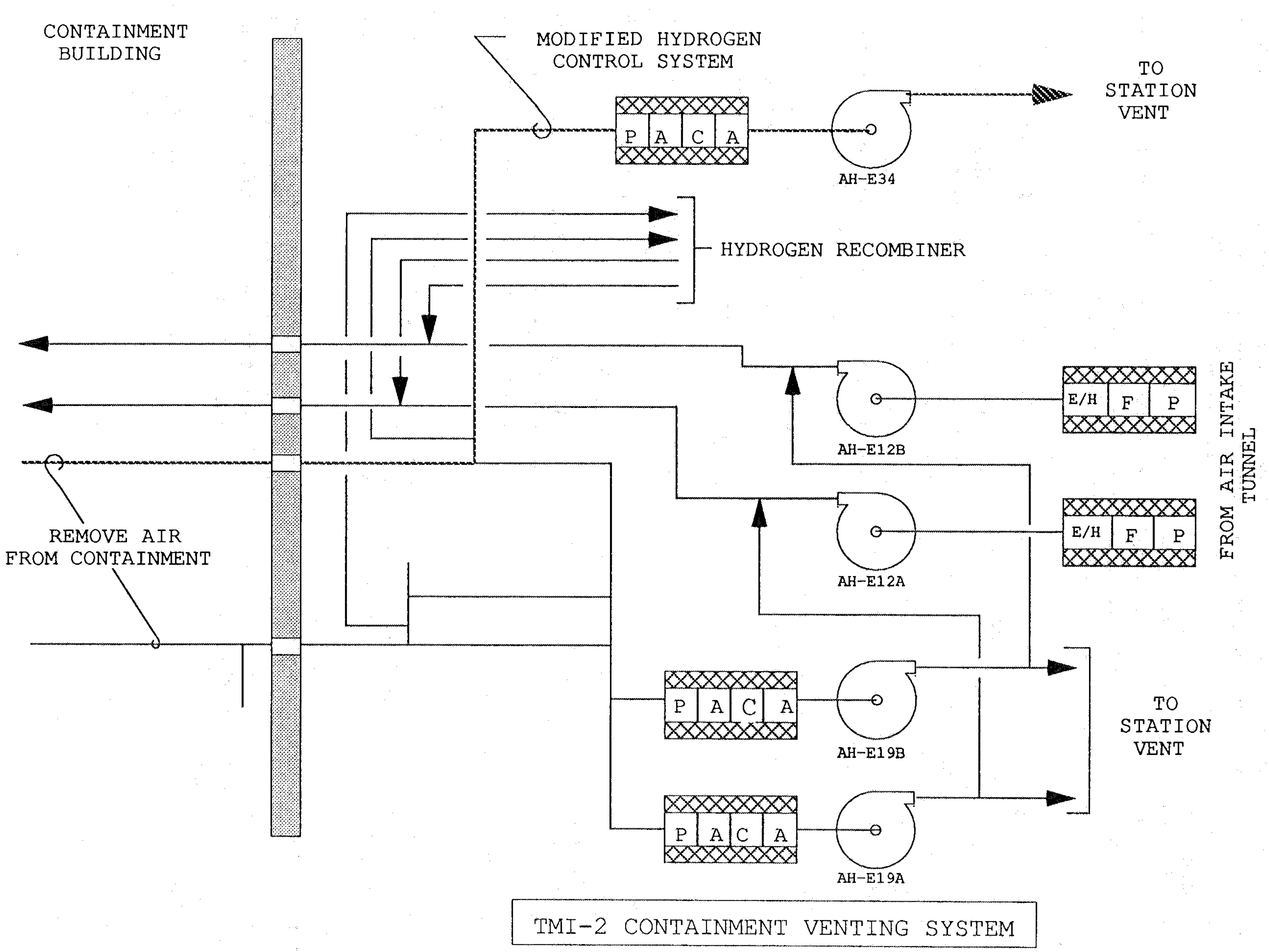


Figure 3-9. TMI-2 Containment Venting System

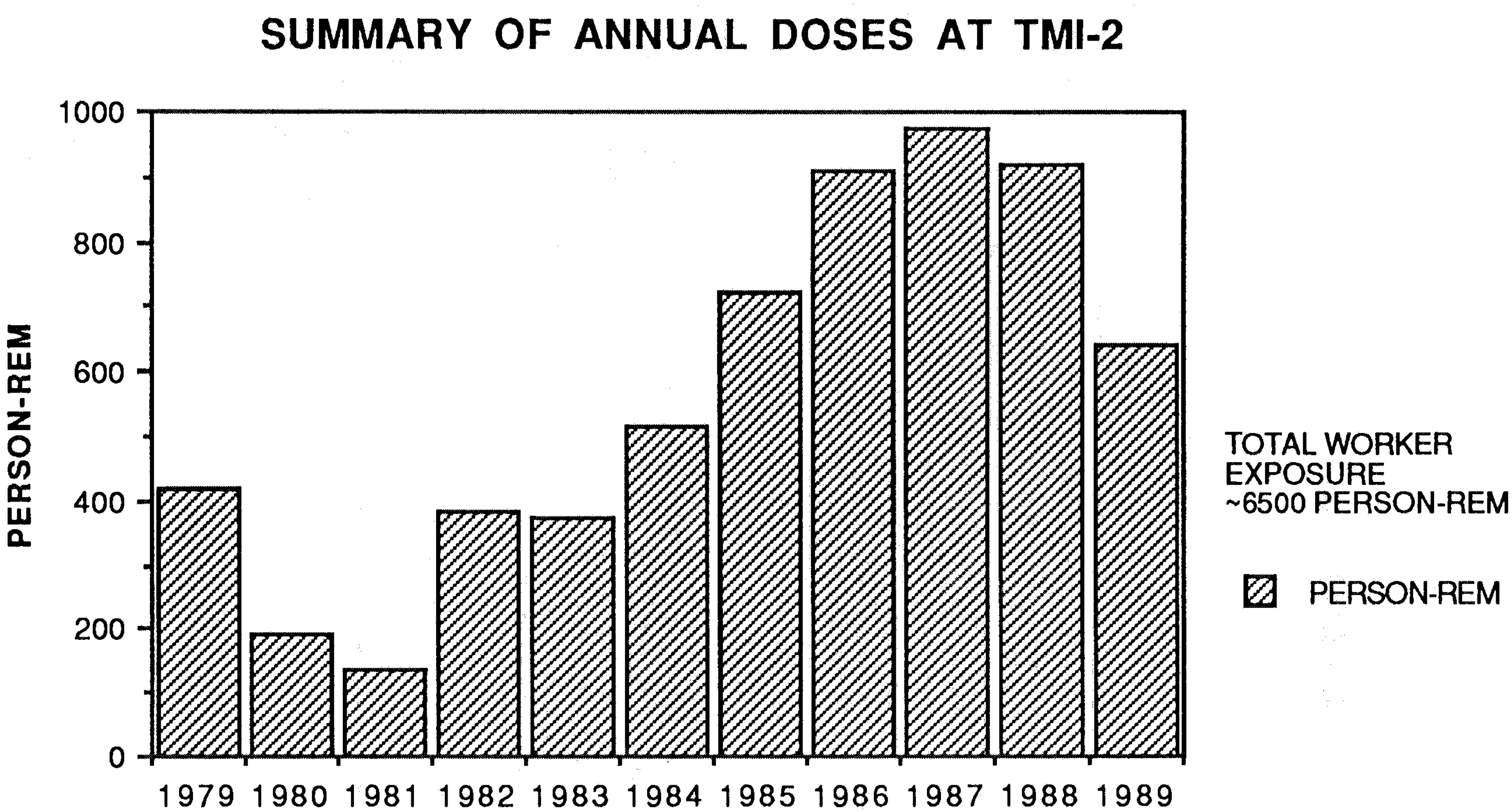


Figure 4-1. Summary of Annual Doses at TMI-2

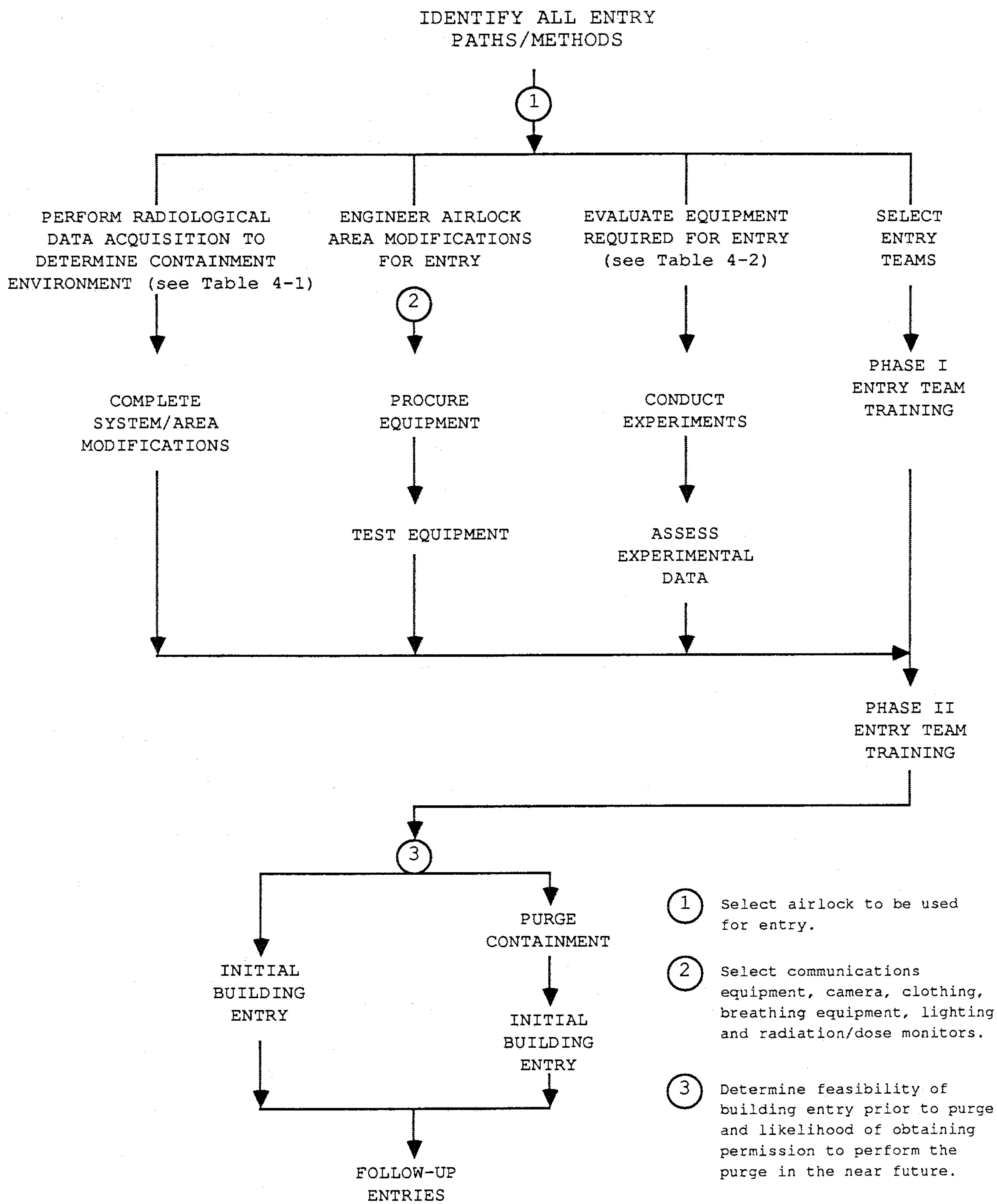


Figure 4-2. Containment Re-entry Strategy

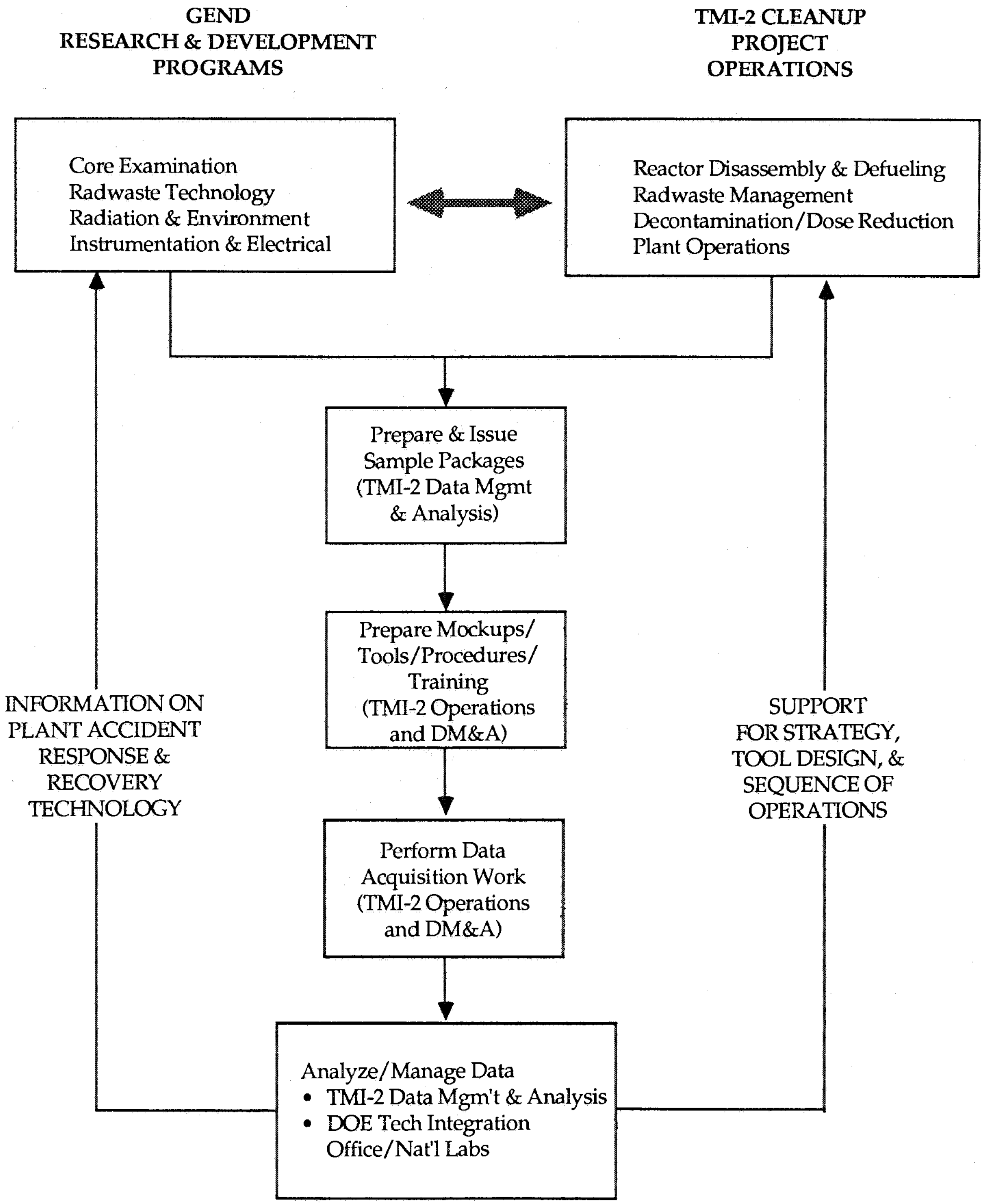


Figure 5-1. Data Requirements/Implementation

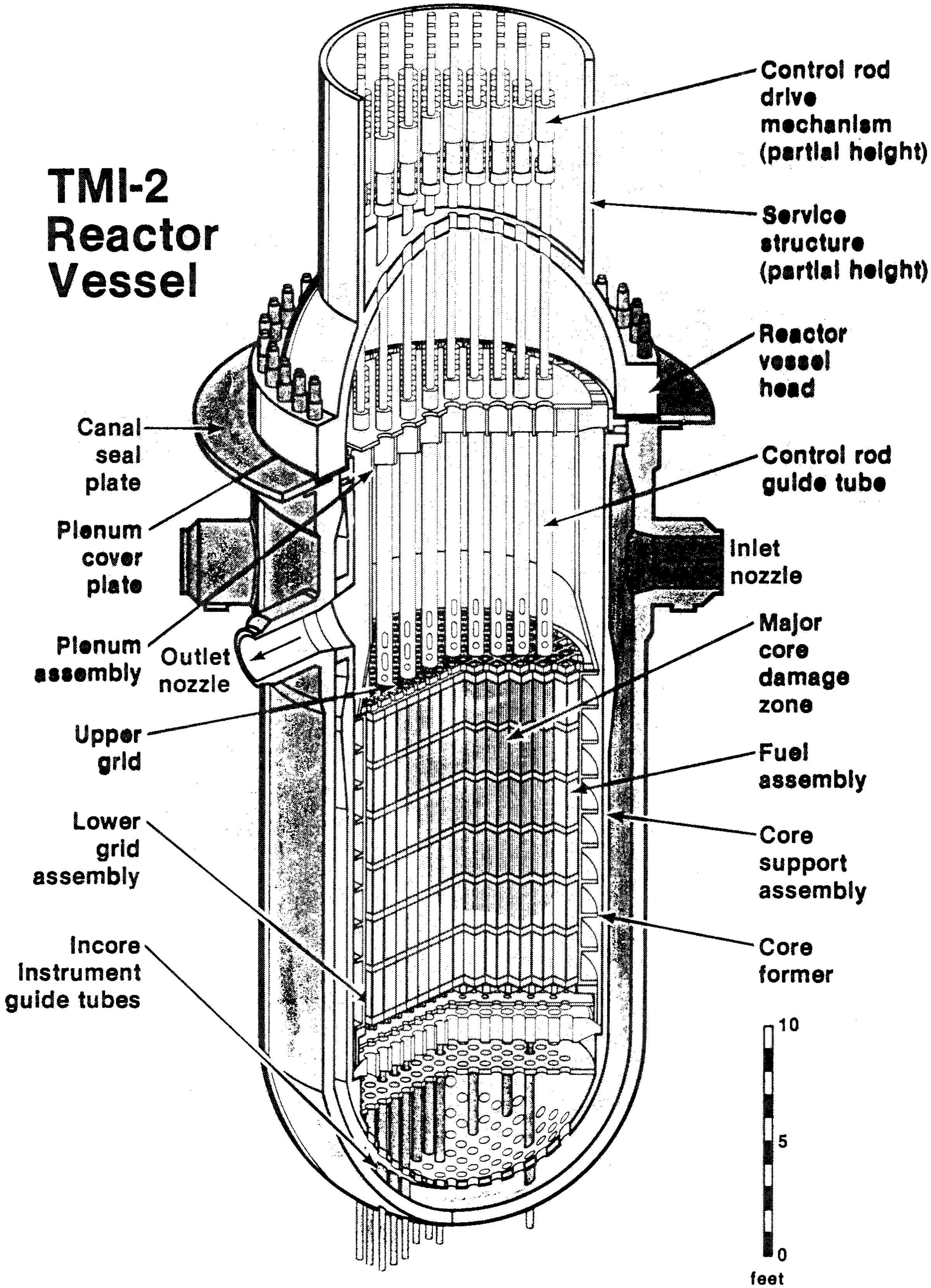


Figure 5-2. Initial Reactor Vessel Damage Projections: 1979–1982

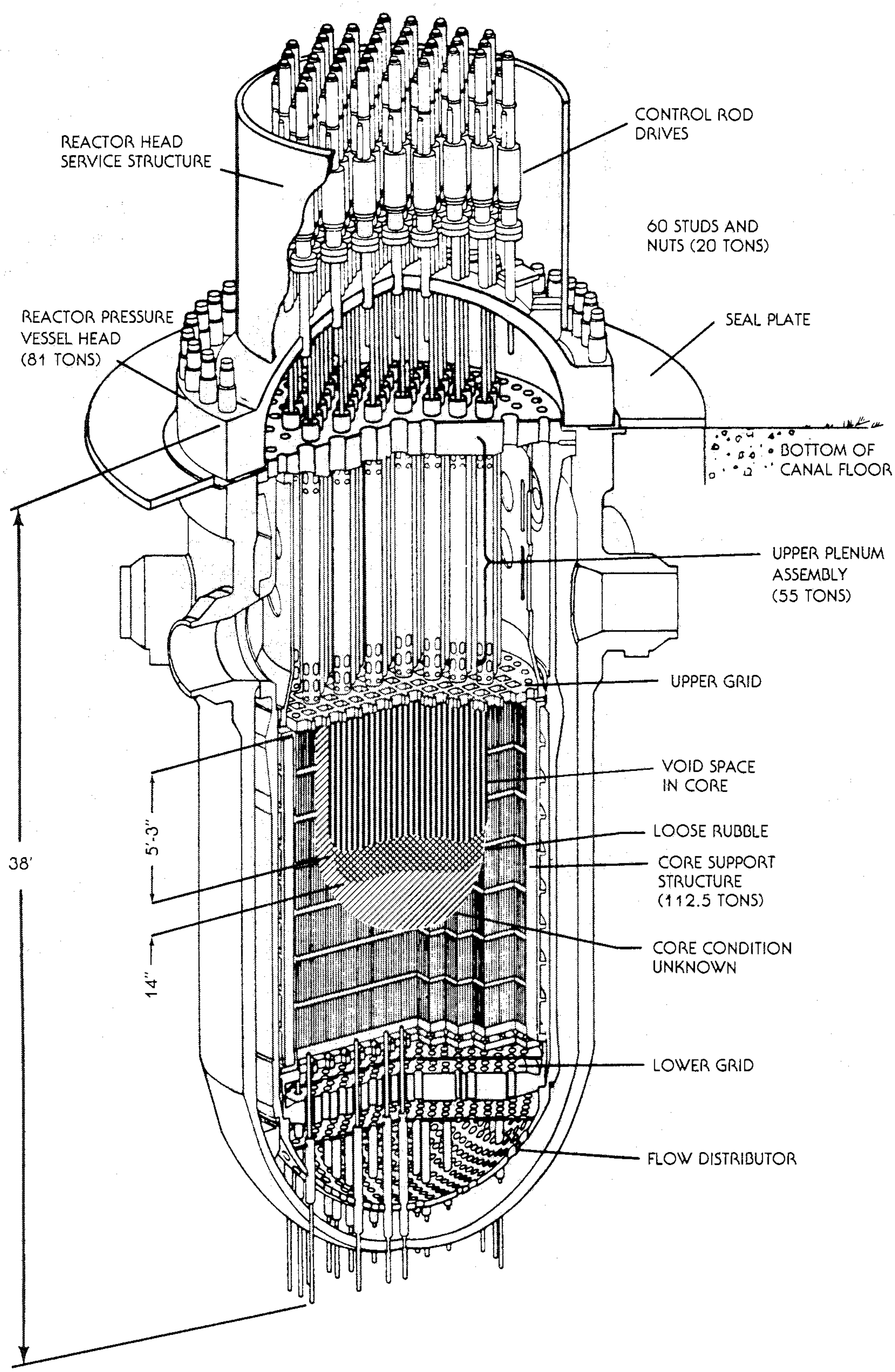


Figure 5-3. Known Post-Quick Look Core Conditions: 1982–1985

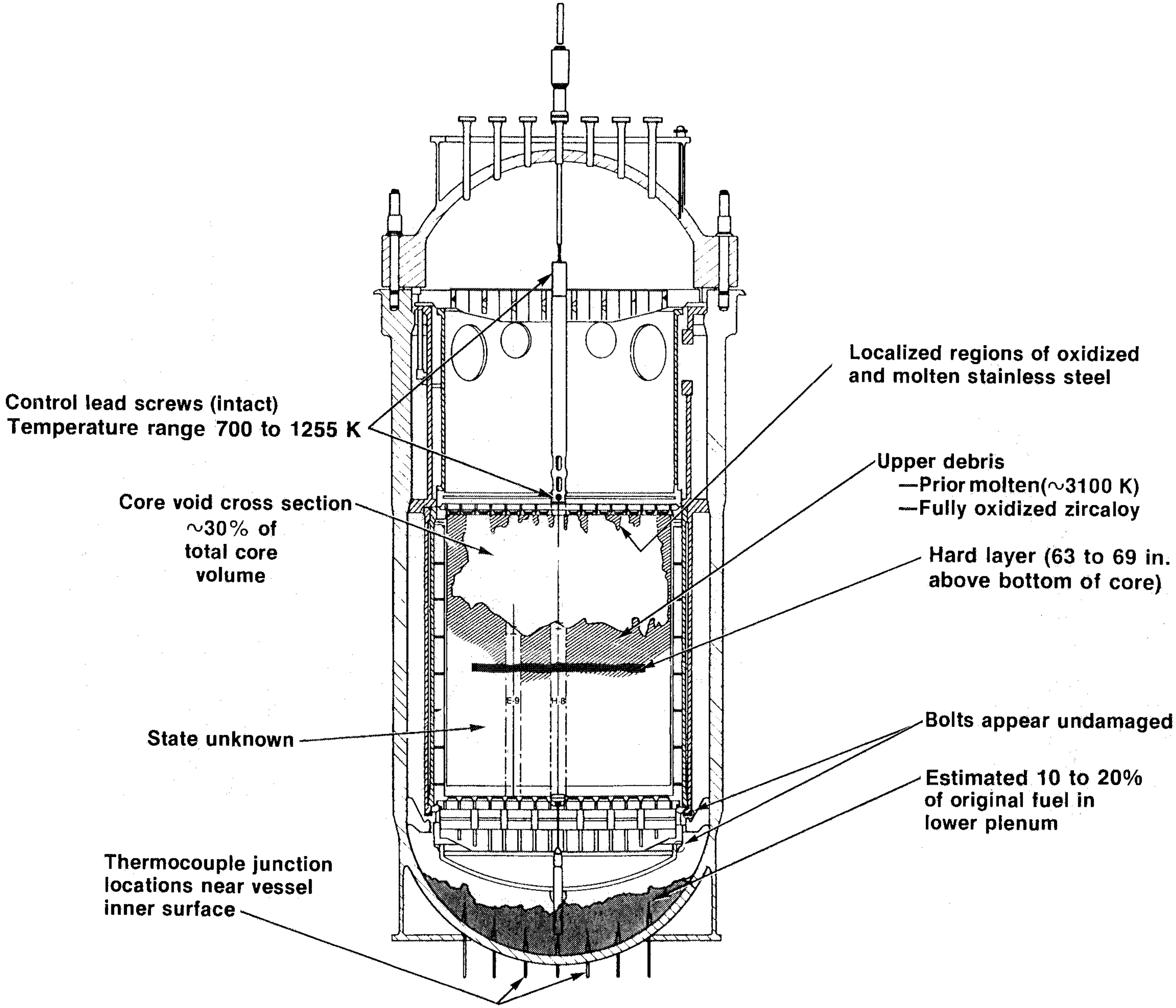


Figure 5-4. Known Core Conditions at the Start of Defueling: 1985–1986

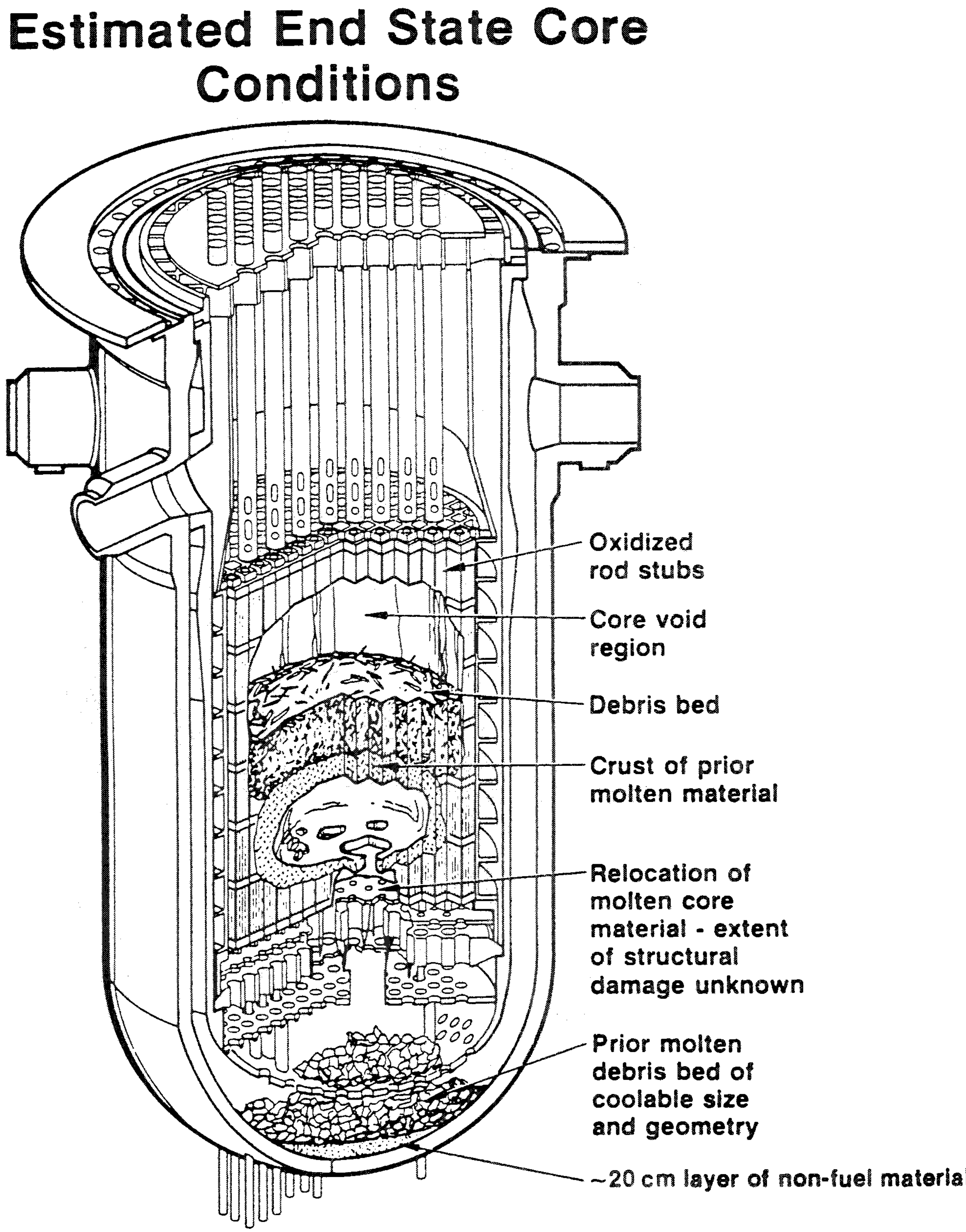


Figure 5-5. Hypothesized End State Conditions before Core Boring: 1986

Hypothesized End-State Condition of the TMI-2 Reactor Core

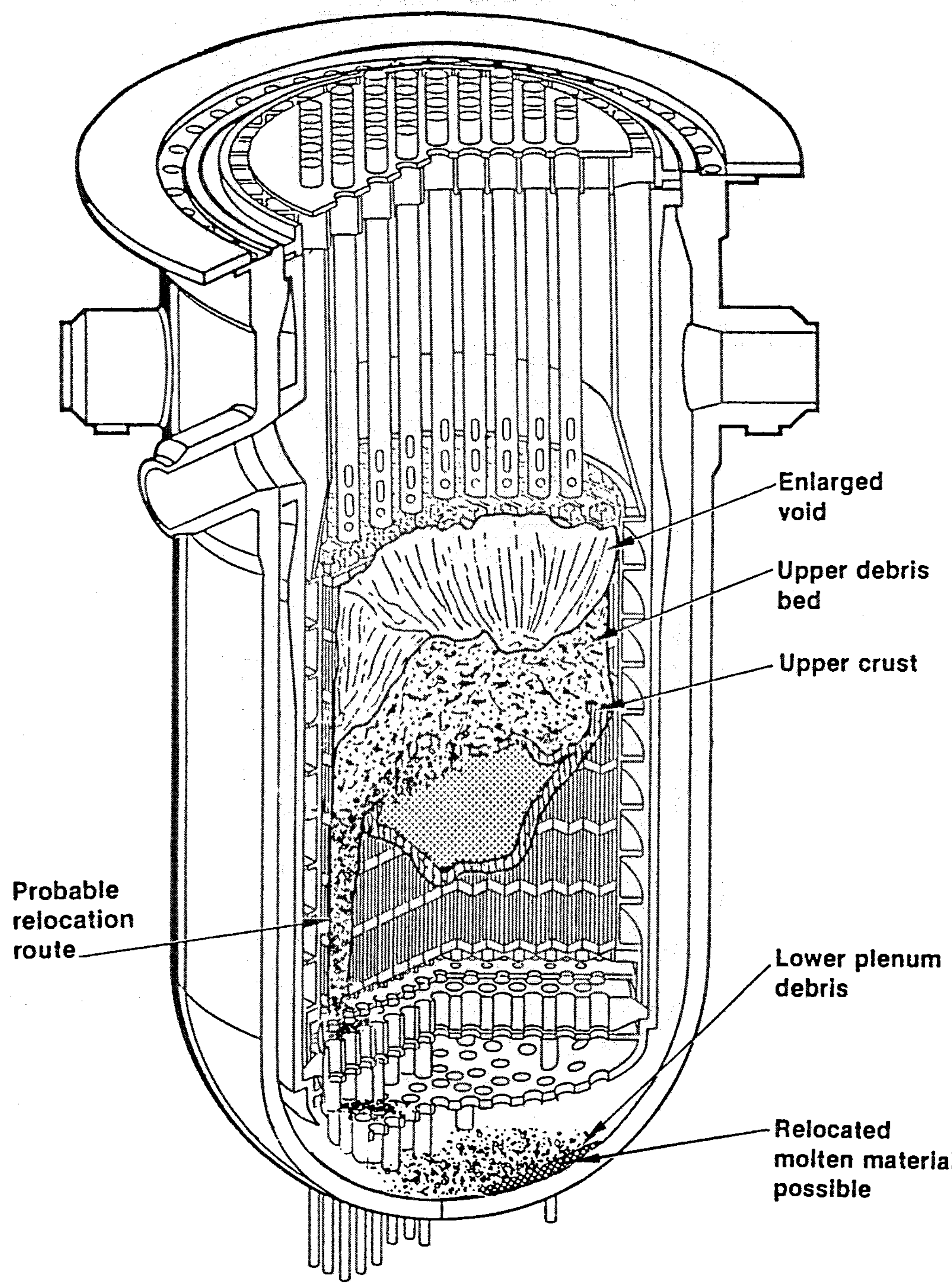


Figure 5-6. Hypothesized End State Conditions after Core Boring: 1986–1987

TMI-2 Core End-State Configuration

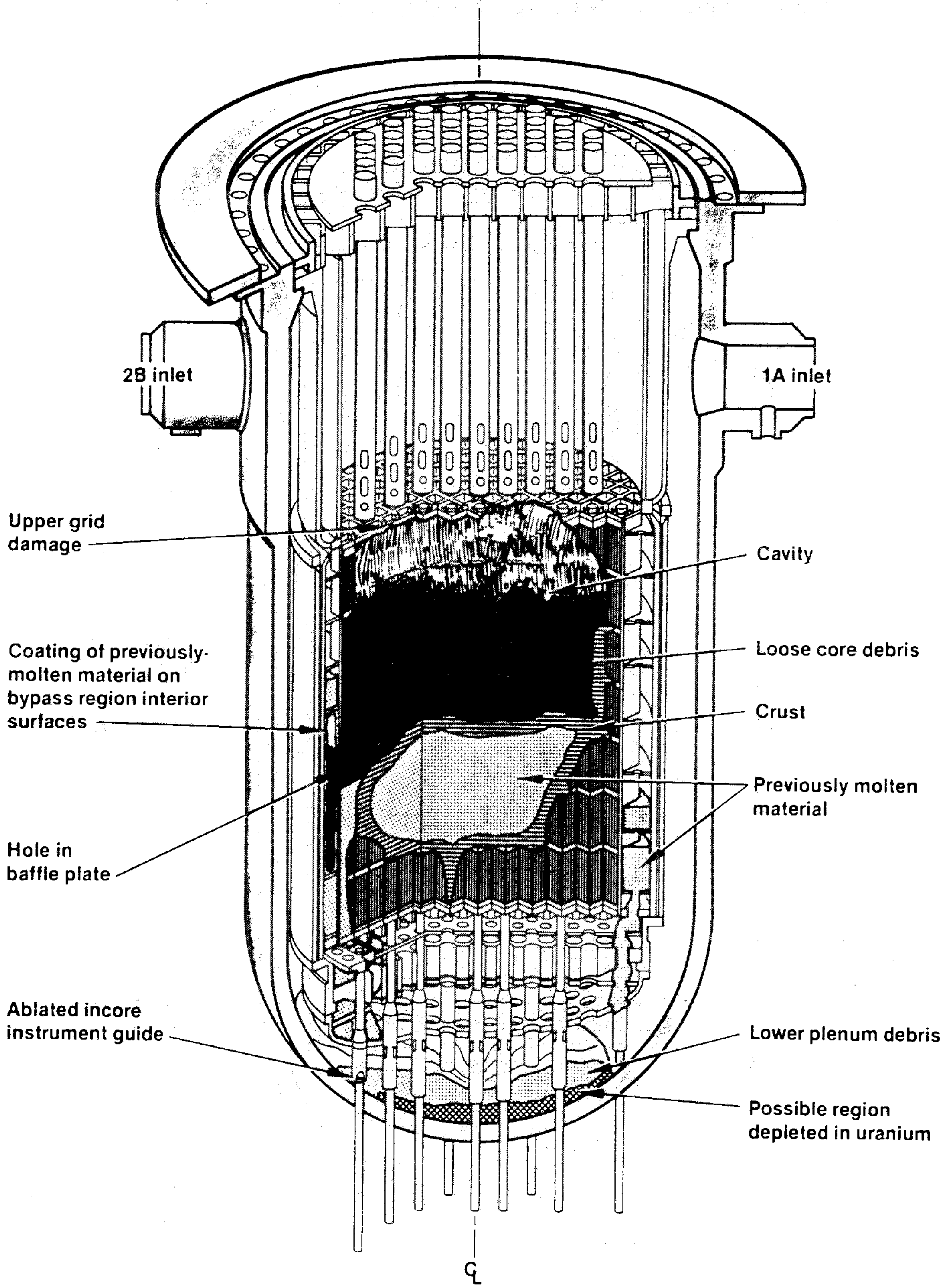


Figure 5-7. Known End State Conditions in the TMI-2 Reactor Vessel: 1987–1990

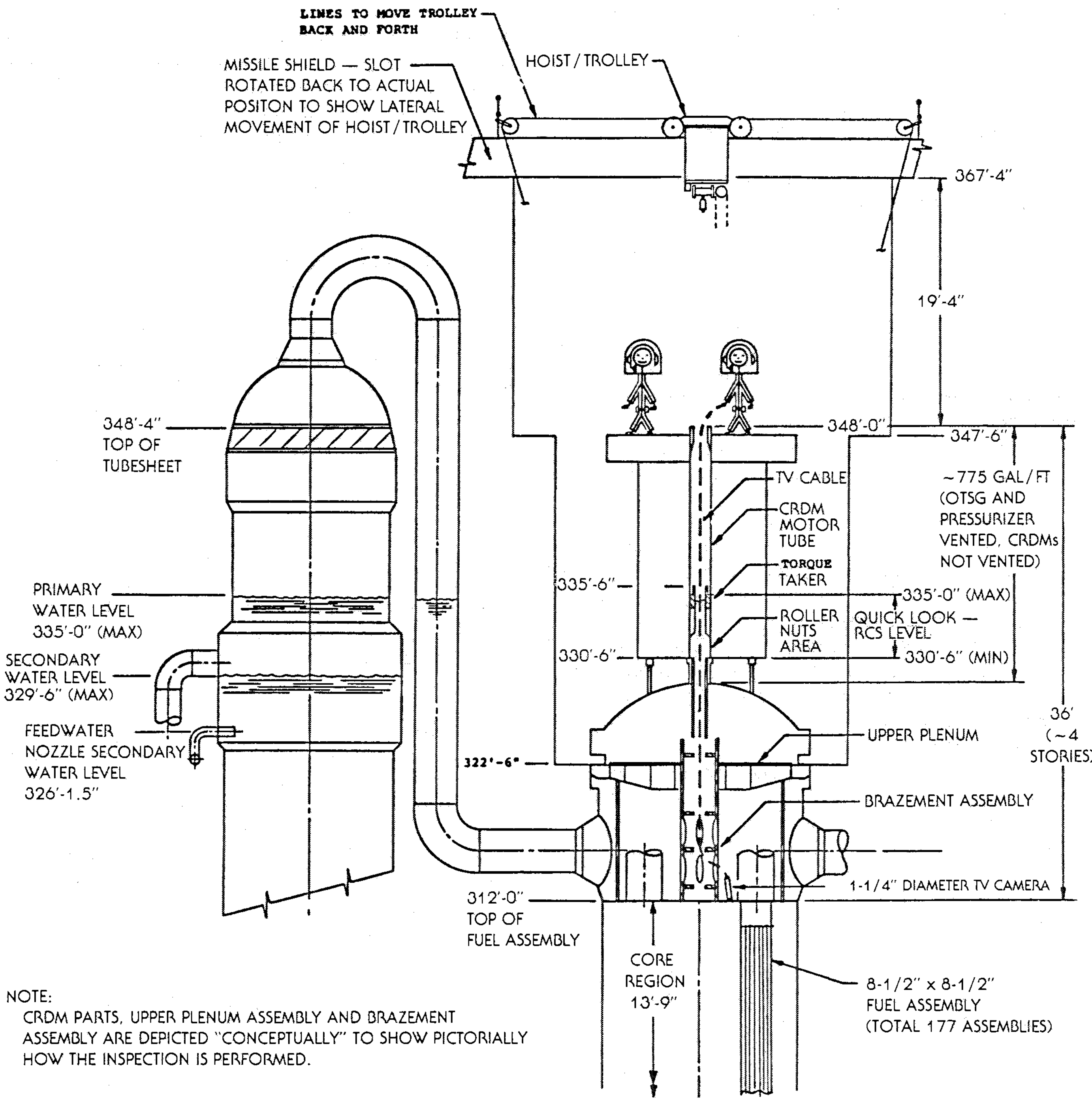


Figure 5-8. Conceptual Arrangement for TV "Quick Look" via Leadscrew Hole

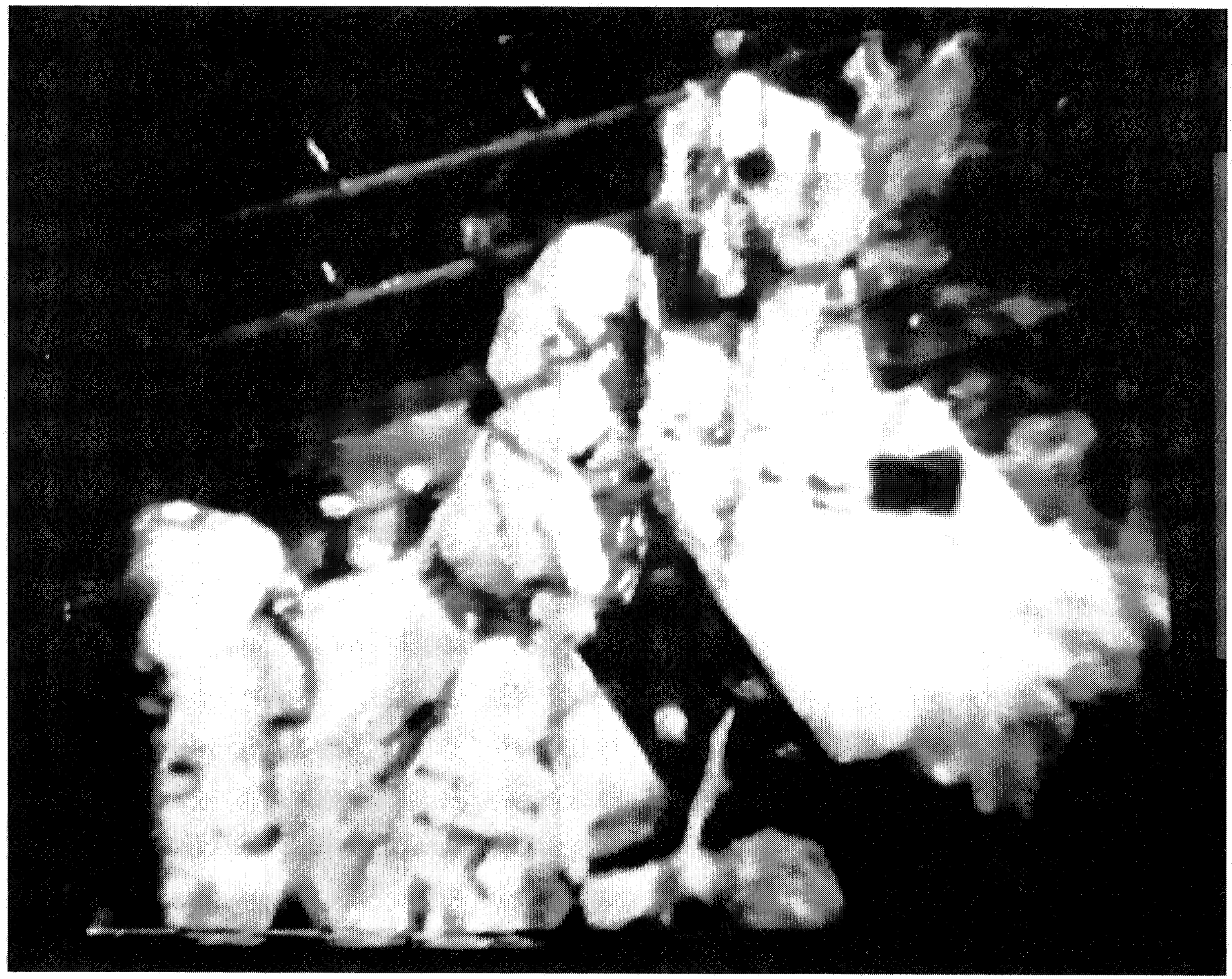


Photo 5-1. Quick Look Team on top of the Reactor Vessel Service Structure

Photo 5-2. View of Debris Bed from Quick Look

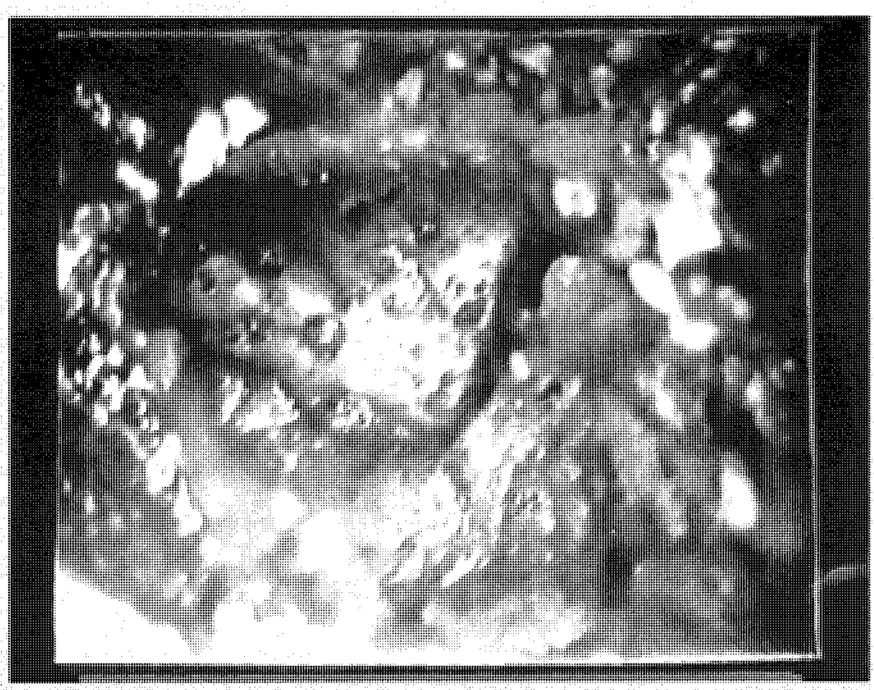


Photo 5-3. View of Debris Bed from Quick Look

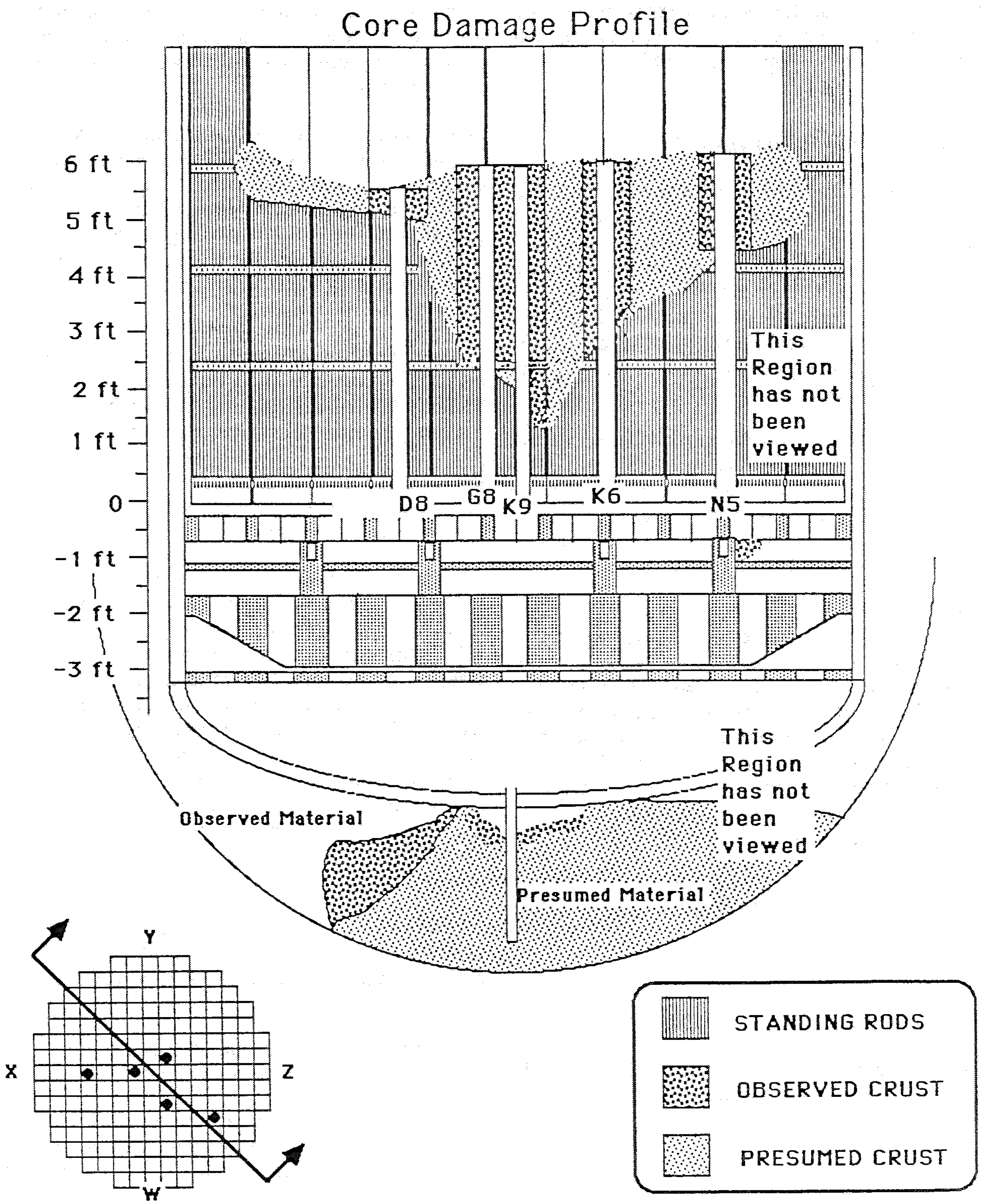


Figure 5-9. Cross-Section of Core with Drill Holes

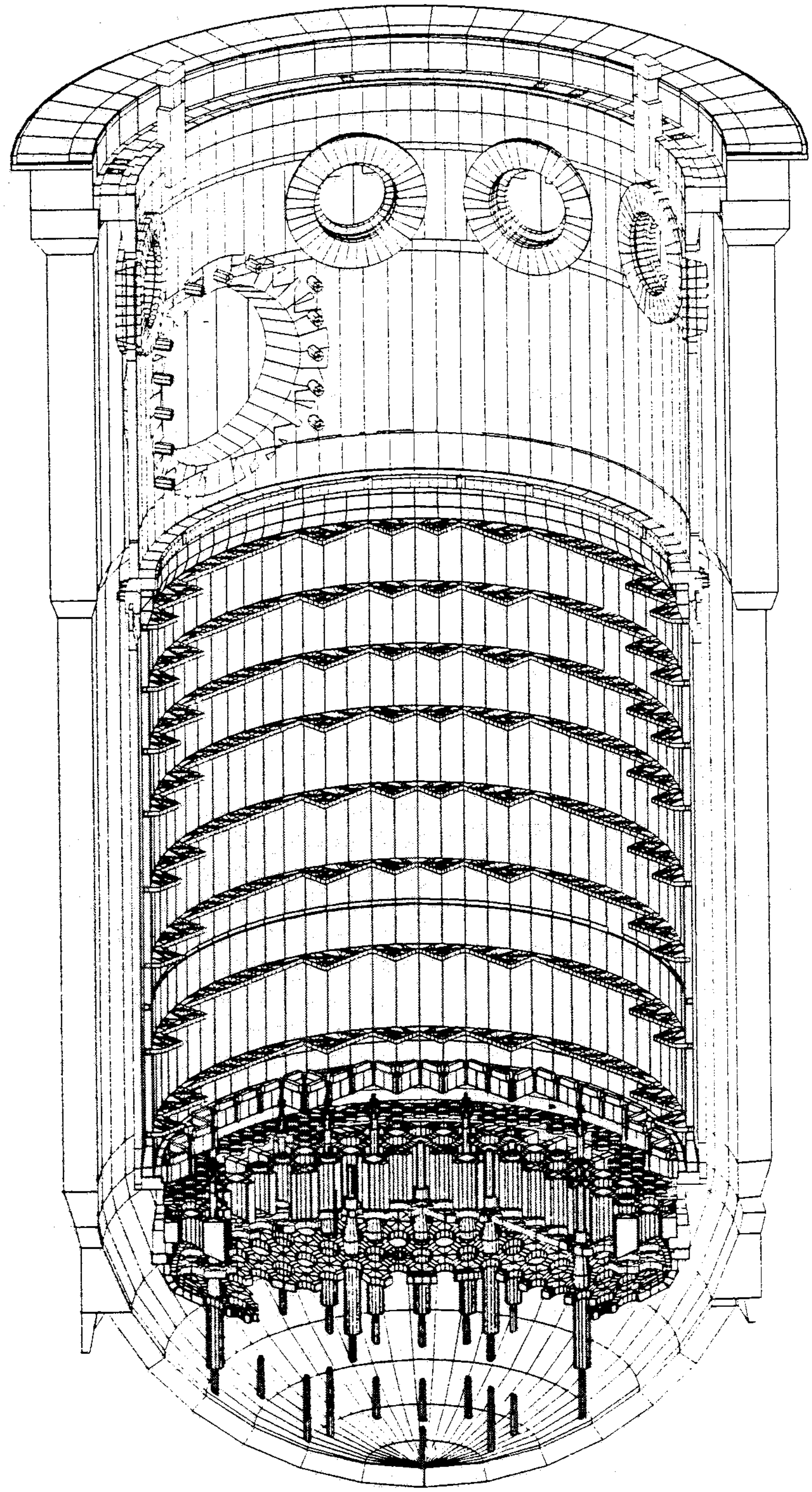


Figure 5-10. Reactor Vessel with Baffle Plates Removed and LCSA Cut Out

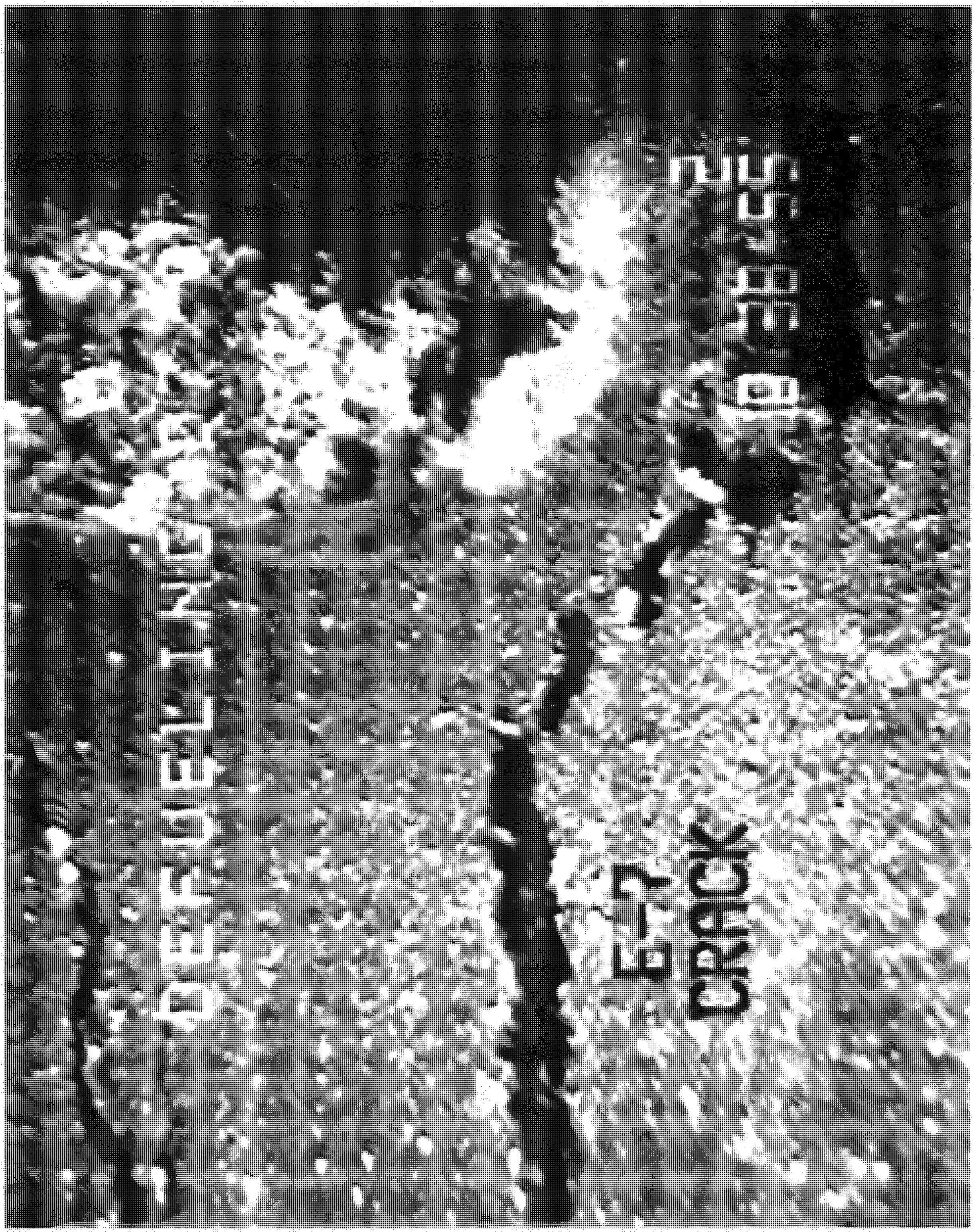


Photo 5-4. A Crack in the Lining of the Lower Head of Reactor Vessel Near Incore Nozzle E-7

WATER PROCESSING AND STORAGE DURING THE TMI-2 CLEANUP

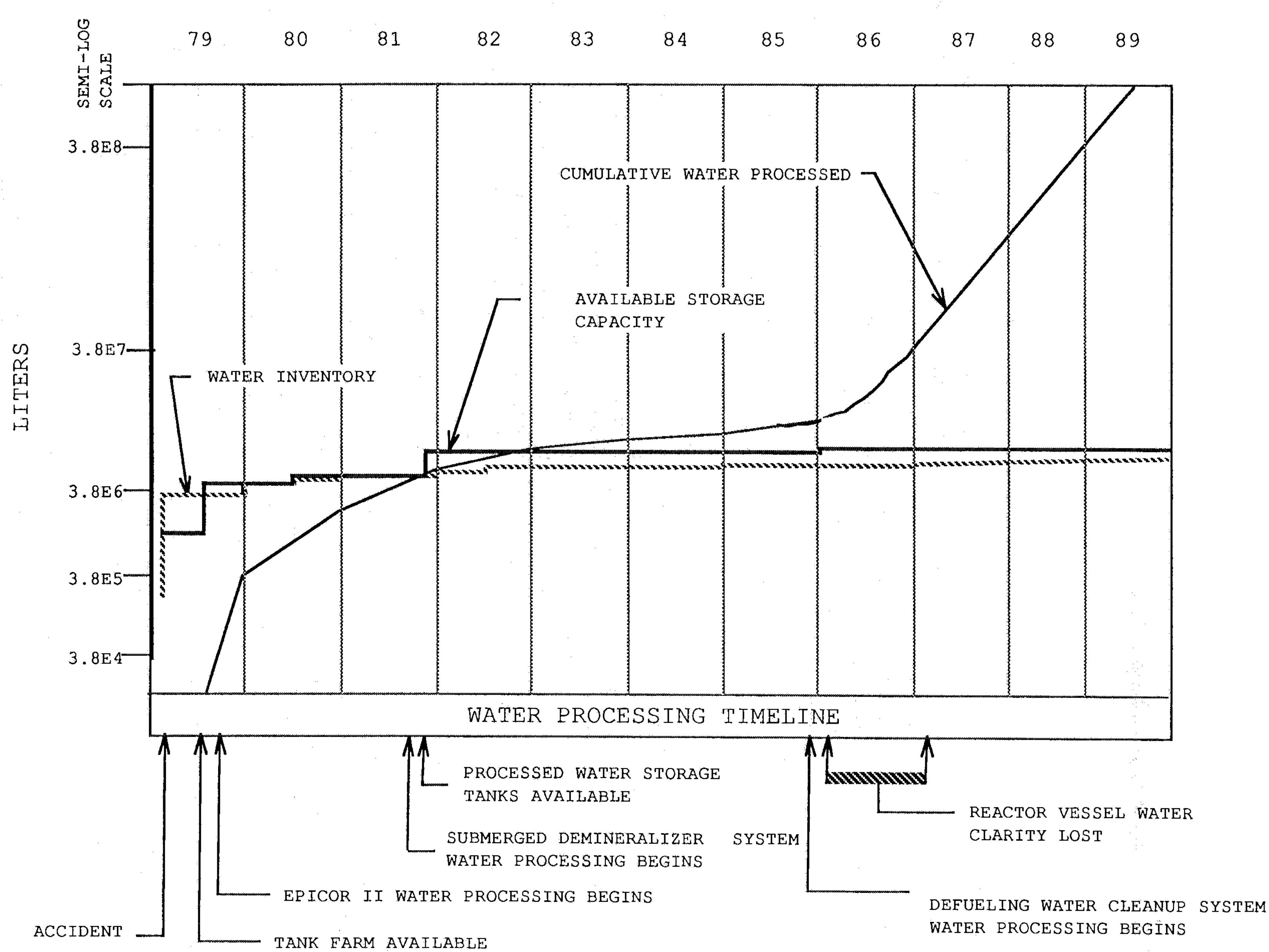


Figure 6-1. Water Processing and Storage during the TMI-2 Cleanup

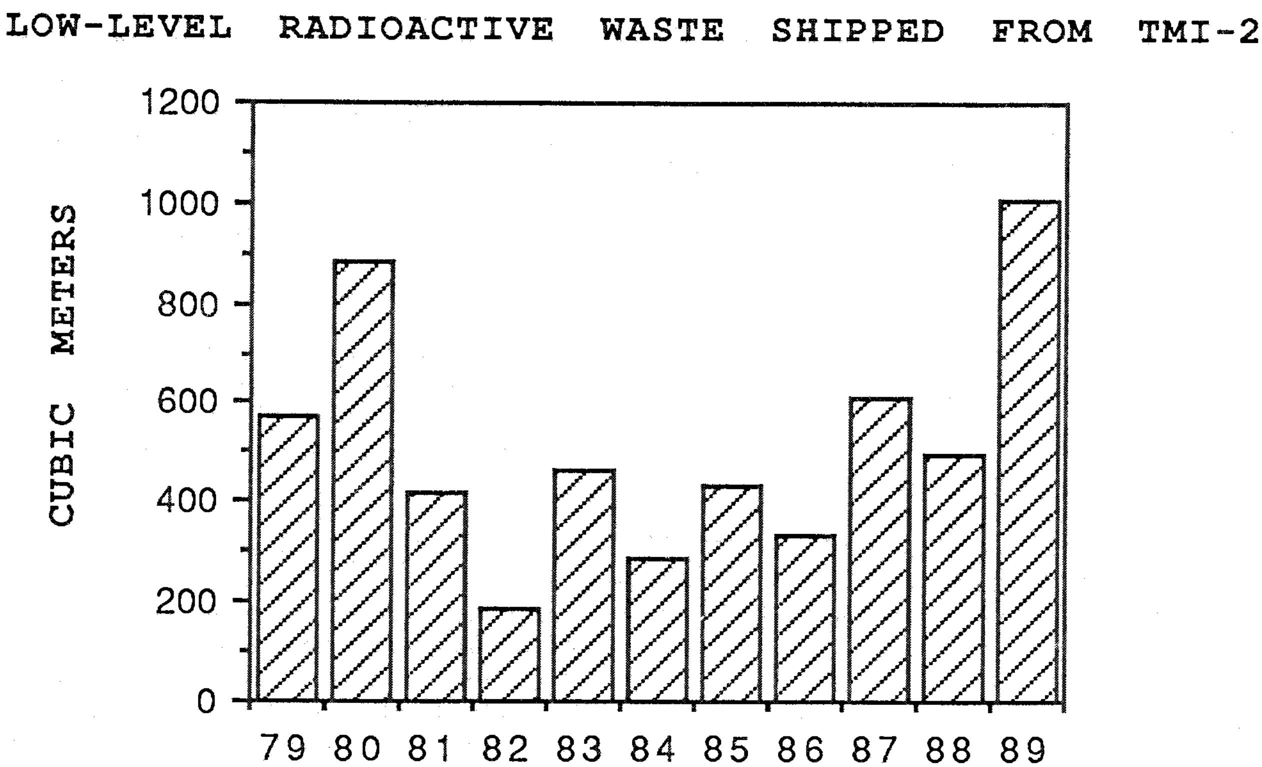


Figure 6-2. Low-Level Radioactive Waste Shipped Offsite During the Cleanup

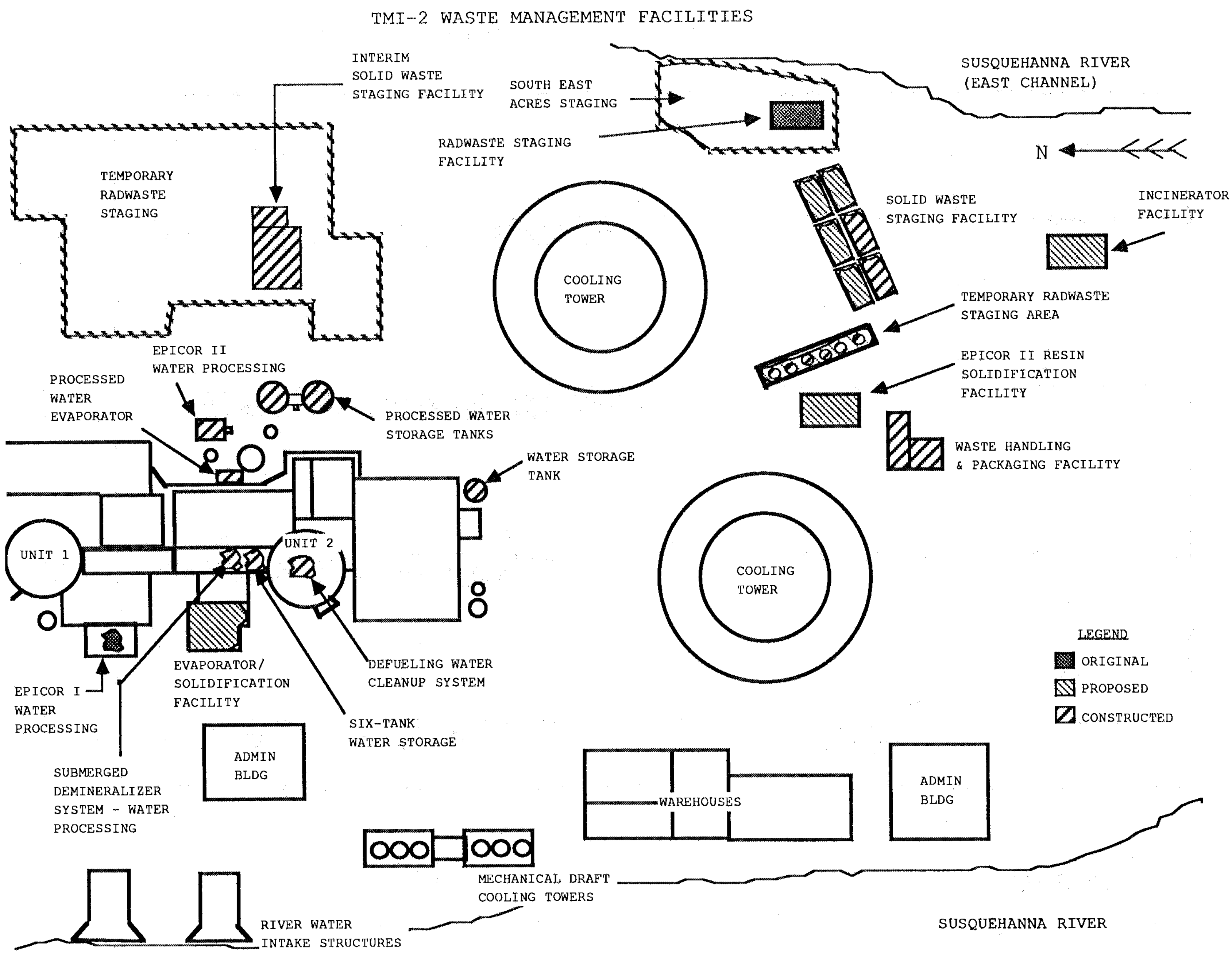


Figure 6-3. TMI-2 Waste Management Facilities

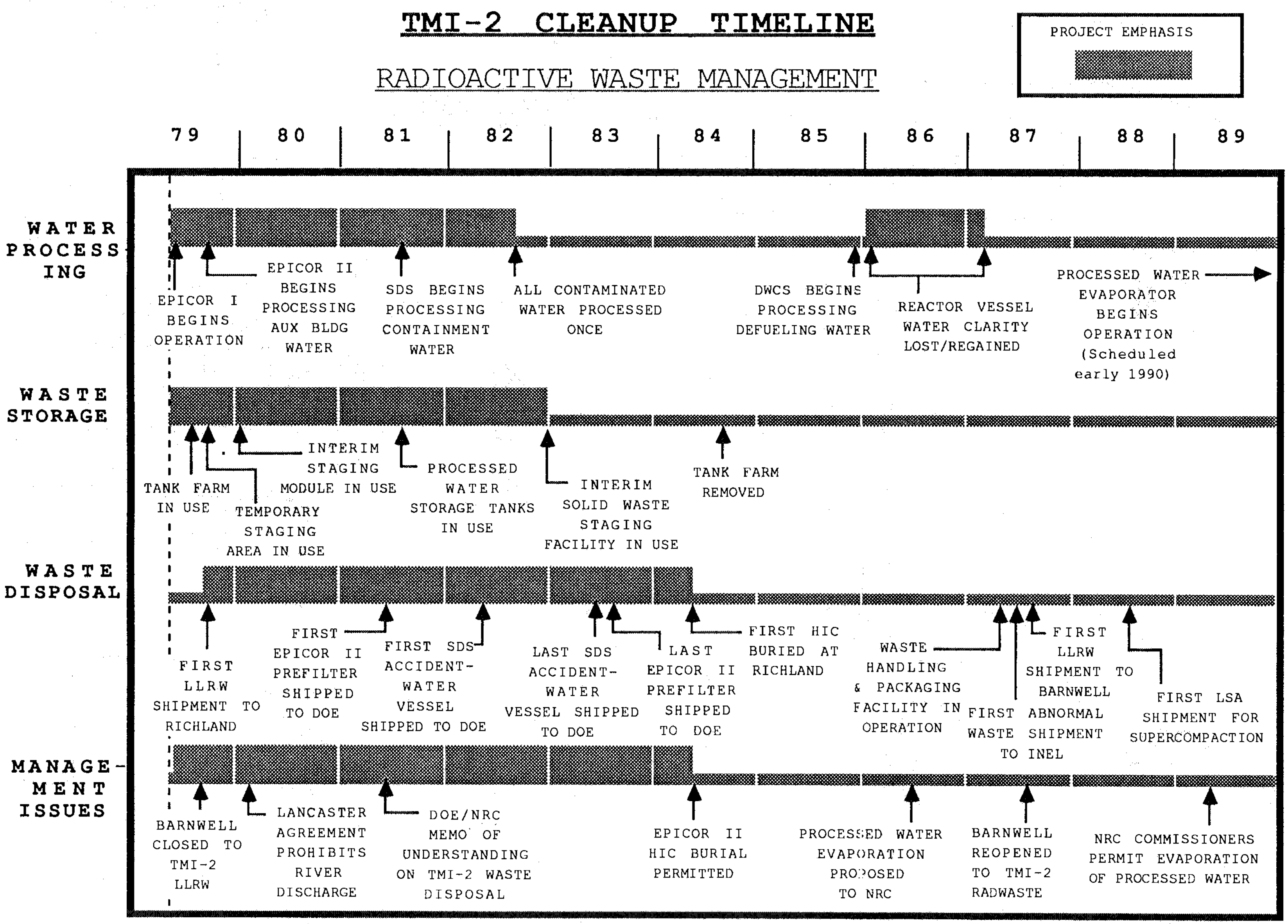


Figure 6-4. TMI-2 Cleanup Timeline: Radioactive Waste Management

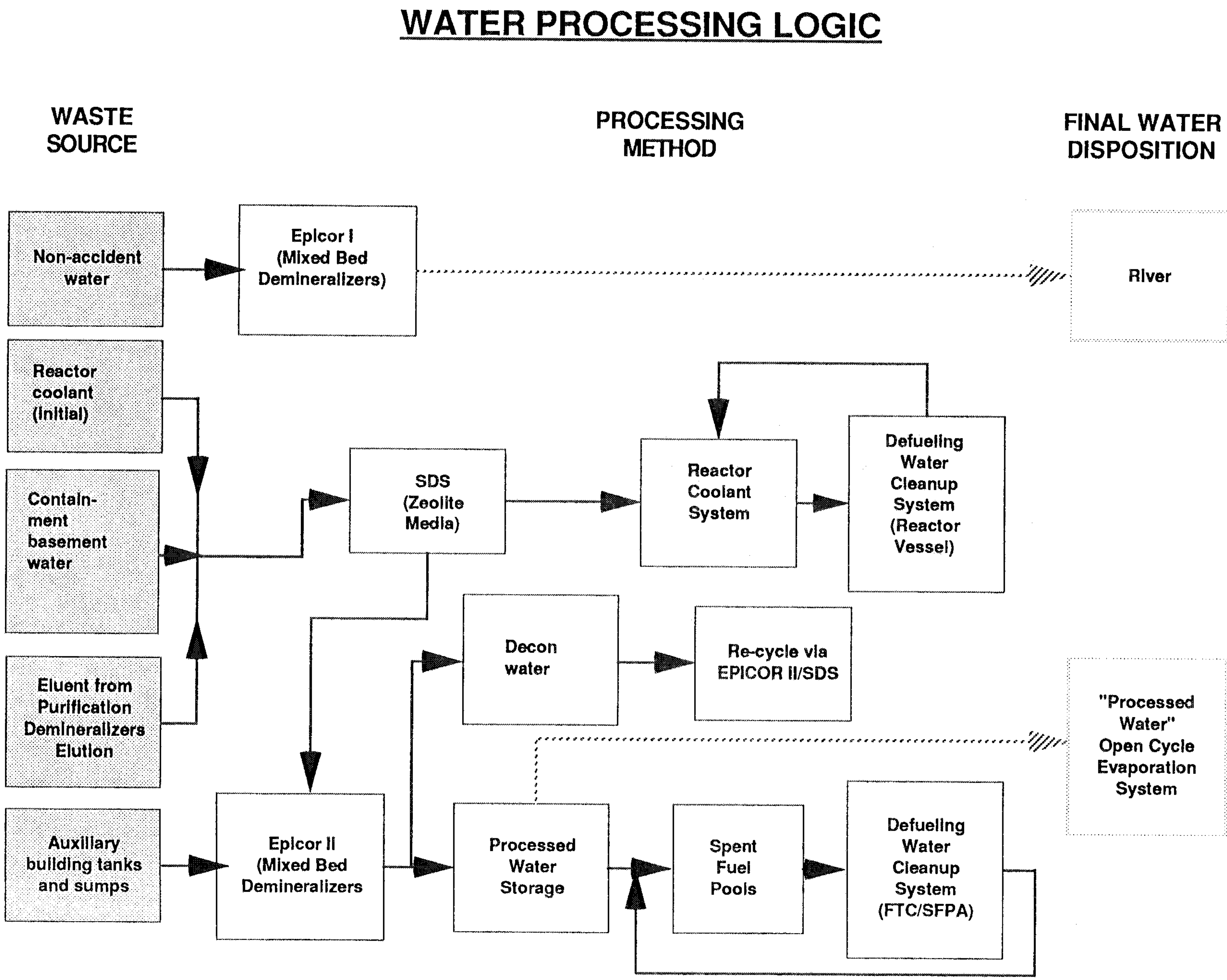


Figure 6-5. Water Processing Logic

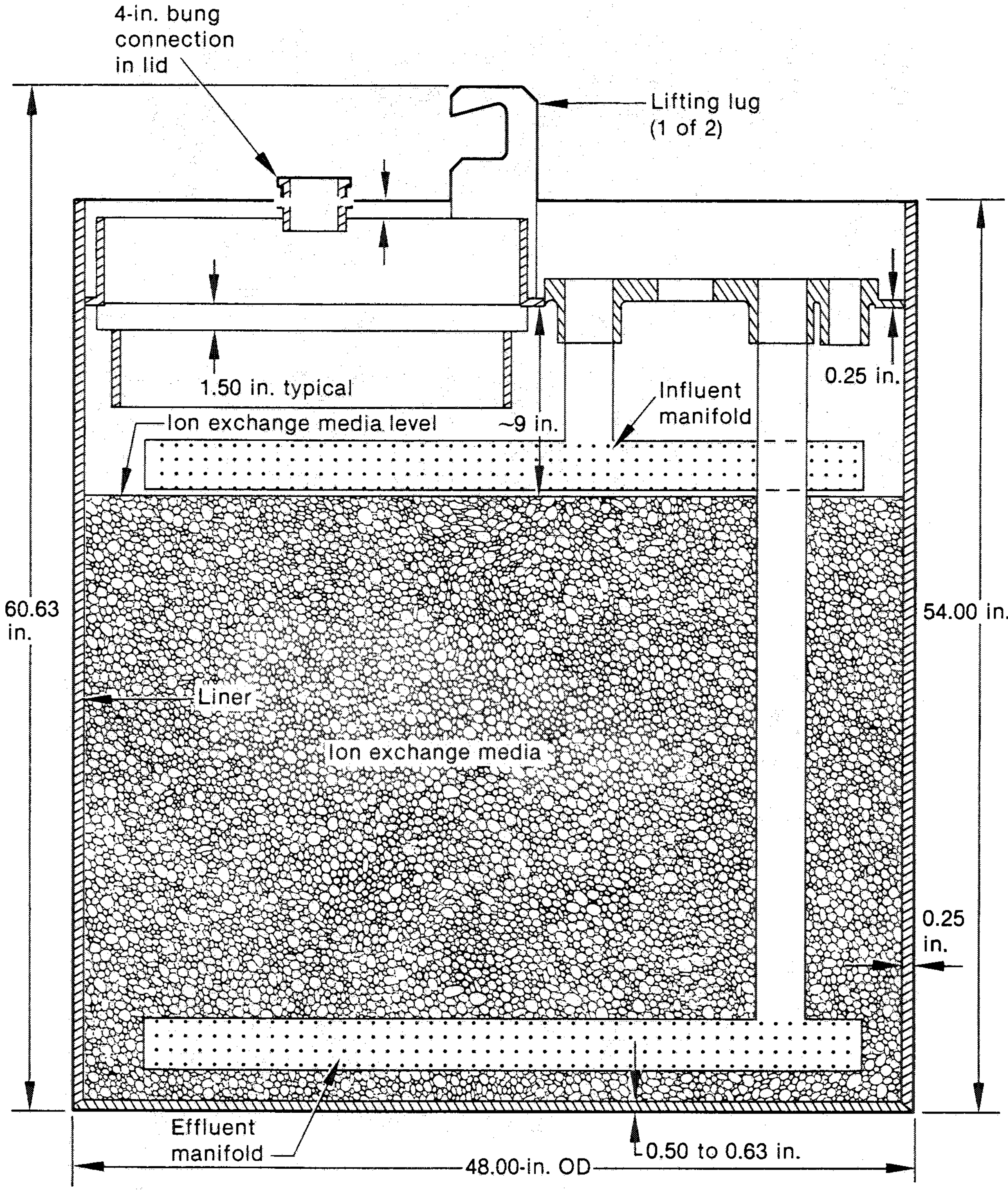


Figure 6-6. Cross-sectional View of Typical EPICOR II Vessel

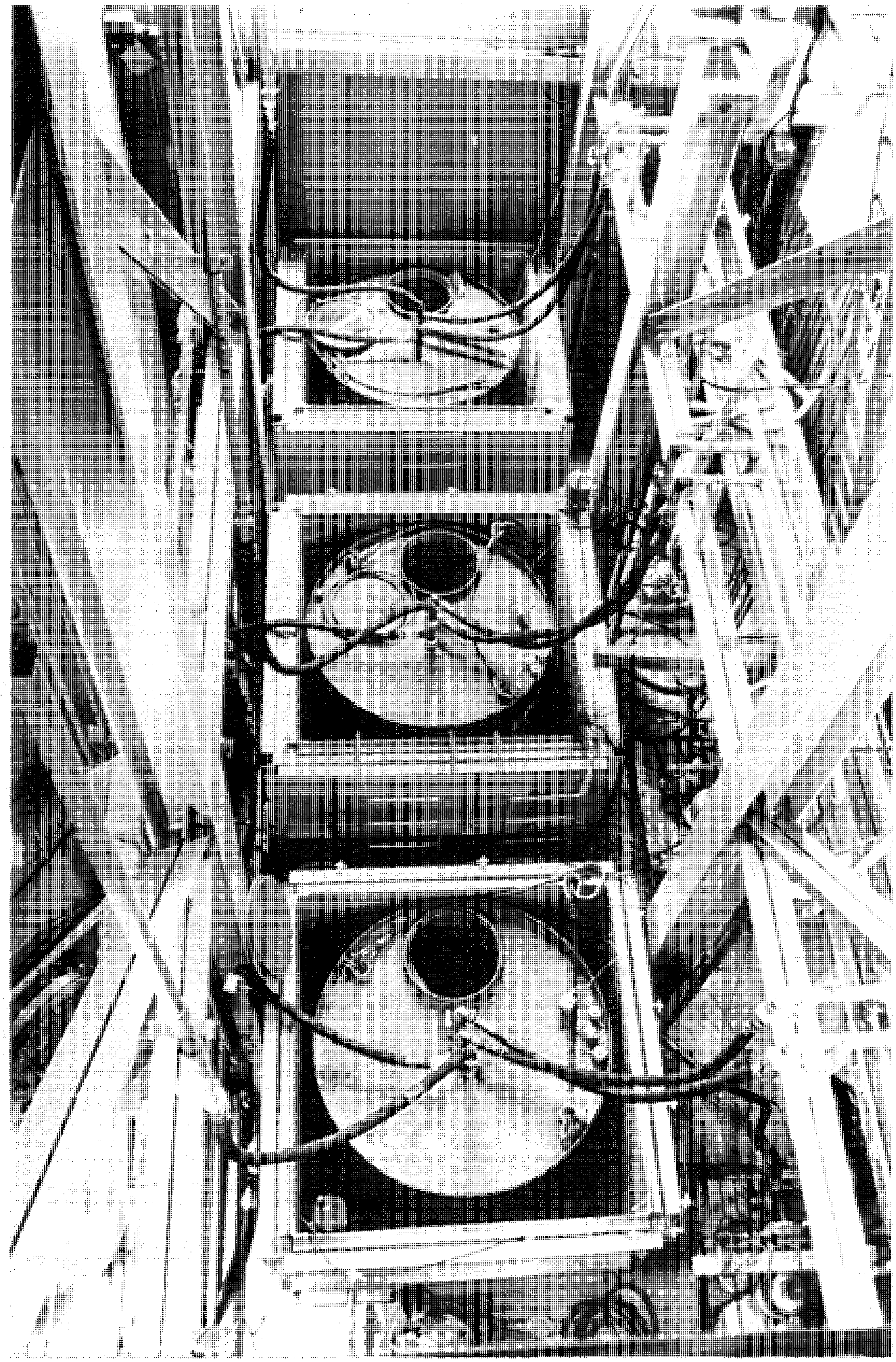


Photo 6-1. EPICOR II Vessels in Place

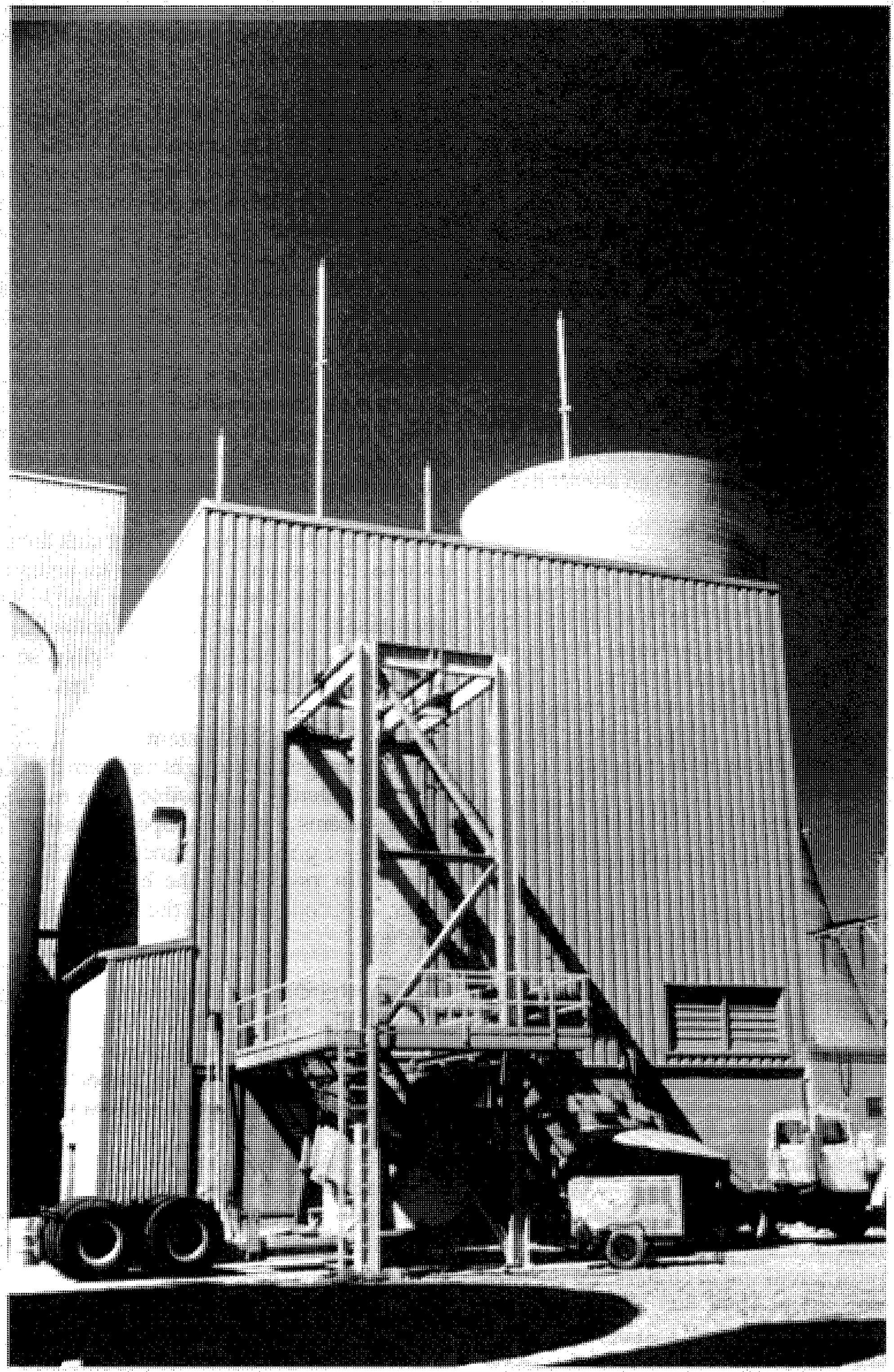
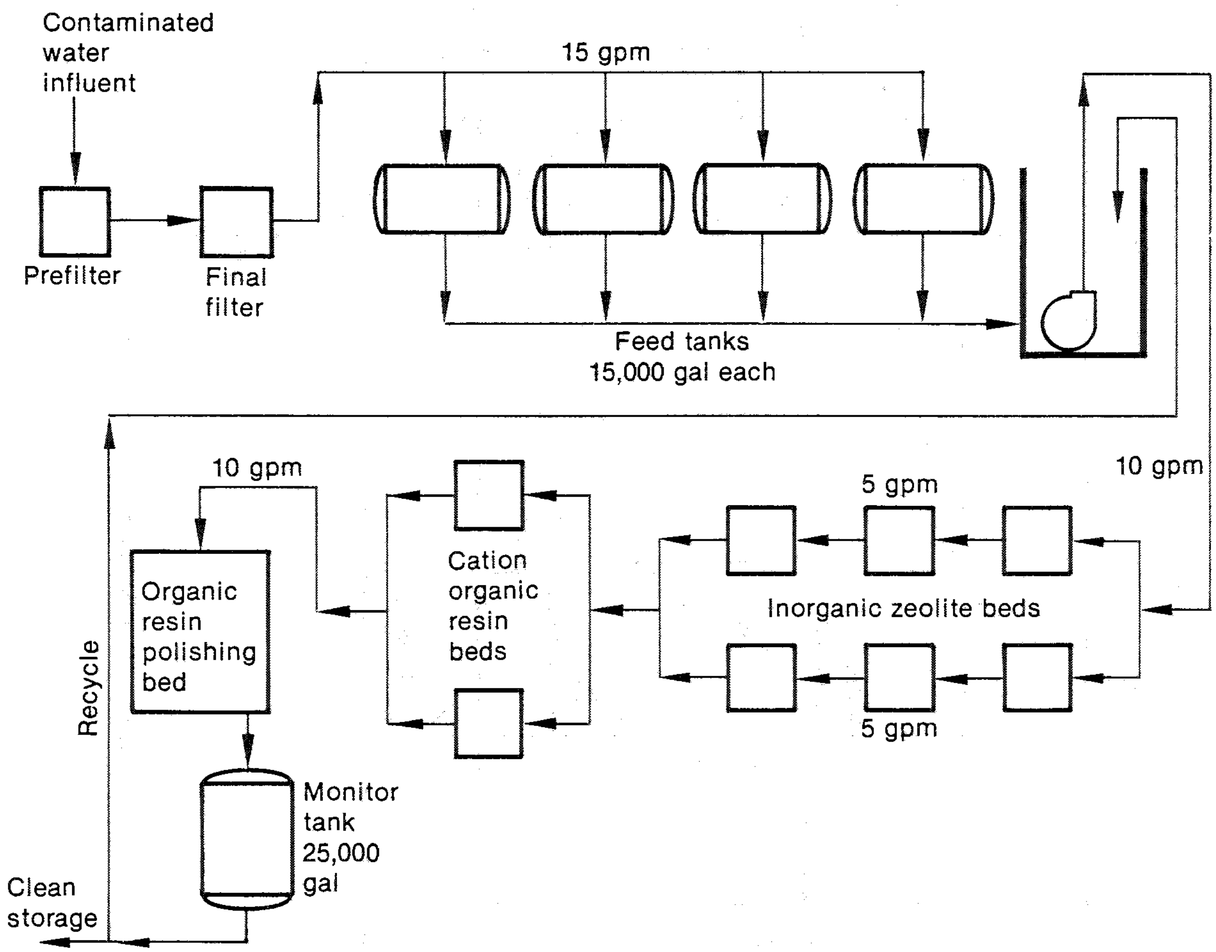
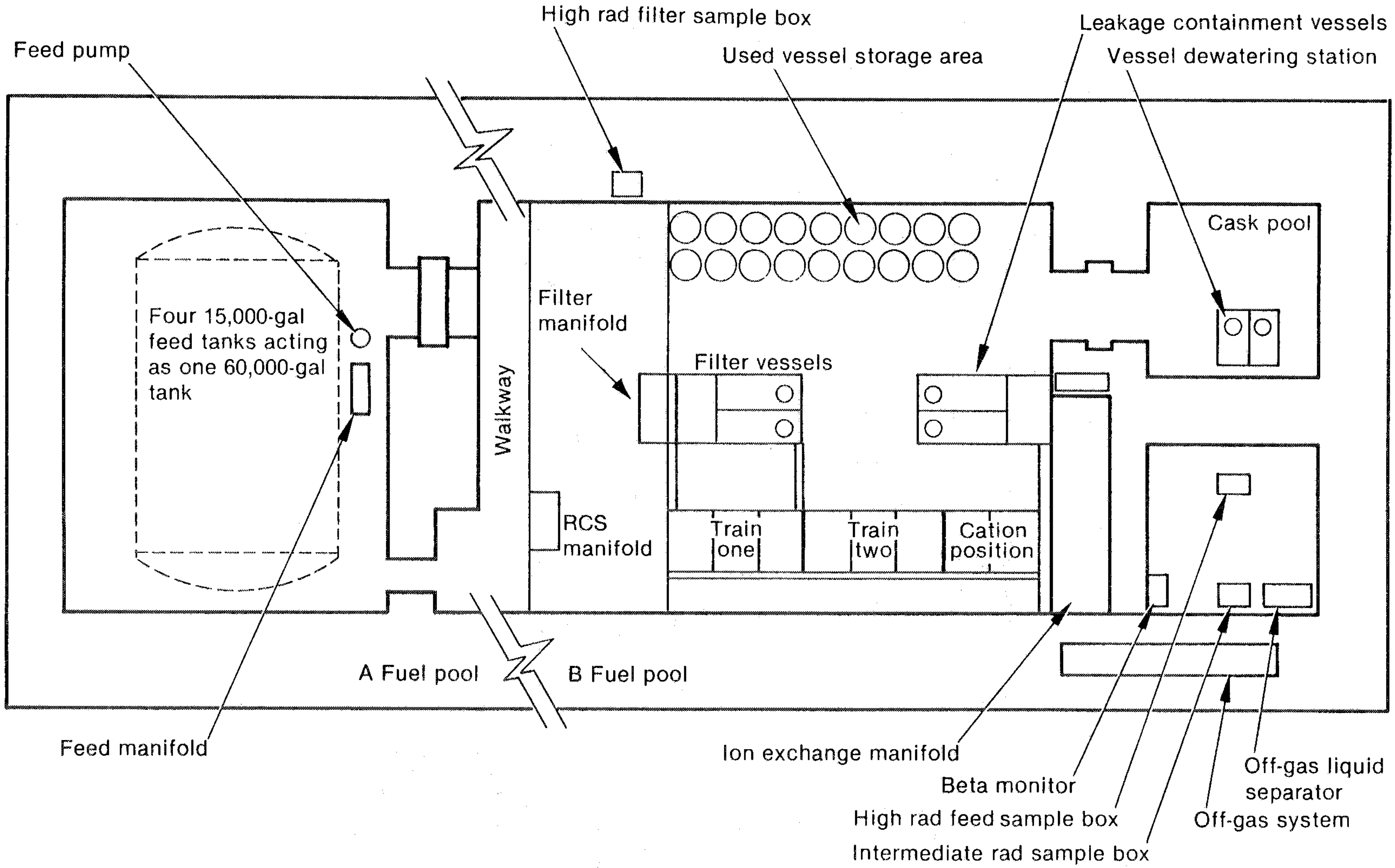


Photo 6-2. EPICOR II/Chemical Cleaning Building



Original SDS flowsheet showing flowrates.

Figure 6-7. Original SDS Flowsheet



Arrangement of SDS components in and around the spent fuel pools.

Figure 6-8. Arrangement of SDS Components in and around Fuel Pools

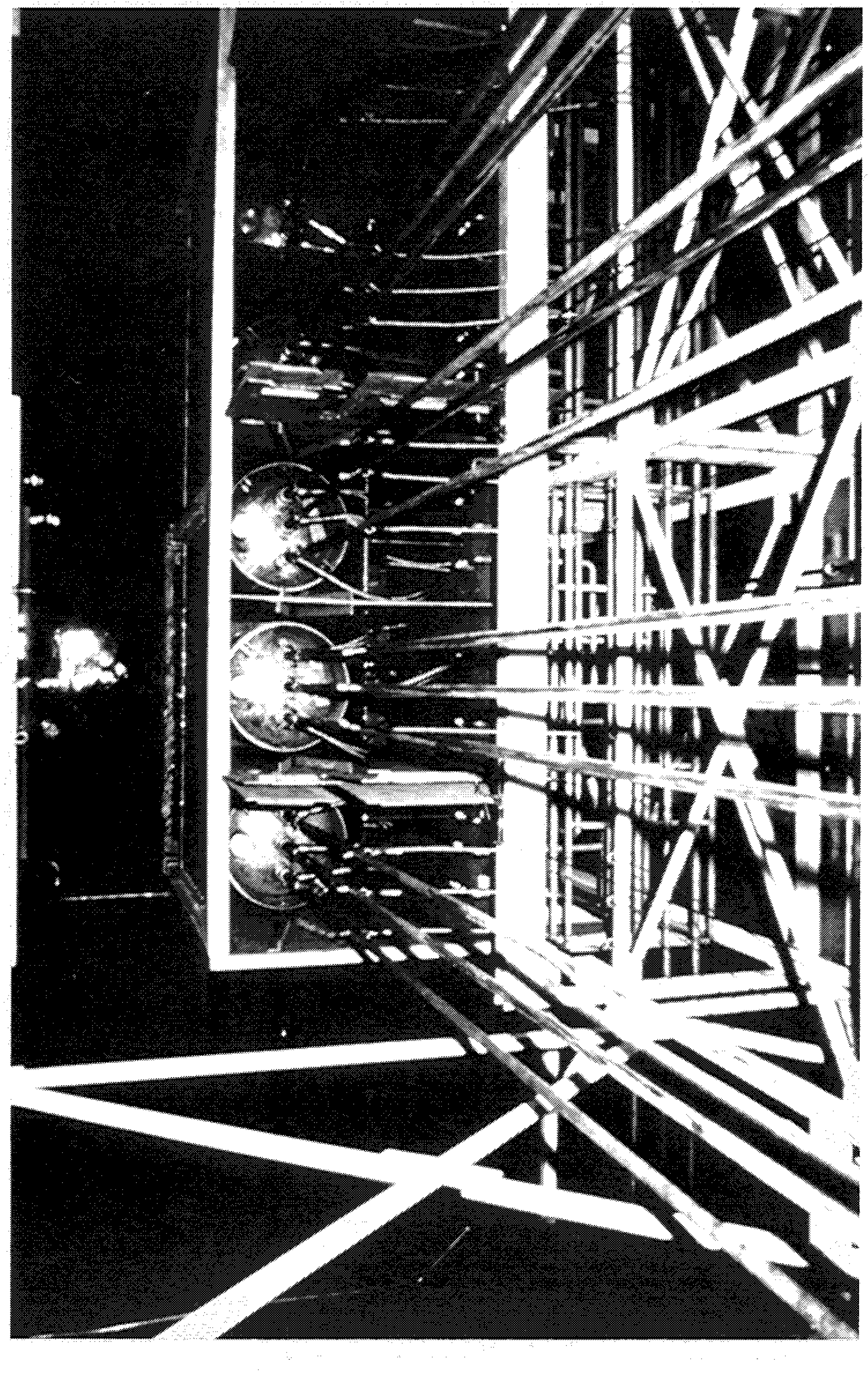


Photo 6-3. SDS in Spent Fuel Pool "B"

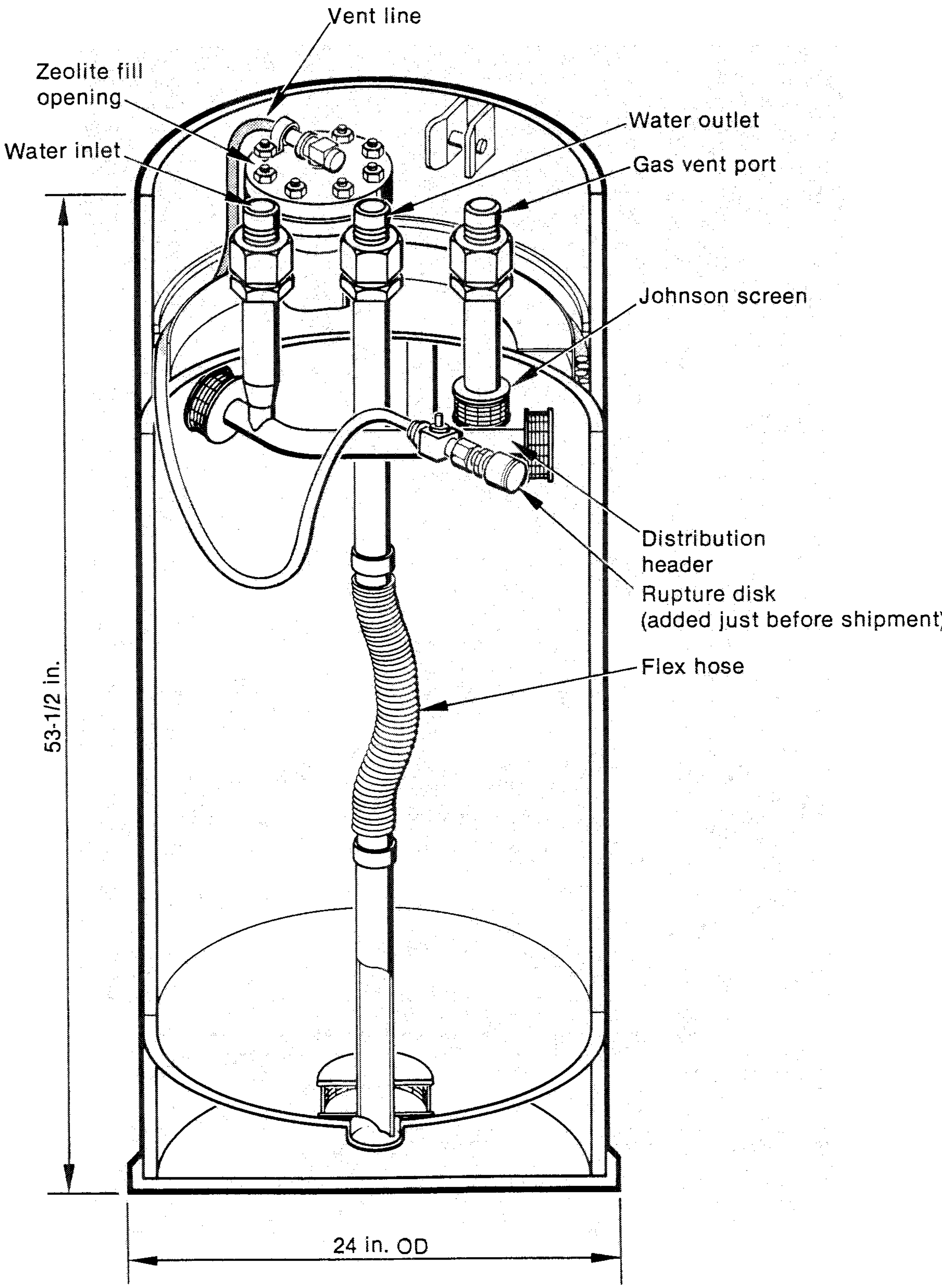
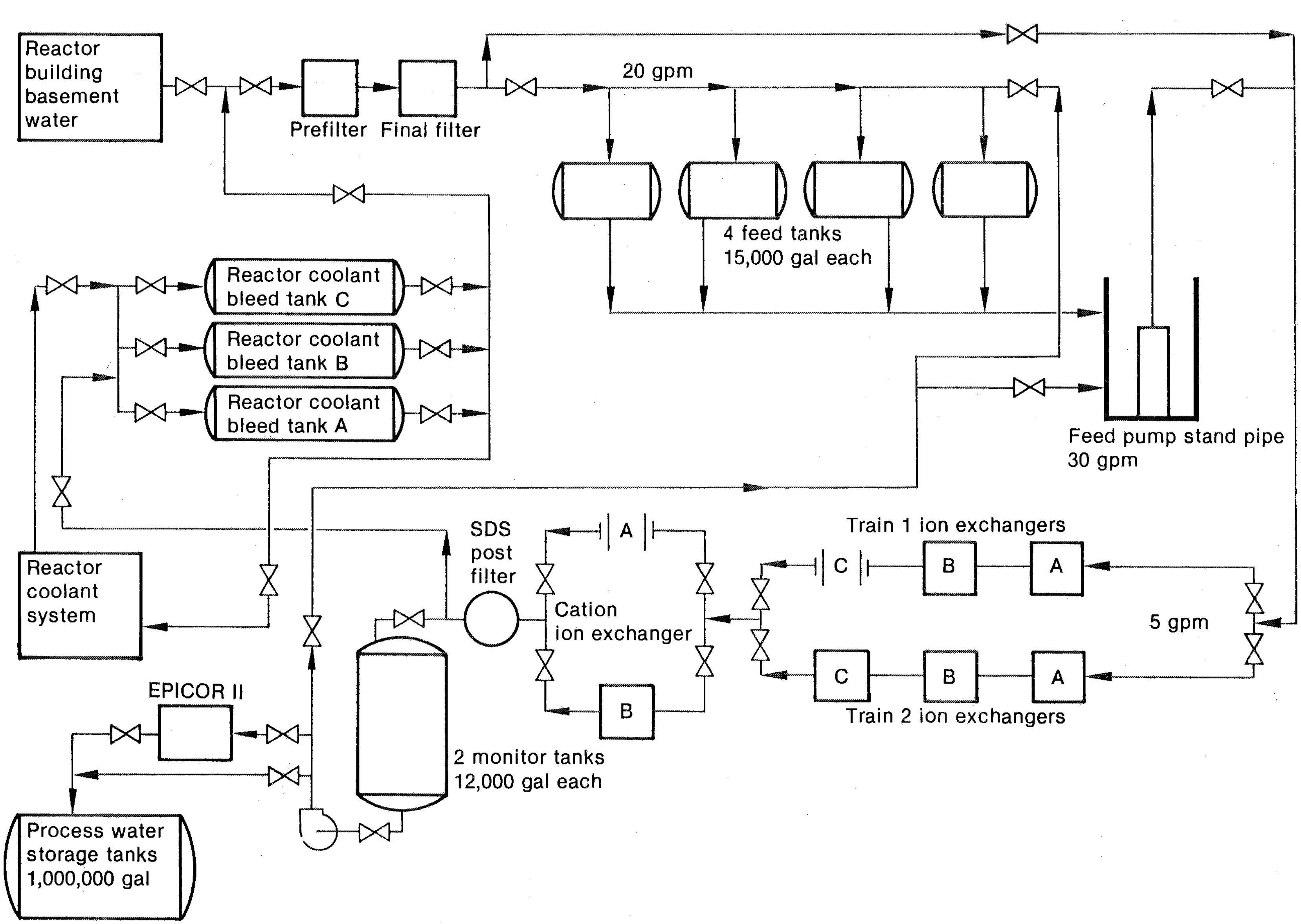


Figure 6-9. Cutaway View of an SDS Vessel



Final flowsheet for water processing through the SDS.

Figure 6-10. Final Flowsheet for SDS

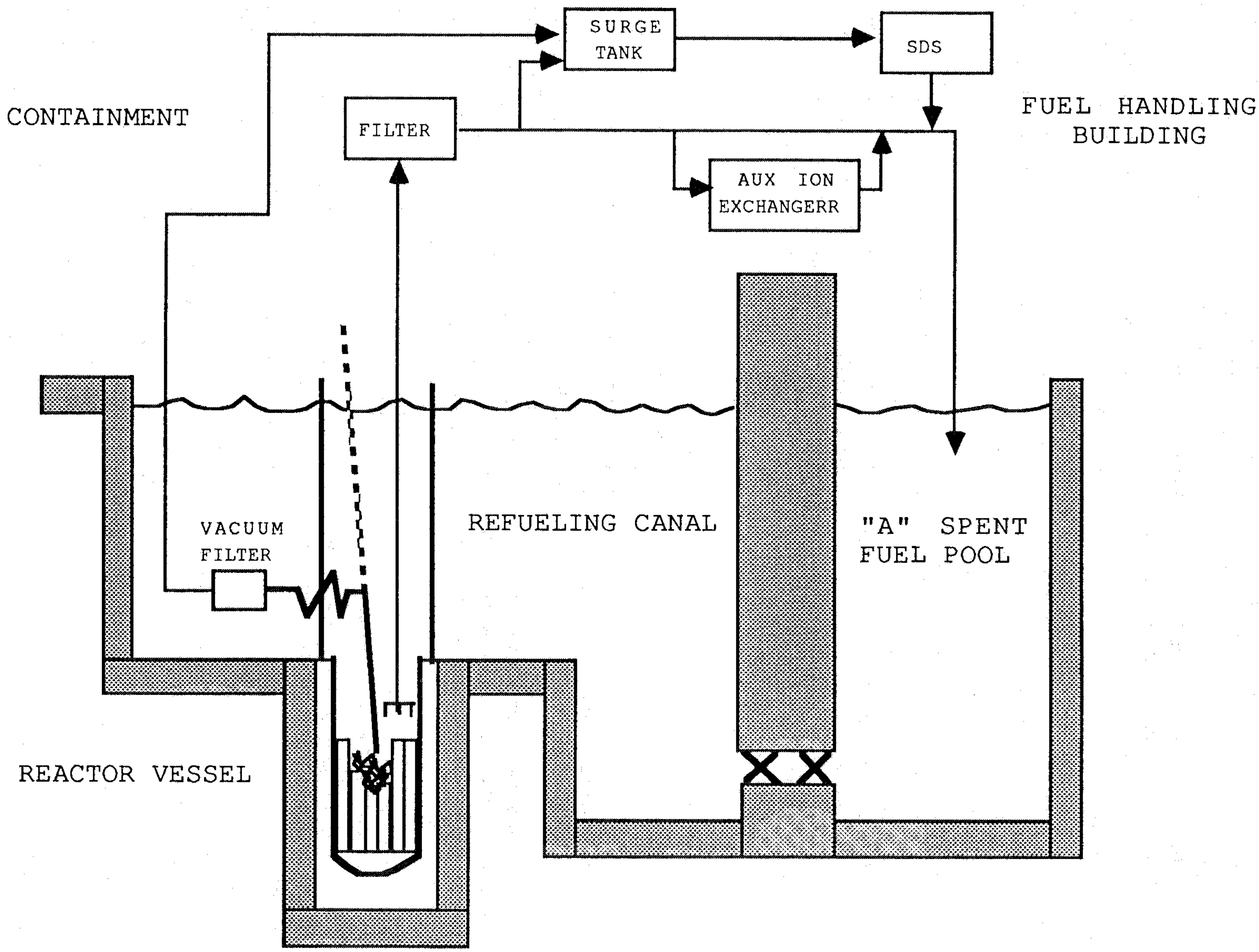


Figure 6-11. Early Conceptual DWCS Design

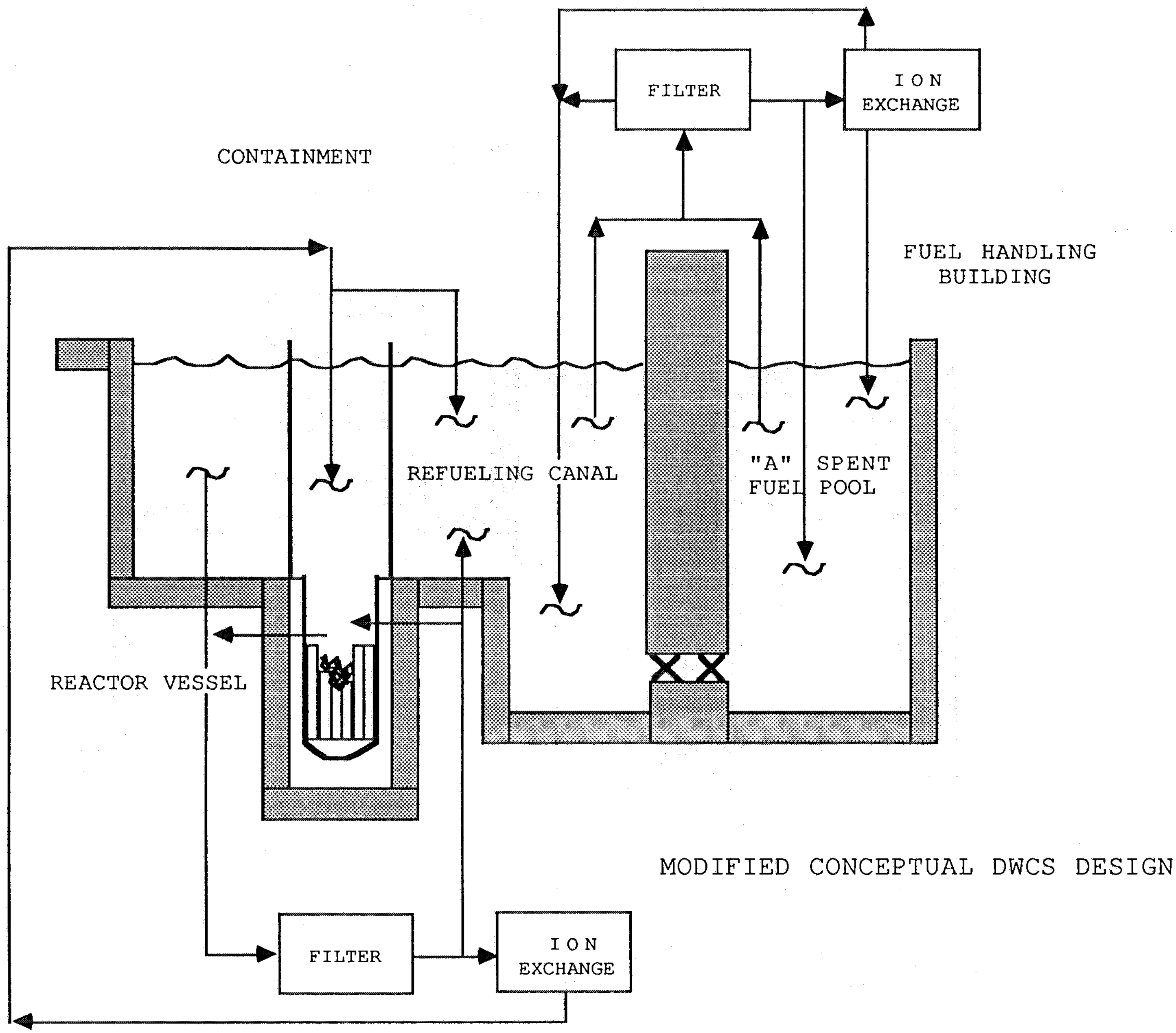


Figure 6-12. Modified Conceptual DWCS Design

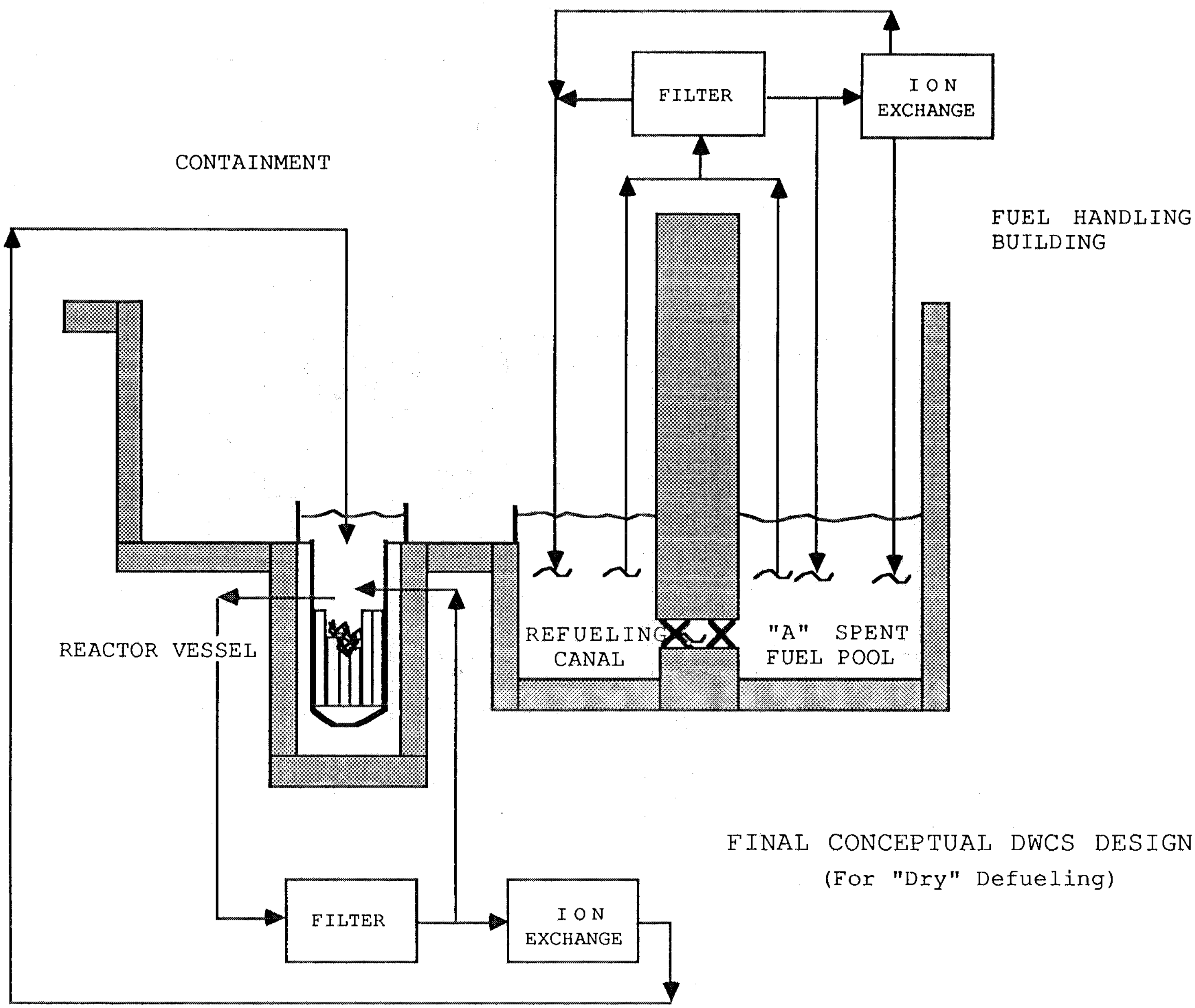


Figure 6-13. Final Conceptual DWCS Design

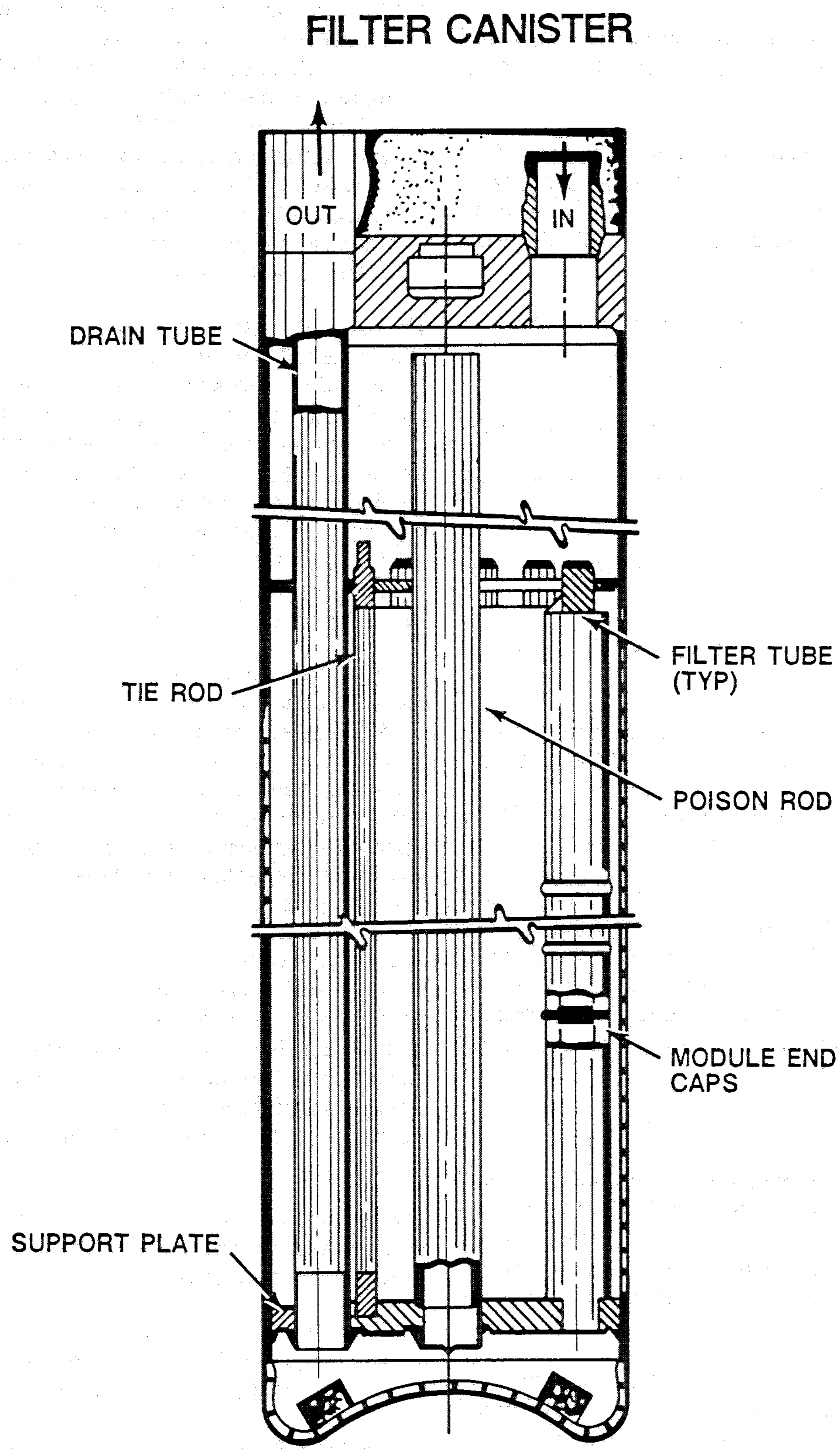


Figure 6-14. Filter Canister

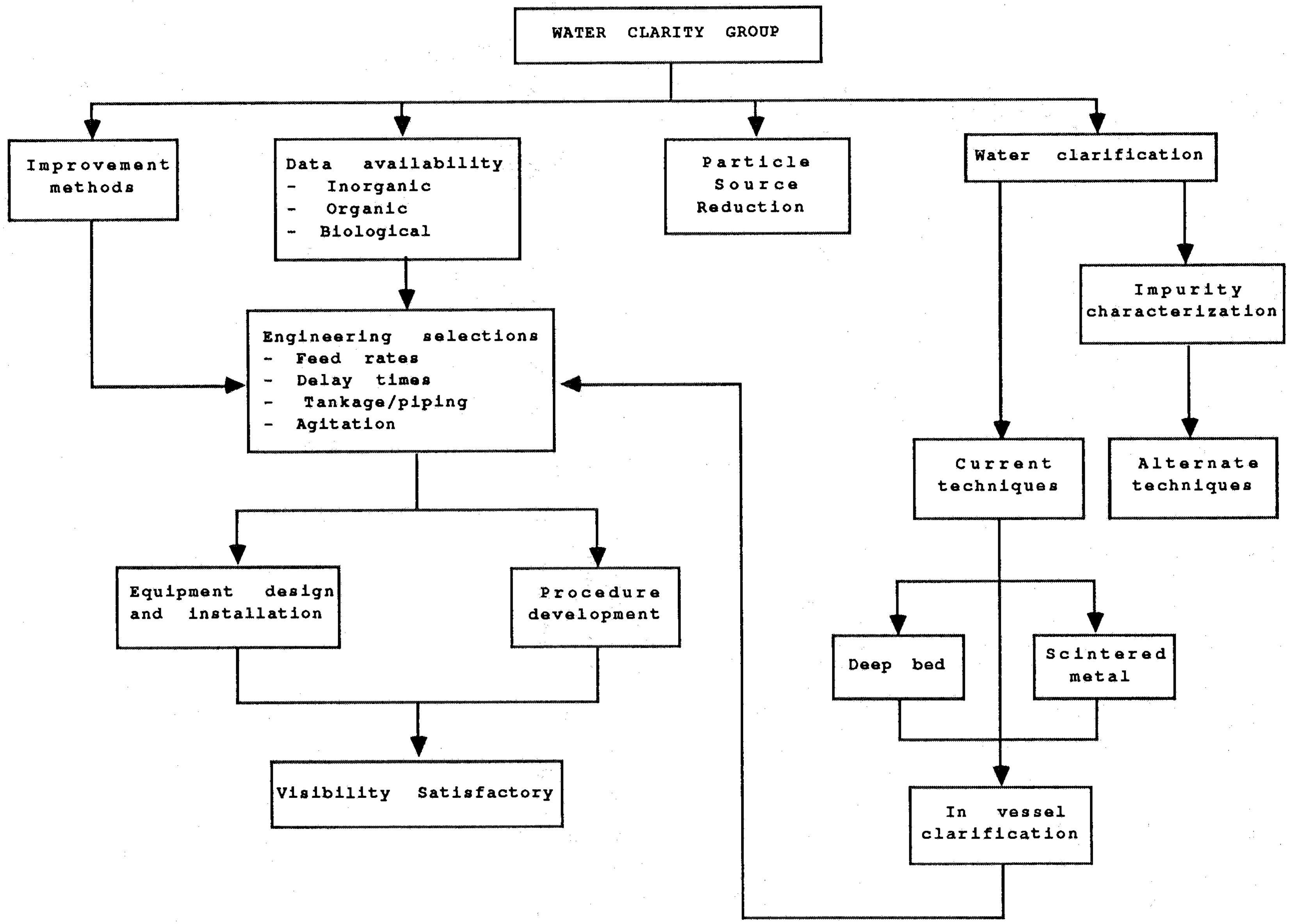


Figure 6-15. Visibility Improvement Logic

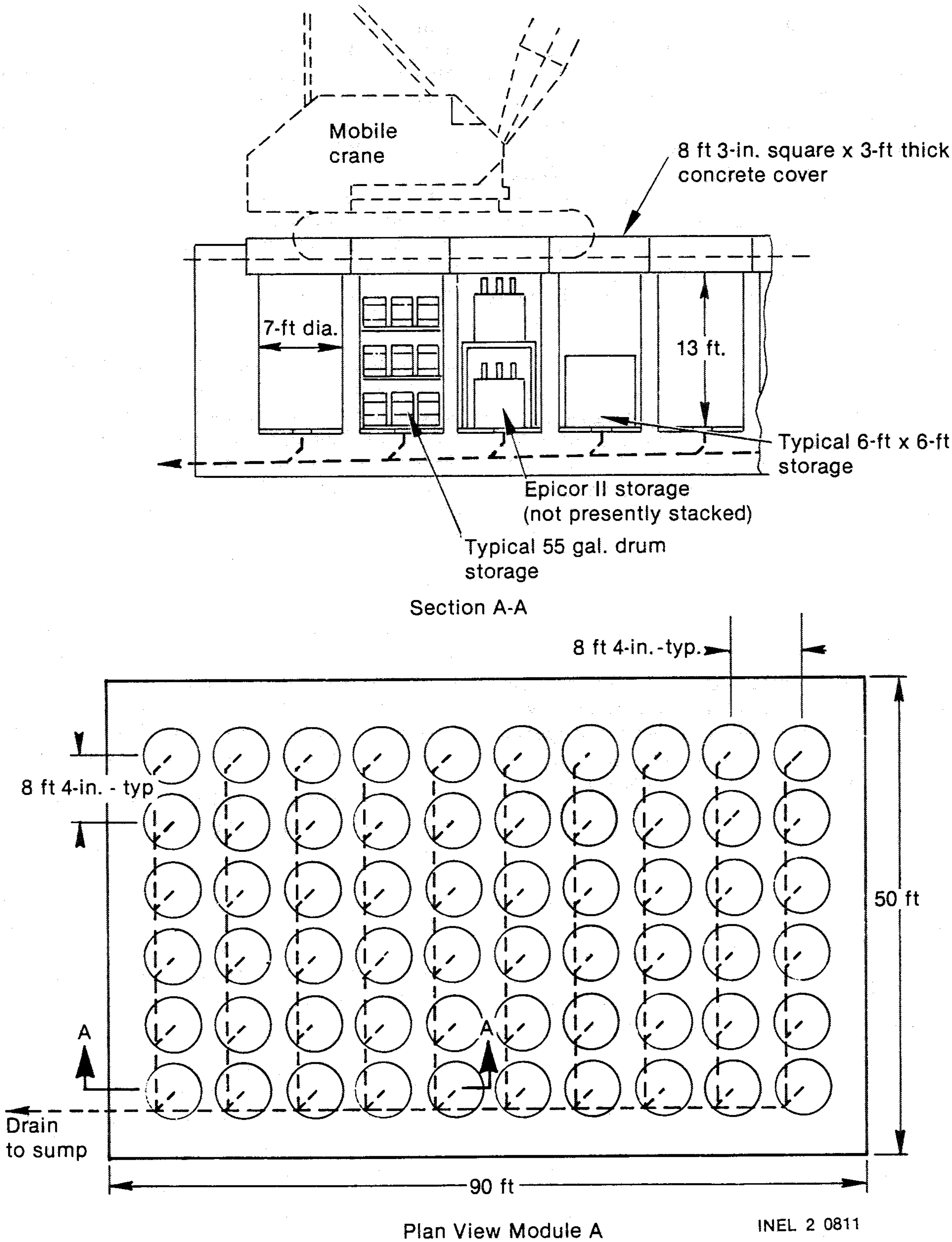


Figure 6-16. Solid Waste Staging Facility

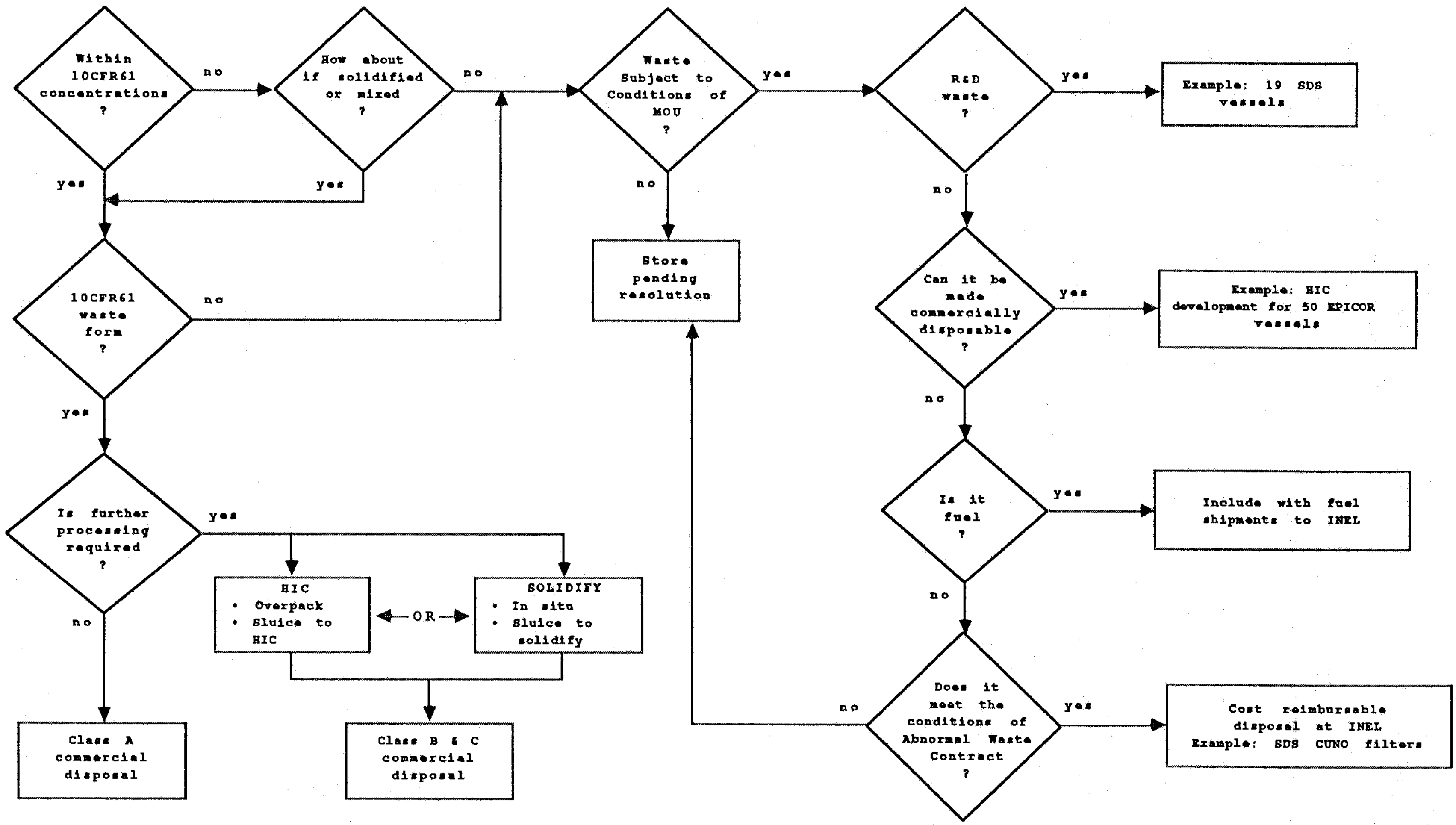


Figure 6-17. TMI-2 Waste Disposal Logic

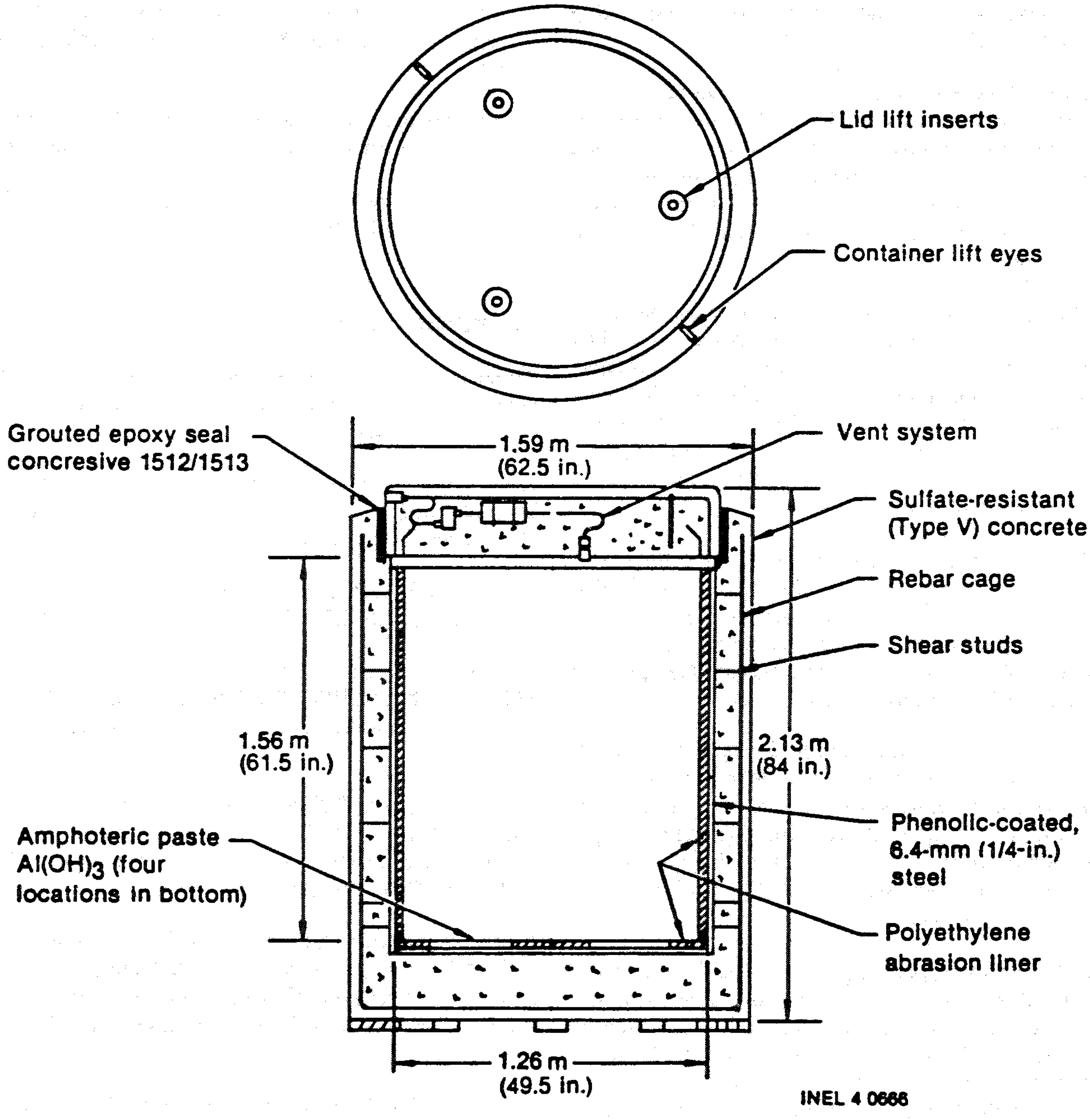


Figure 6-18. Design of EPCIOR II HIC

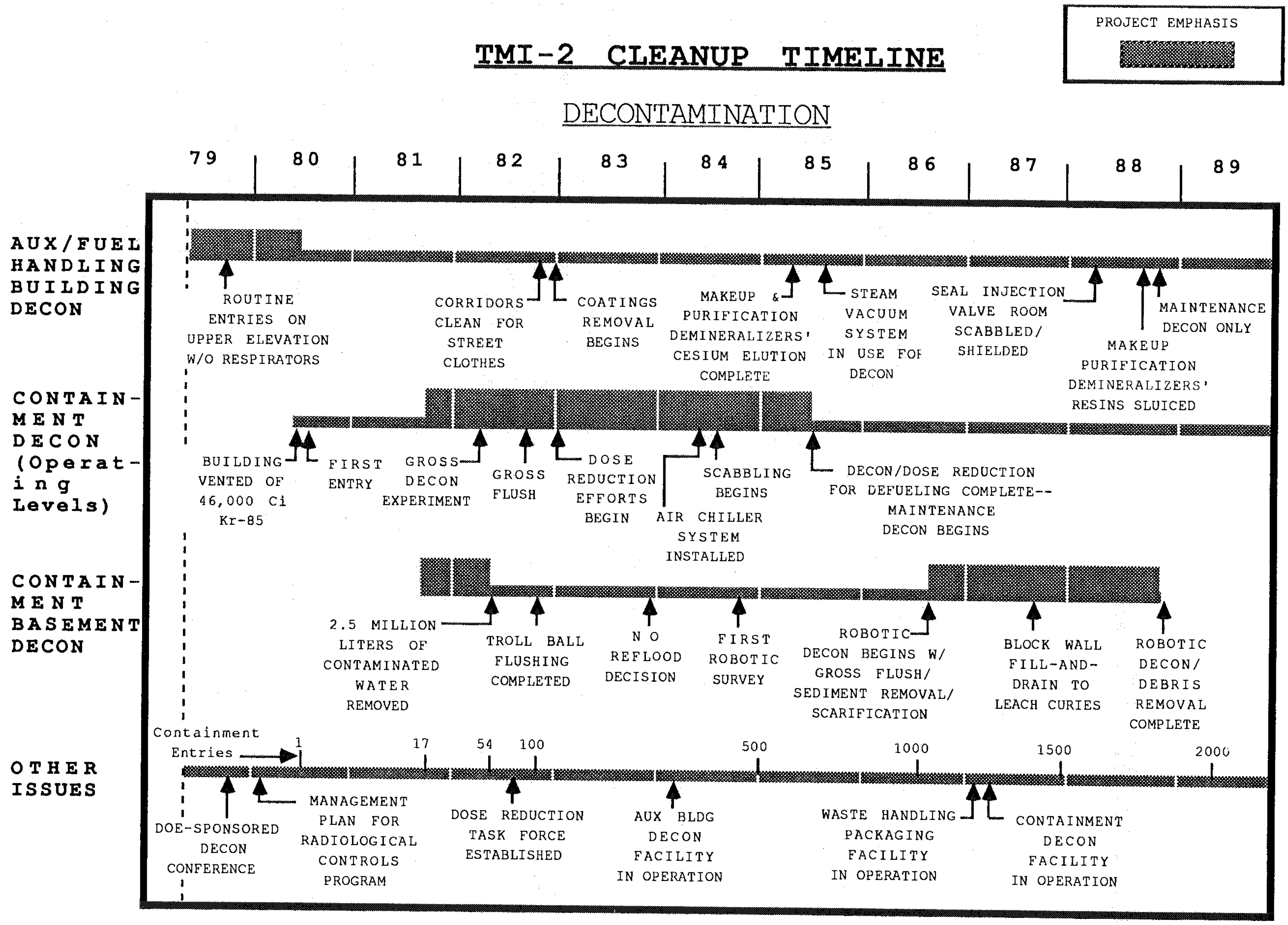


Figure 7-1. TMI-2 Cleanup Timeline: Decontamination

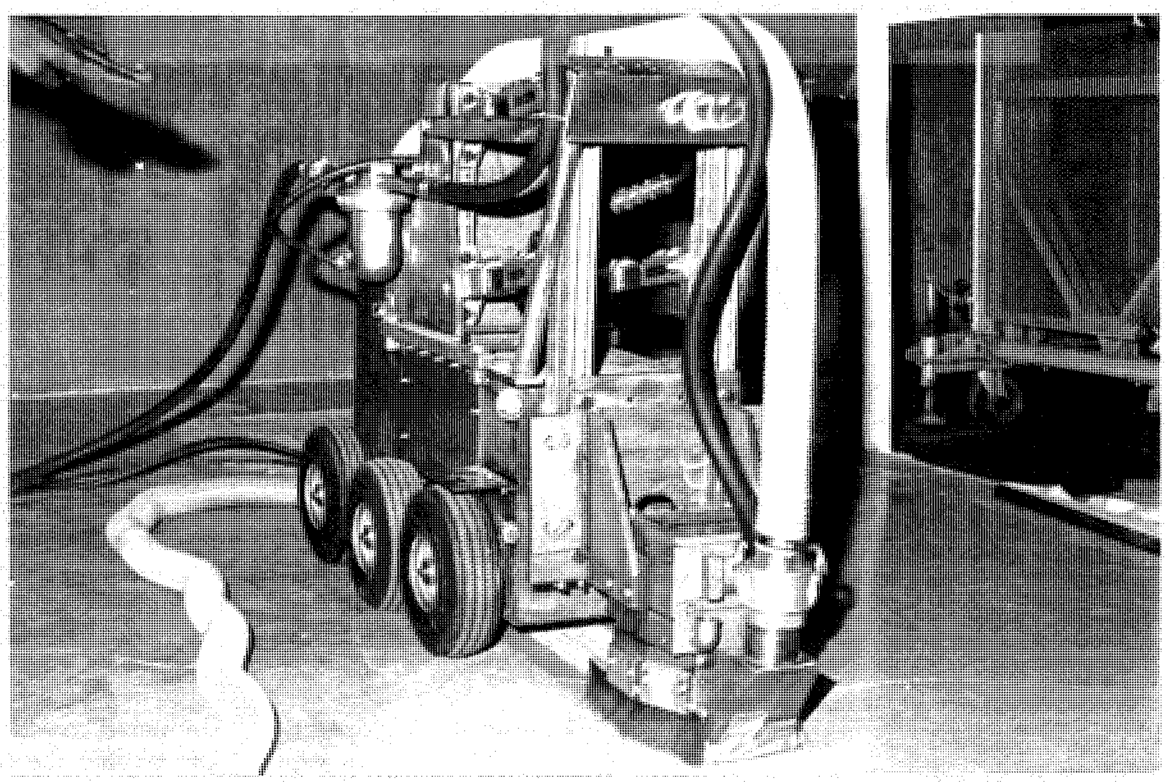


Photo 7-1. LOUIE-2

The letdown block orifice (MU-FE-1) was a 46-cm long section of 3.8-cm stainless steel pipe in the makeup and purification system. It reduced the reactor coolant letdown pressure by using a series of internal restricting orifices, which became clogged with debris during the accident.

Removing the block orifice required substantial effort. Approximately 100 gm of fuel debris and cladding were estimated to be deposited in the block orifice and associated piping (Daniel, et al. 1982). Its high readings, in combination with intruding pipes and structures, made robotic decontamination impractical and general surface decontamination non-ALARA.

Three solutions were considered:

- Chemical flush—Rejected because of projected high dose rates, expensive equipment, and lack of approved reagents
- Recirculating filter flush—Rejected because of high dose rates, expensive equipment, and uncertainty of success
- Removal and installation of new piping—Selected because it entailed less projected personnel exposure, guaranteed reduction in area dose, and provided a high probability of later dose reduction using turbulent water flushing.

A hydraulically operated, reciprocating hacksaw was used; it had a set of opposed jaws that allowed it to be attached to the pipe and cut without personnel present. In late 1986, the block orifice was drained, cut up, packaged, and removed for disposal, and a new spool piece was installed. The general area dose rates dropped from 1–4 R/h to 100–150 mR/h, allowing general surface area decontamination to begin (Murphy 1986).

7.3.2.4 Purification Demineralizers

The cleanup of the two makeup and purification (MUP) demineralizer vessels was unique because it was a low-profile, challenging project that proceeded with little fanfare over several years. The radioactivity contained in the vessels was substantial, but not in a location that interfered with cleanup and defueling operations.

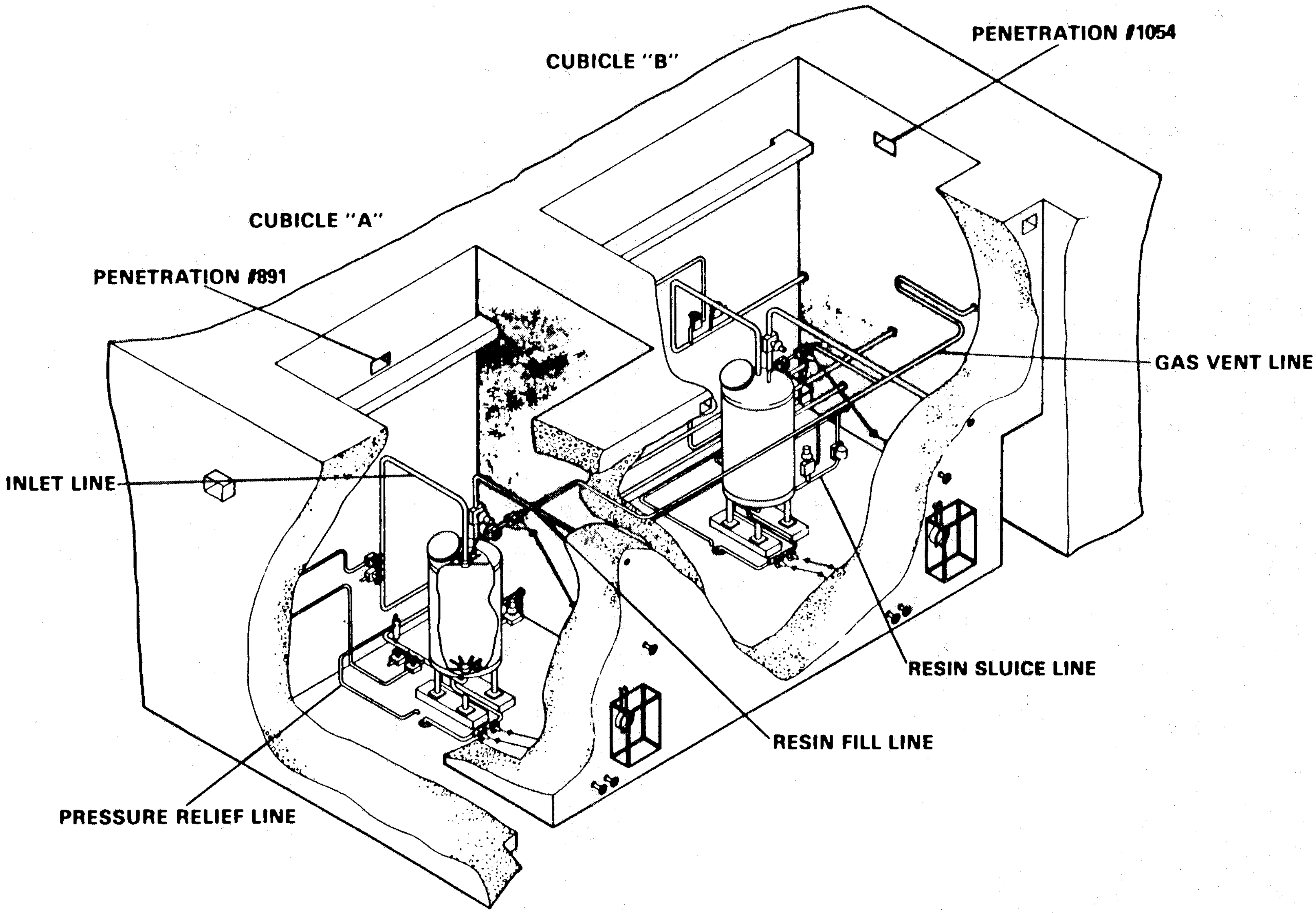


Figure 7-2.Makeup & Purification Demineralizer Cubicles

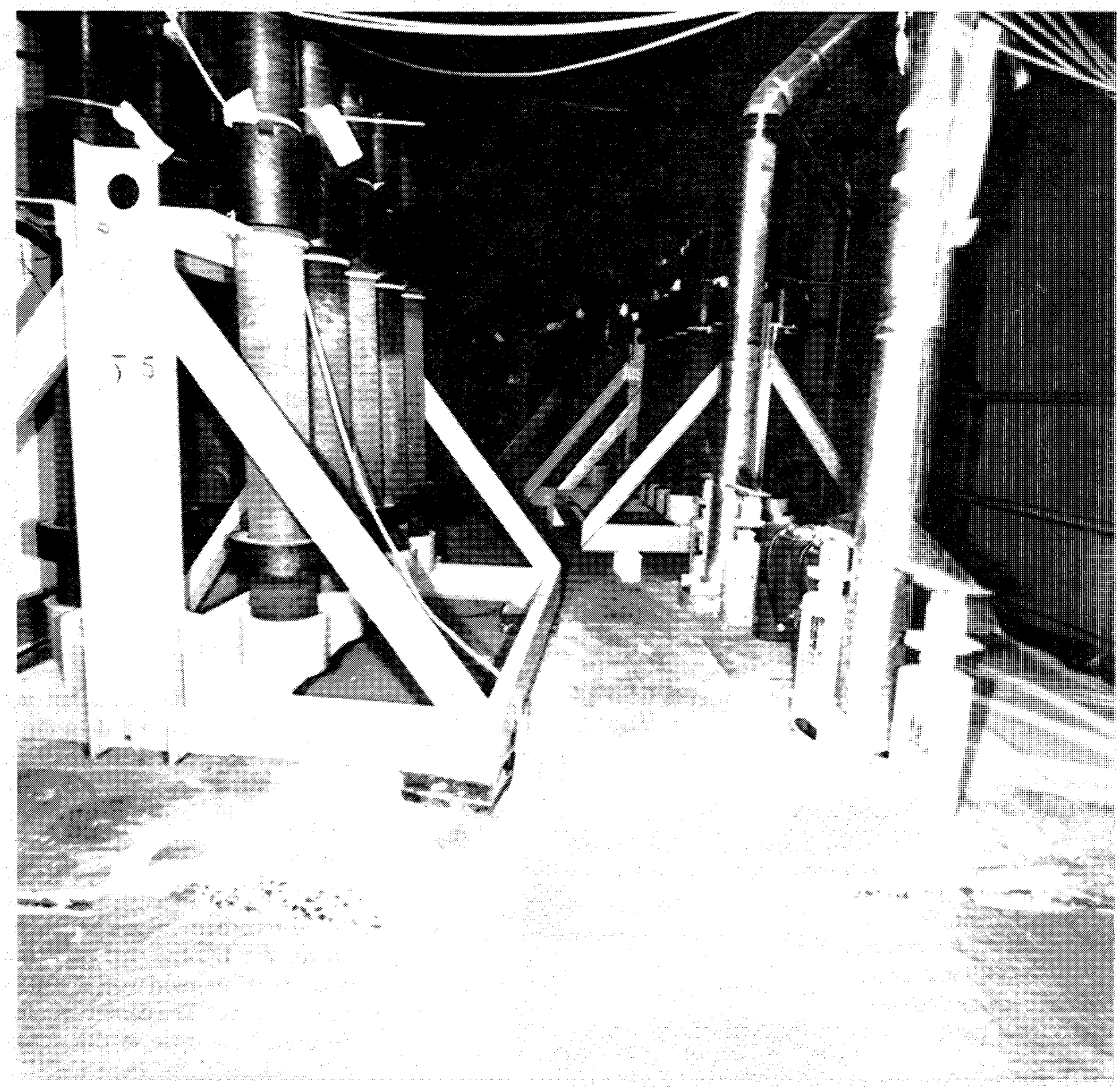


Photo 7-2. Scabbled Floor on El. 347'

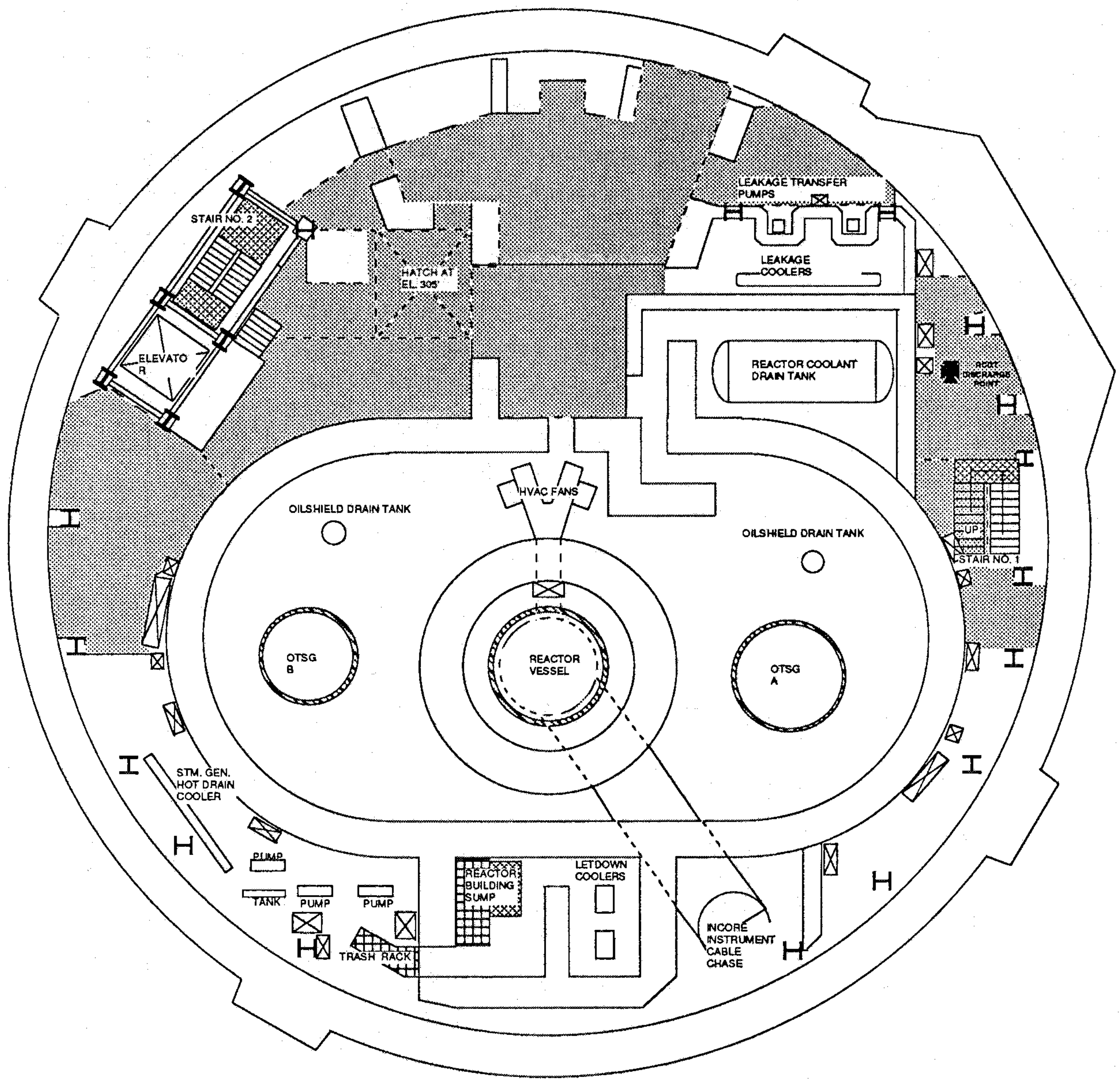


Figure 7-3. Containment Basement Floor Plan Showing Areas Accessible to Remotely Operated Vehicles

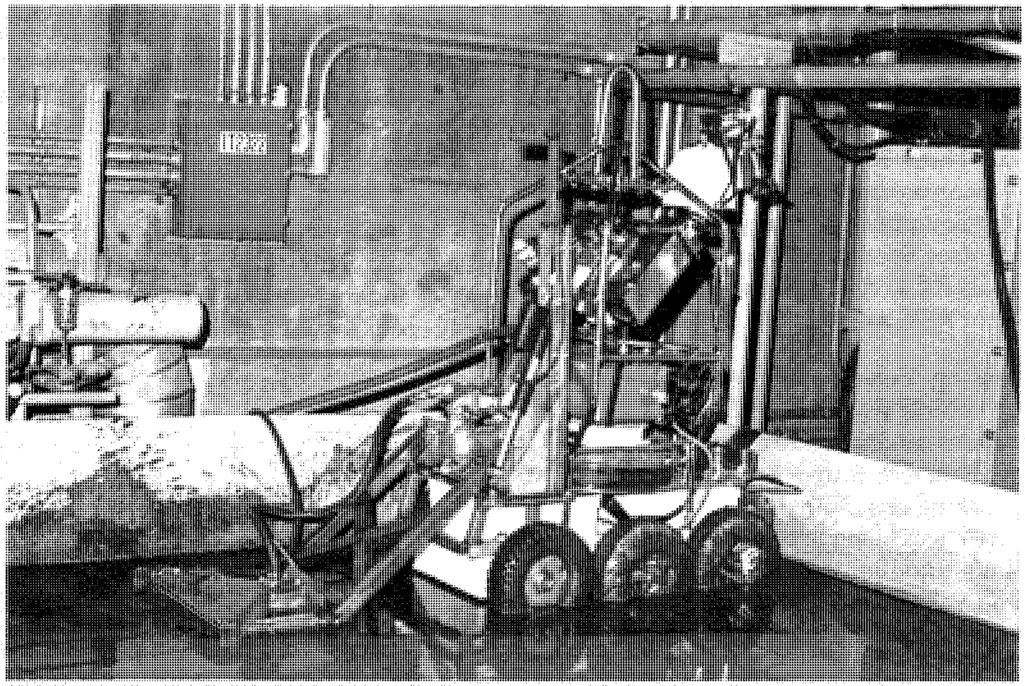


Photo 7-3. RRV with Sediment Pickup Device

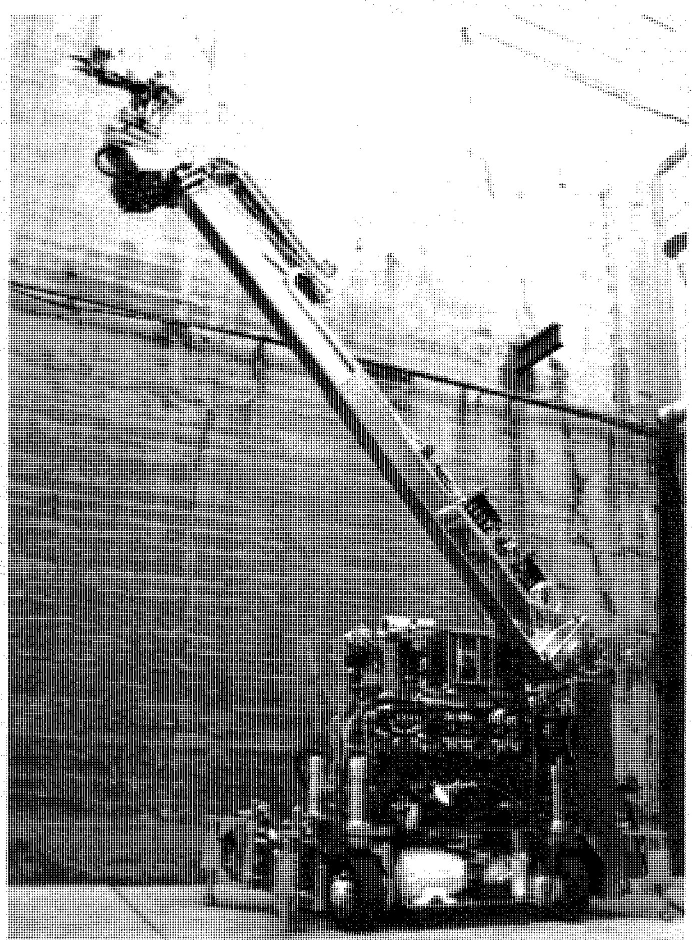


Photo 7-4. Remote Work Vehicle — Workhorse

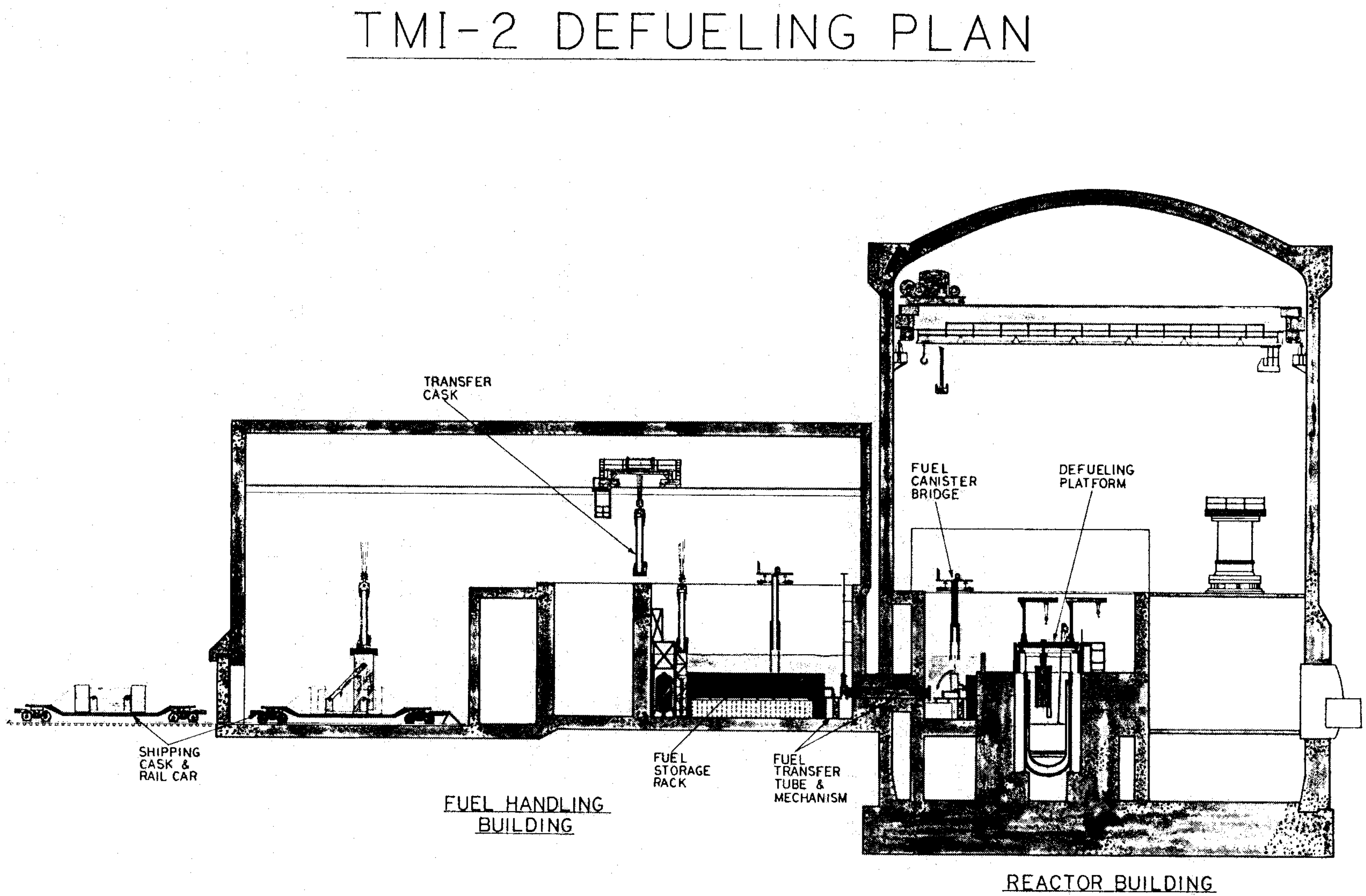


Figure 8-1. TMI-2 Defueling Plan

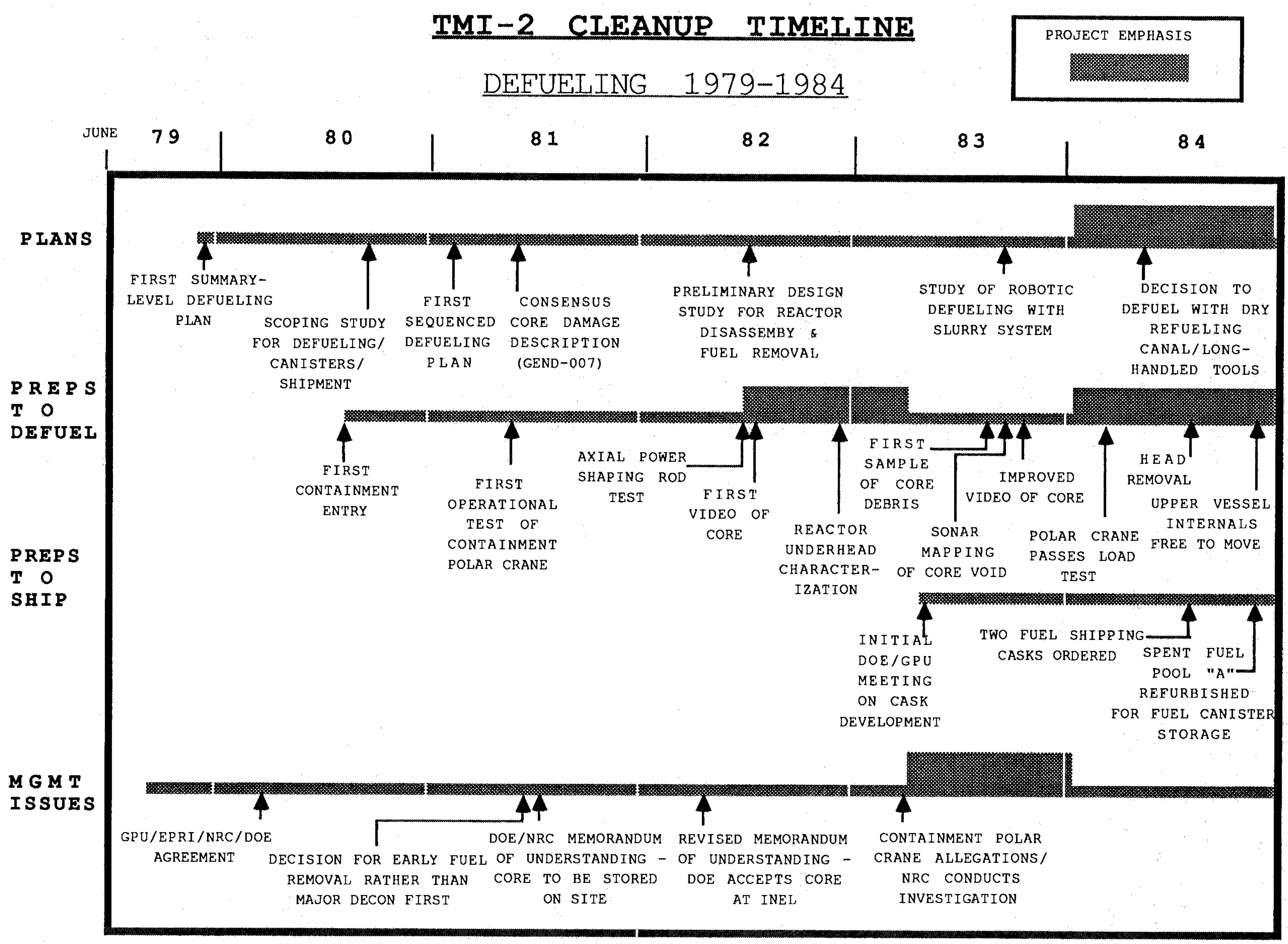


Figure 8-2a. TMI-2 Cleanup Timeline: Defueling 1979–1984

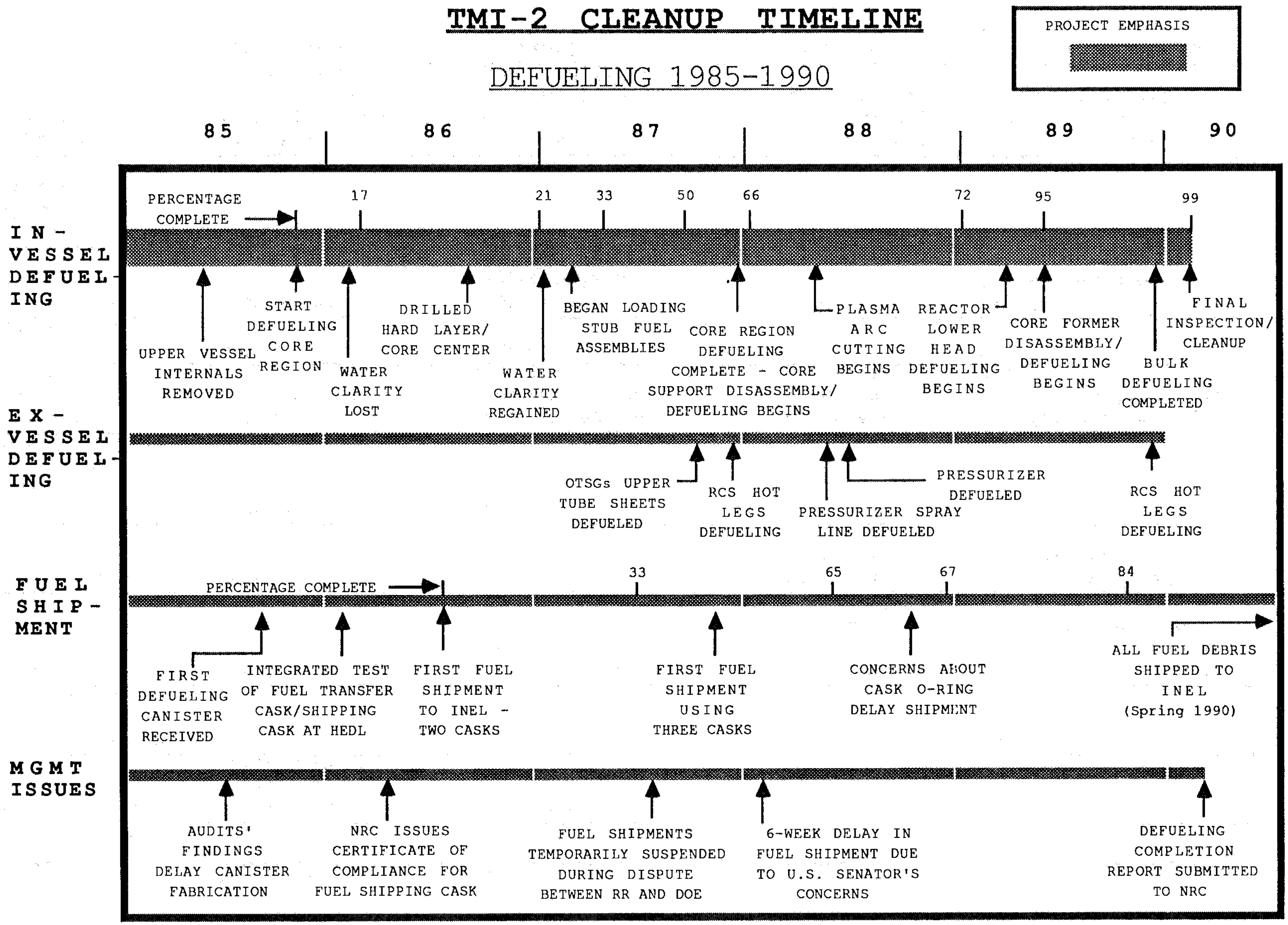


Figure 8-2b. TMI-2 Cleanup Timeline: Defueling 1985–1990

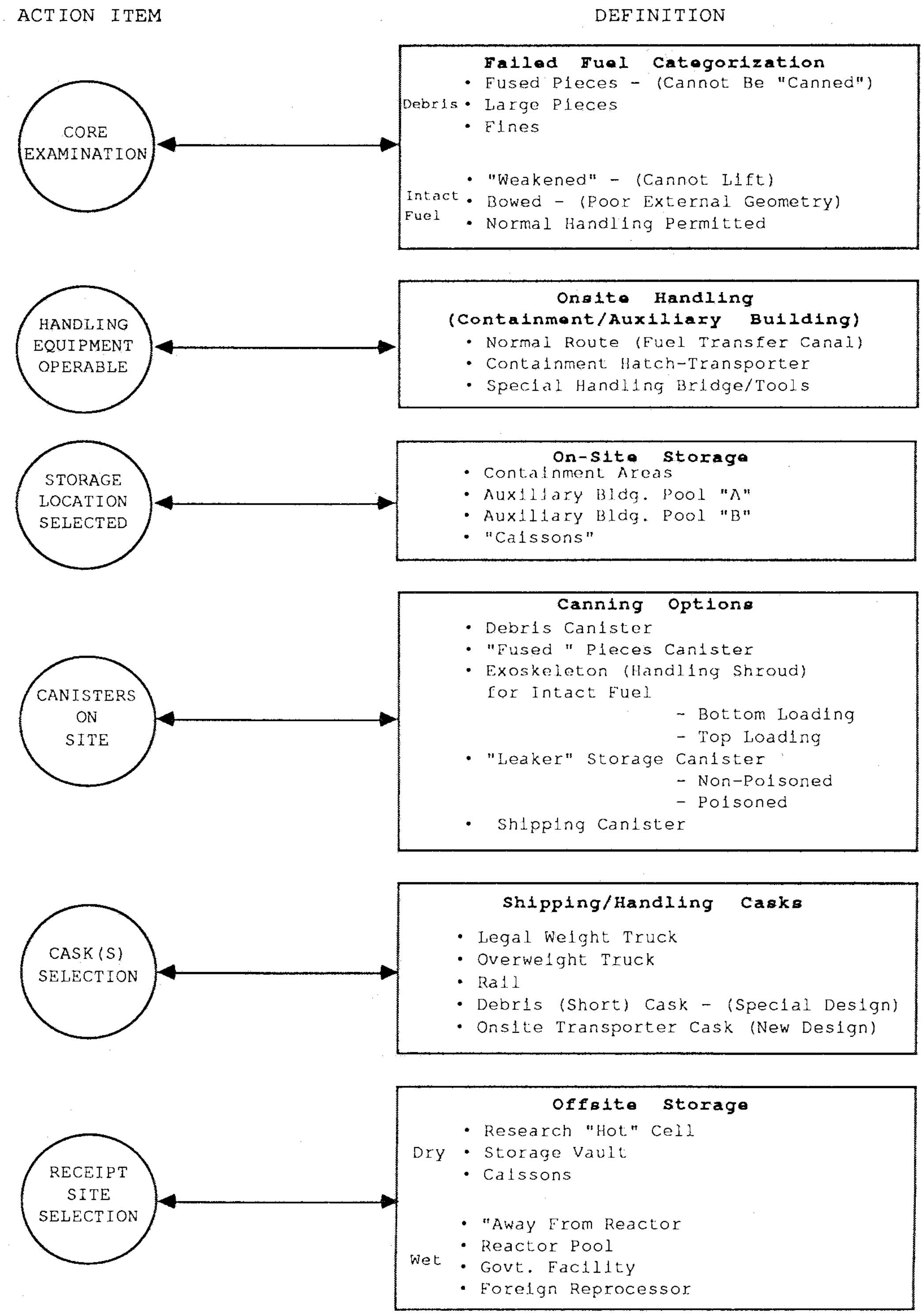


Figure 8-3. Key Decision Areas for TMI-2 Defueling

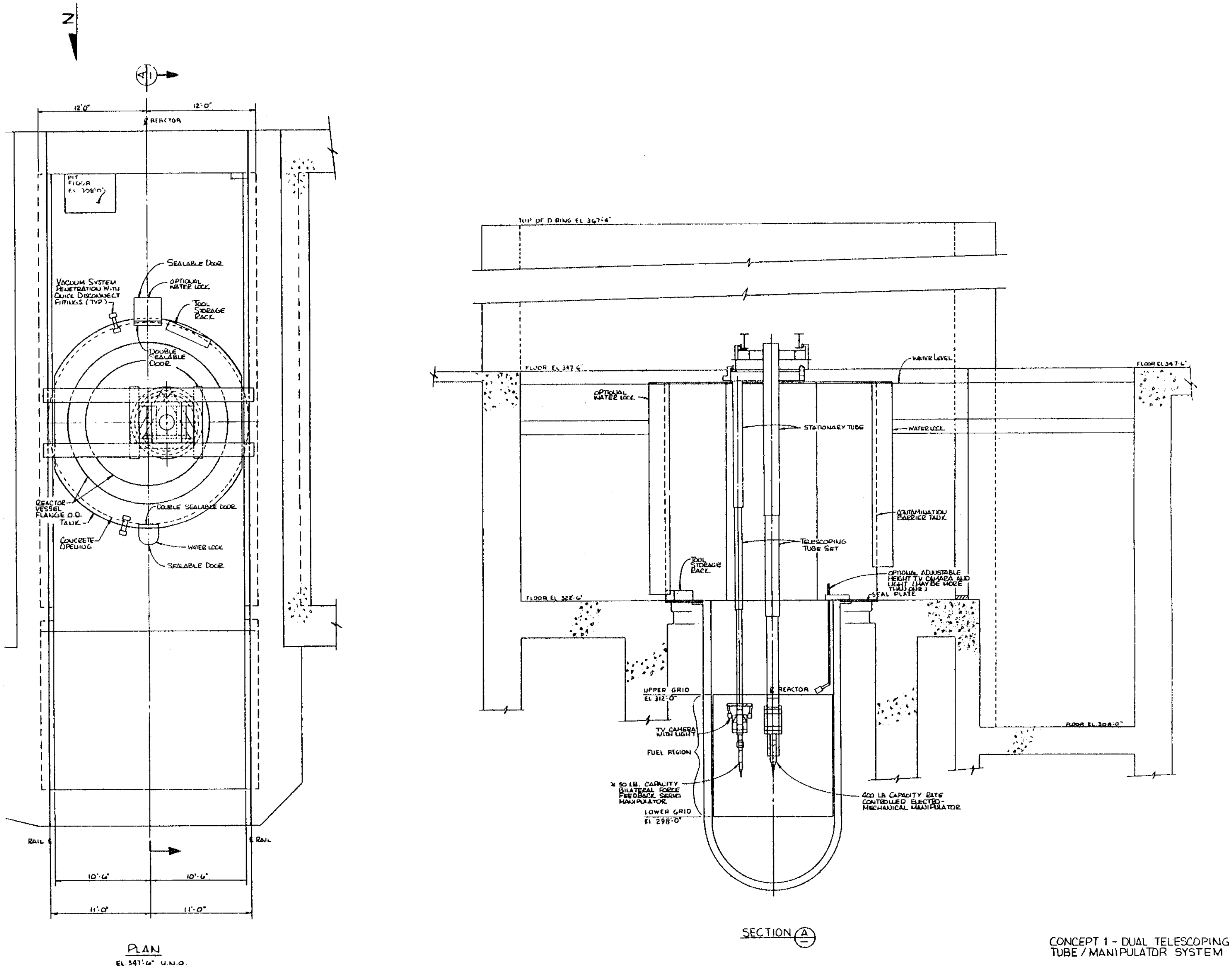


Figure 8-4. Dual Telescoping Tube/Manipulator System

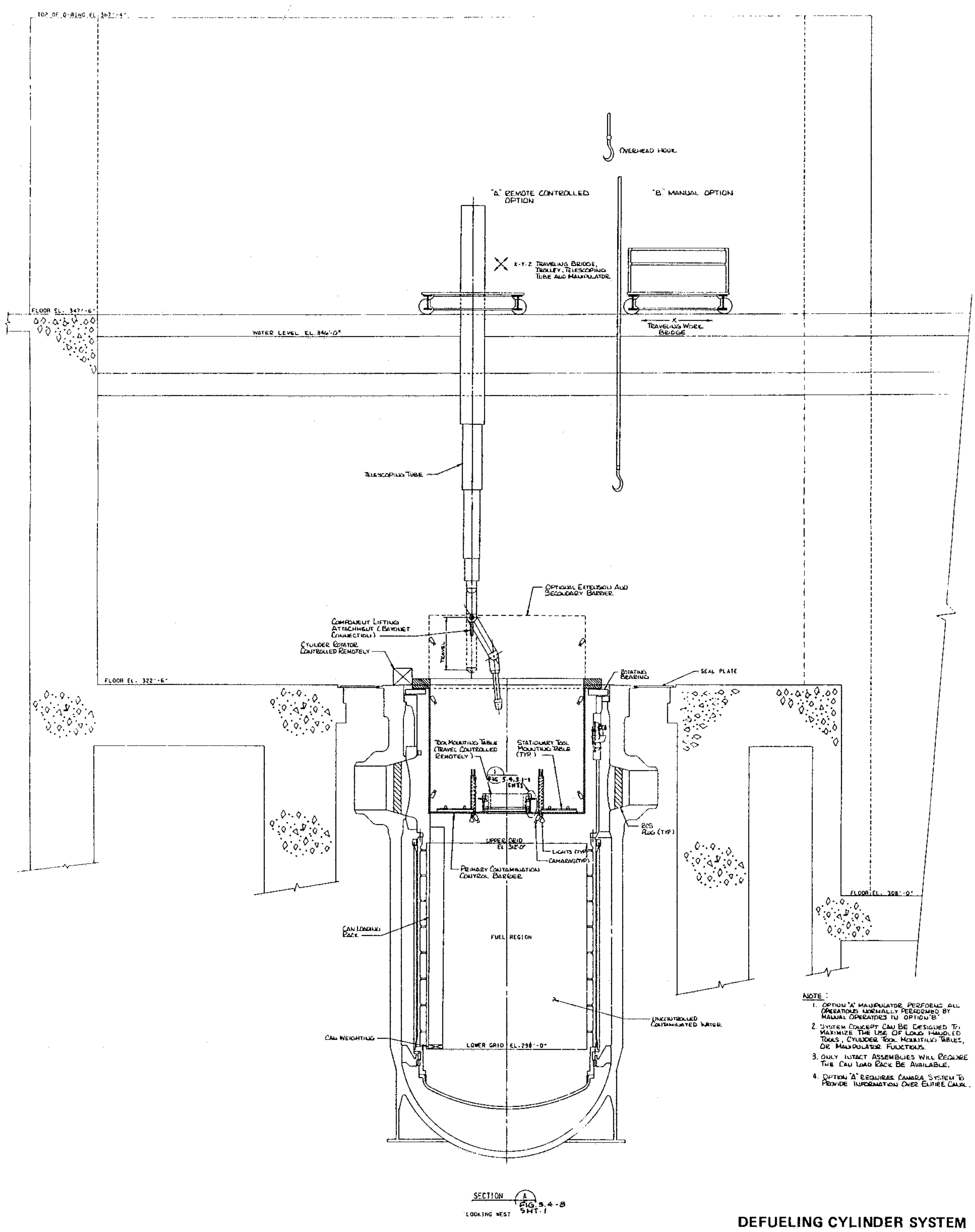


Figure 8-5. Manual Defueling Cylinder System

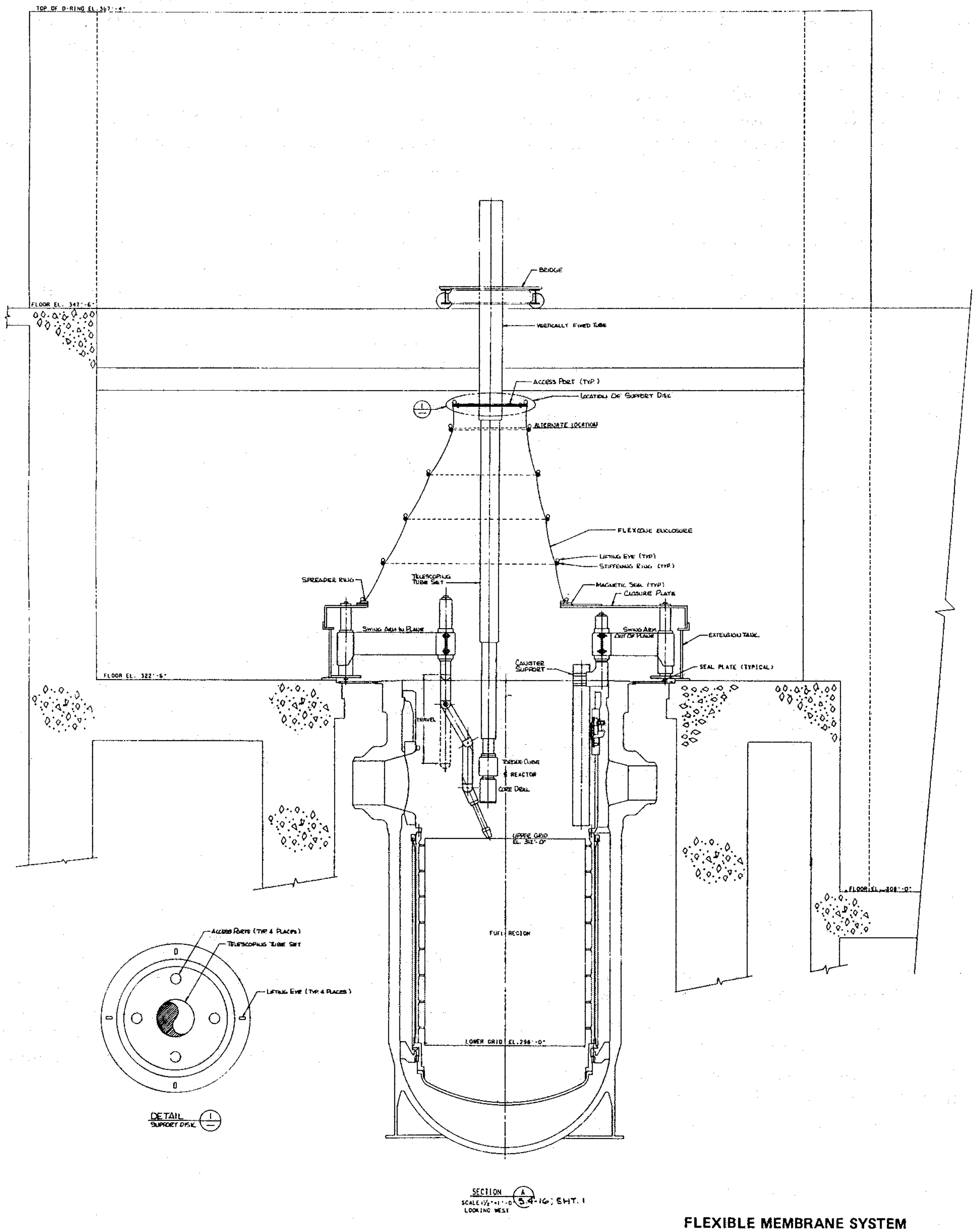


Figure 8-6. Flexible Membrane Defueling System

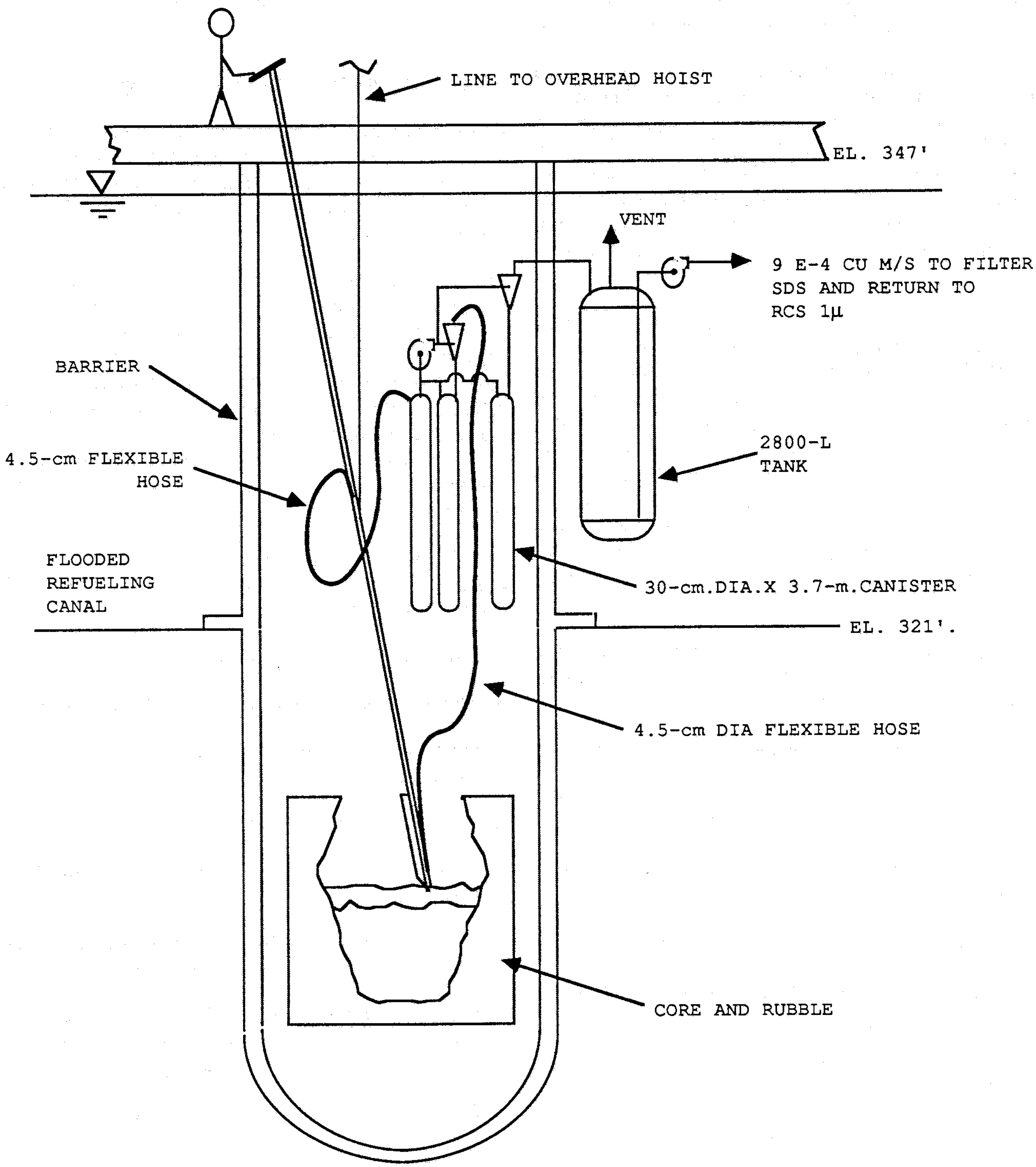


Figure 8-7. Proposed Reactor Core Rubble Removal System

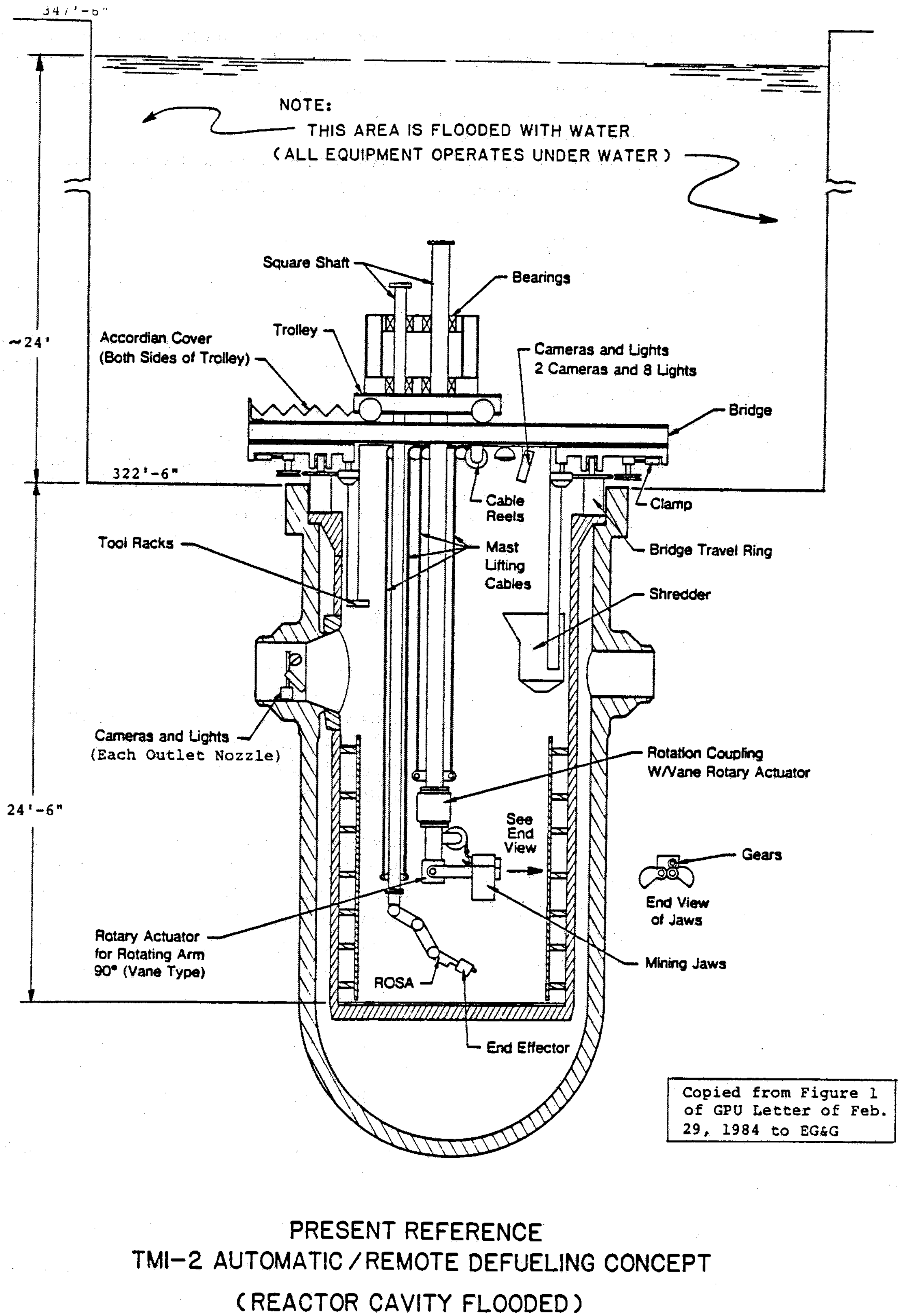
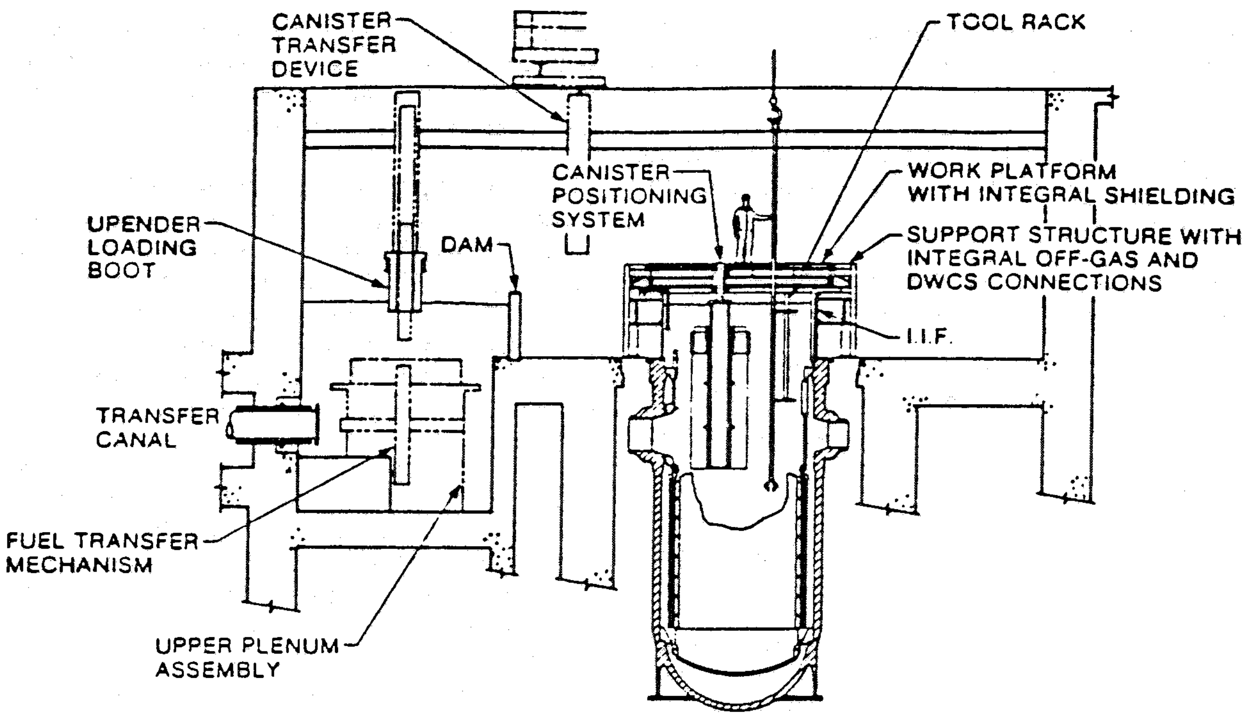
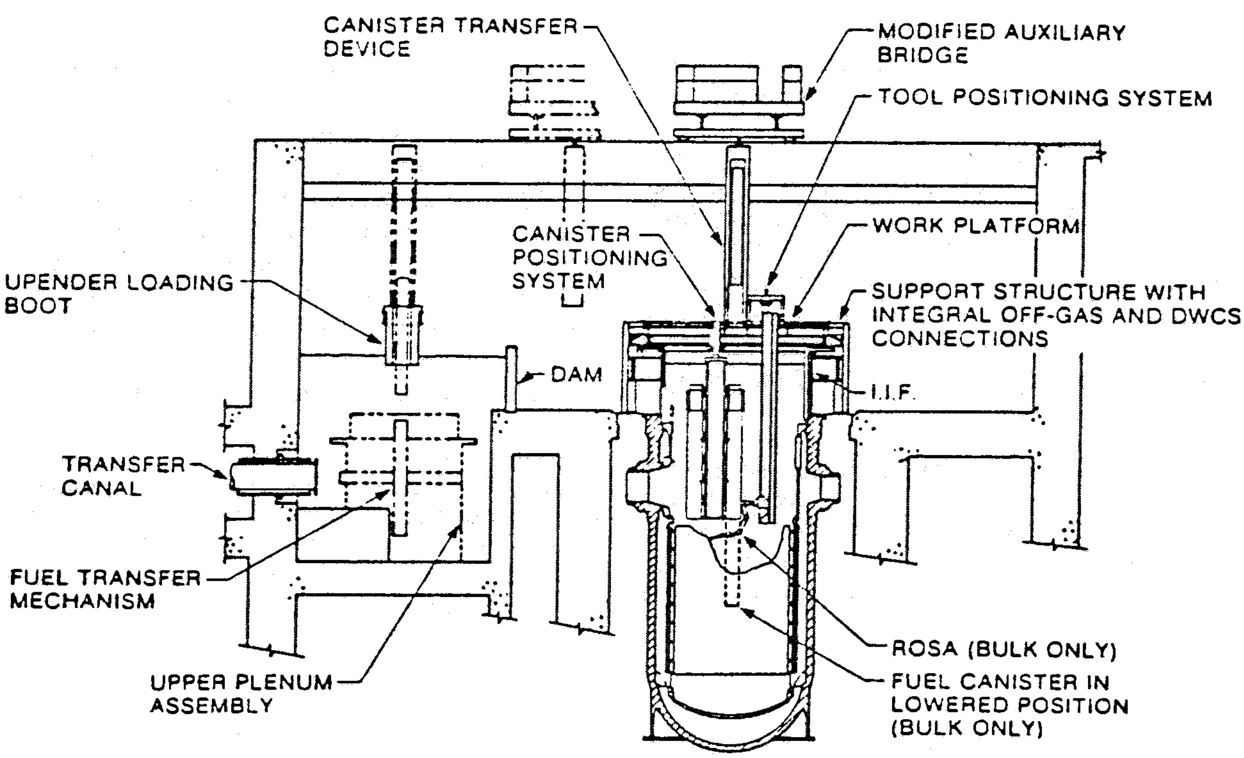


Figure 8-8. Automatic/Remote Defueling Concept



Early defueling system.



Bulk defueling system.

Figure 8-9. Early and Bulk Defueling Systems

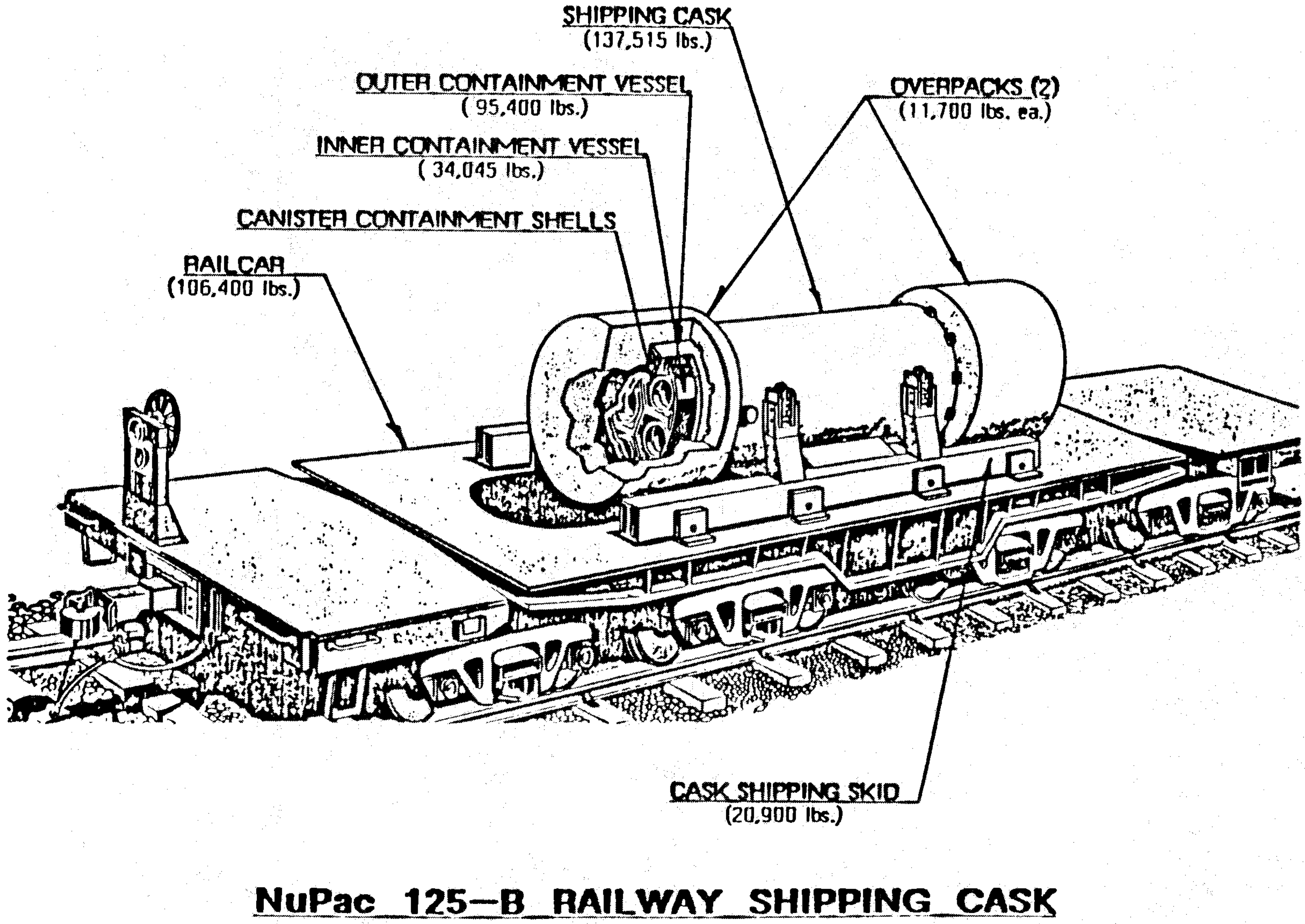


Figure 8-10. Fuel Shipping Cask

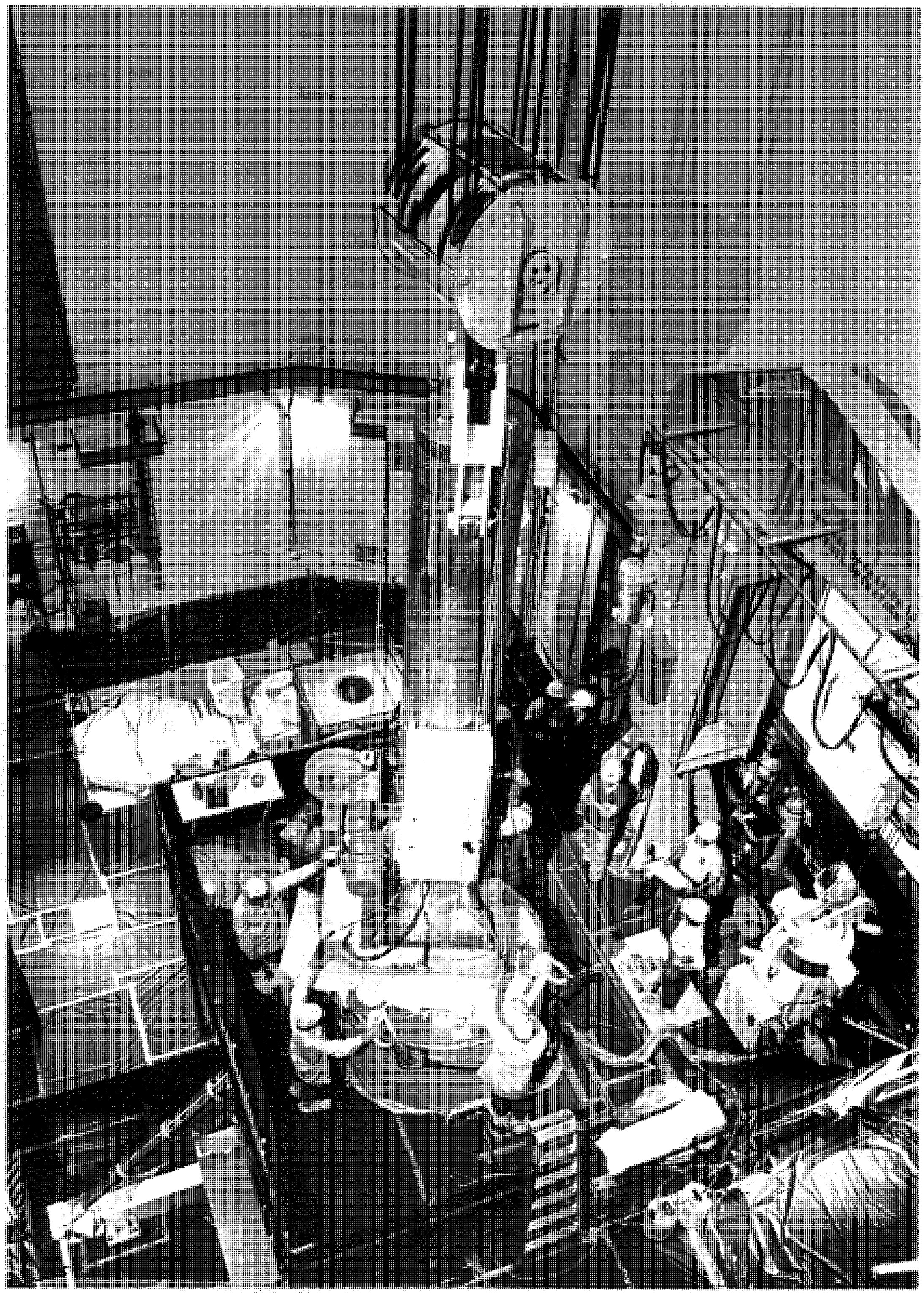


Photo 8-1. Fuel Shipping Cask Loading Station

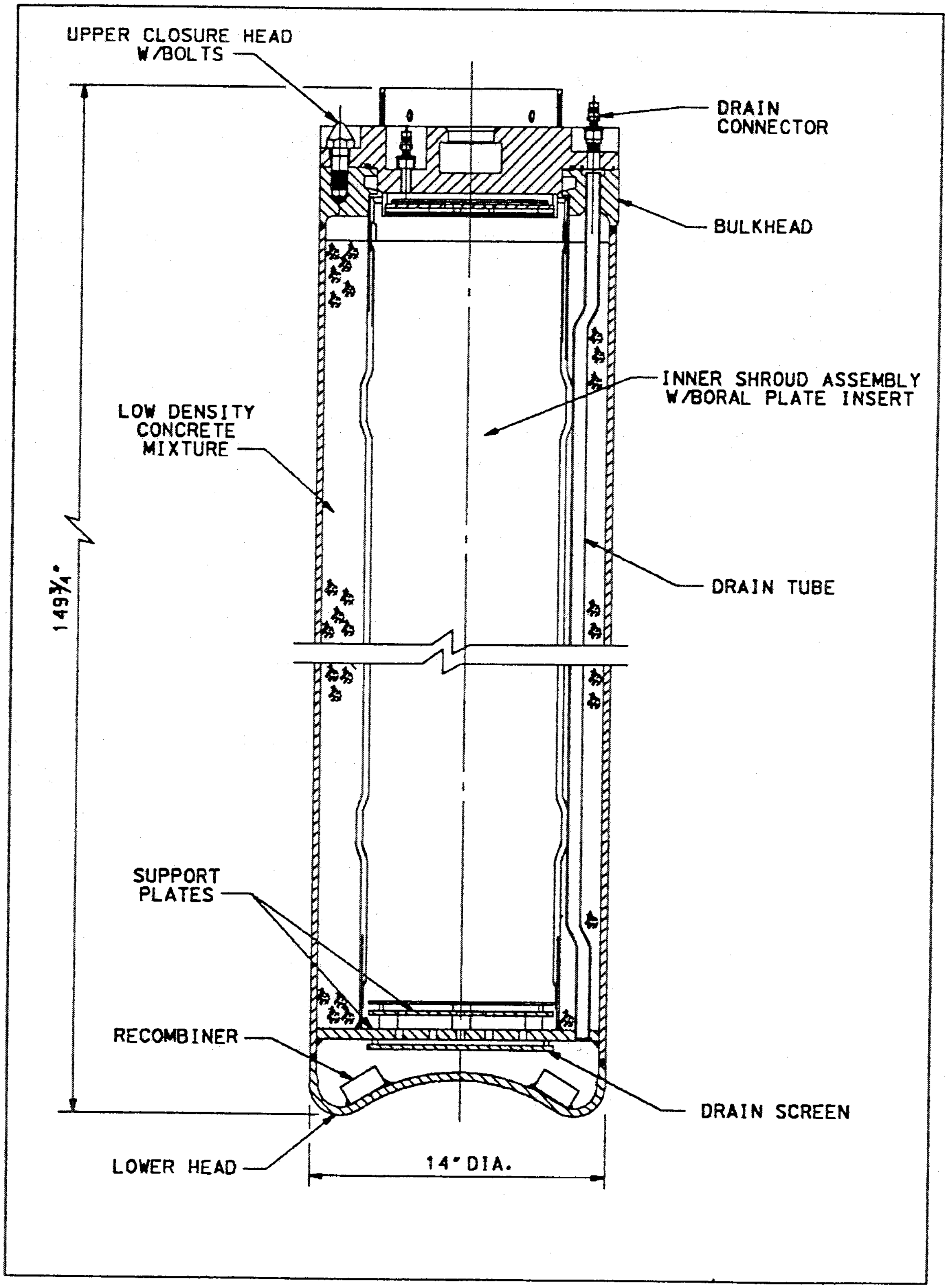


Figure 8-11. Fuel Canister

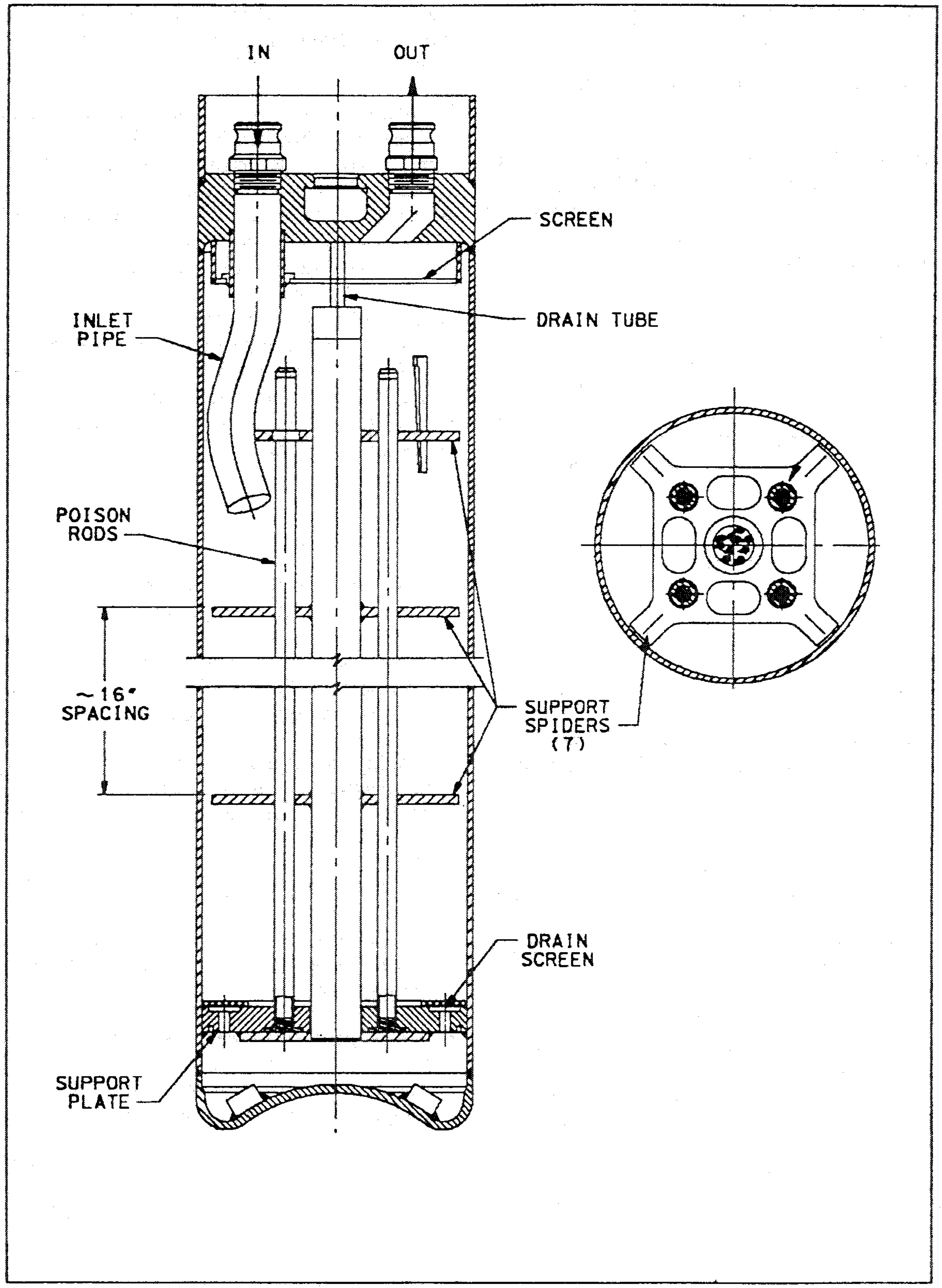


Figure 8-12. Knockout Canister

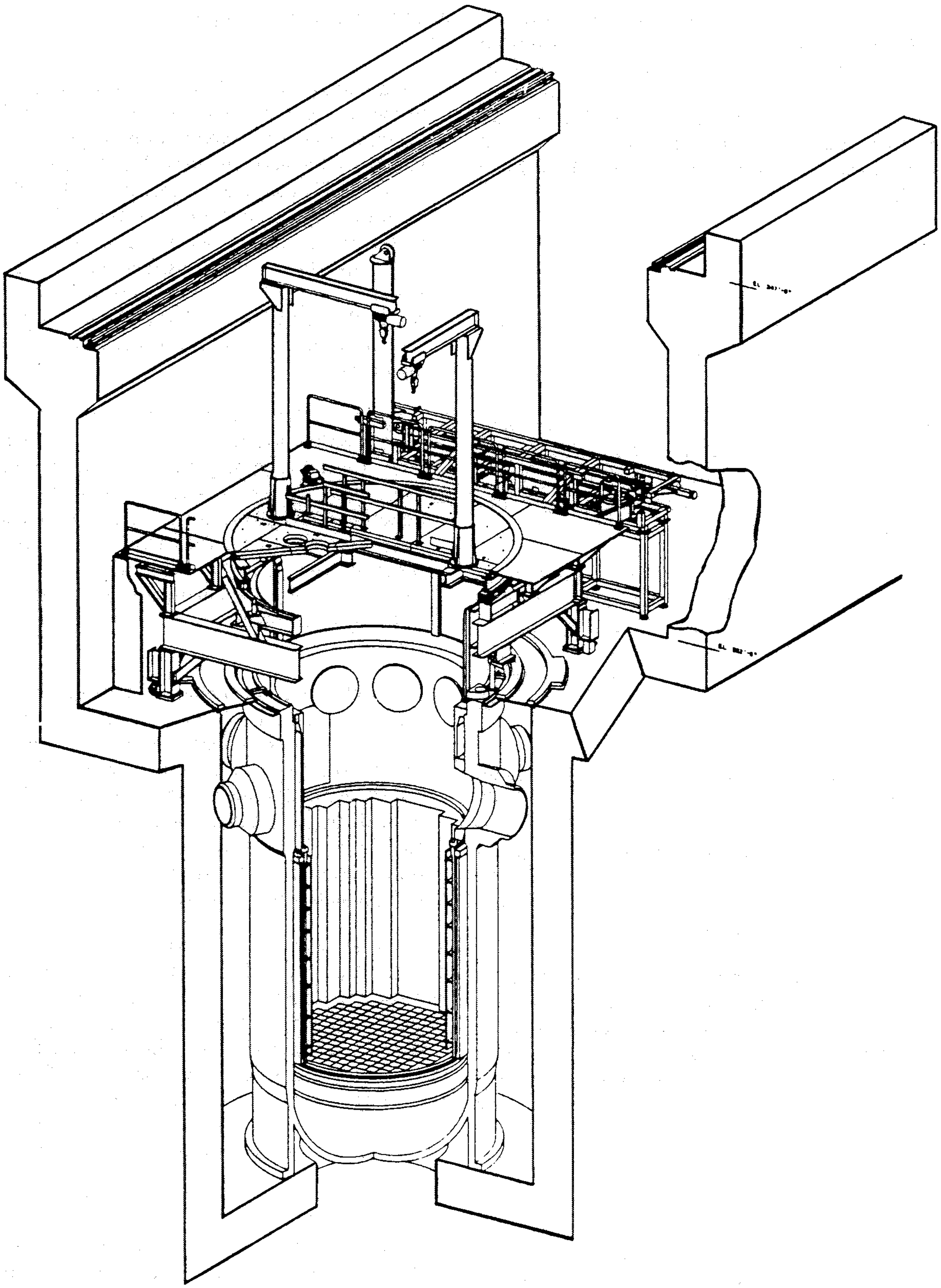


Figure 8-13. Reactor Vessel with work Platform

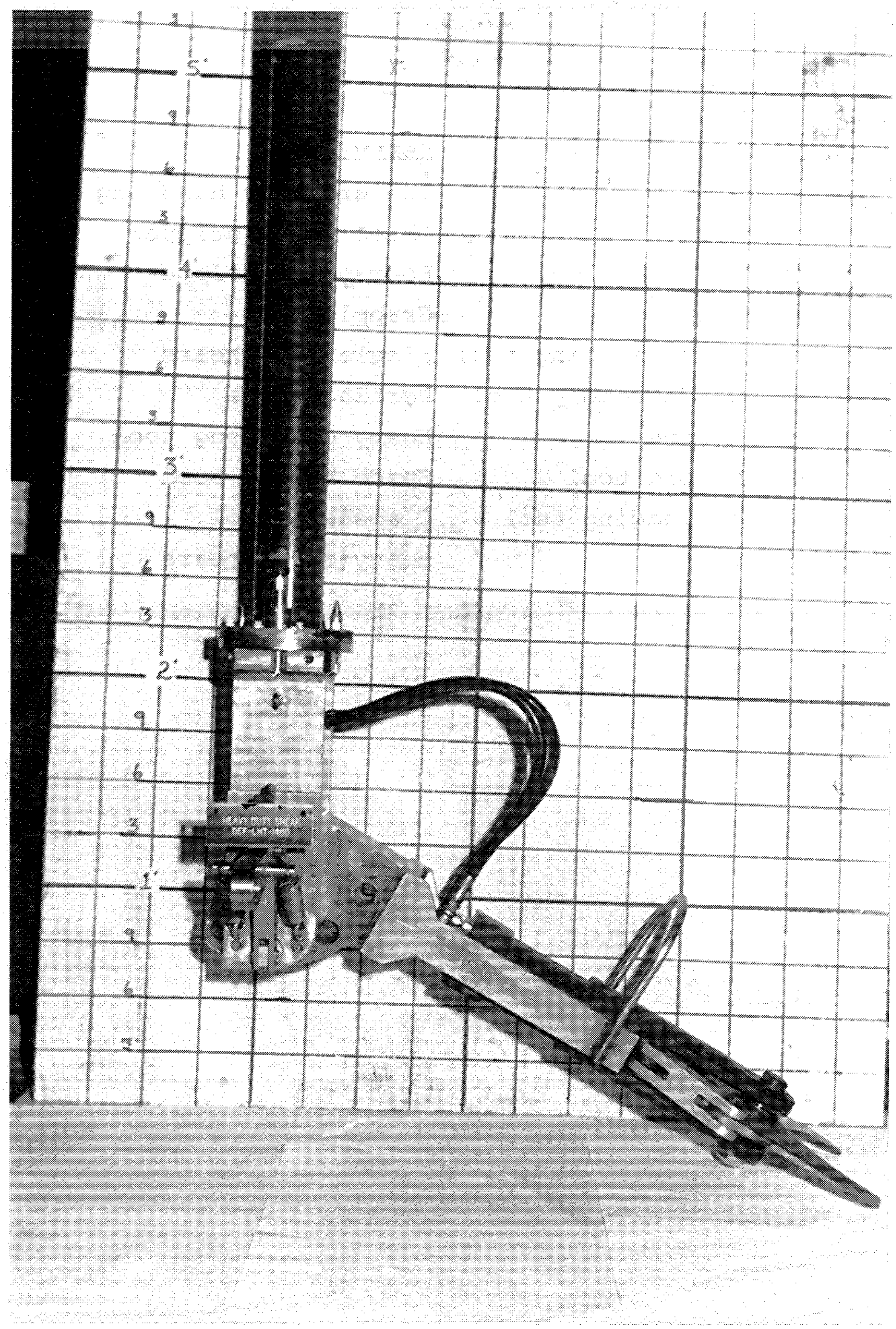


Photo 8-2. Heavy Duty Shears

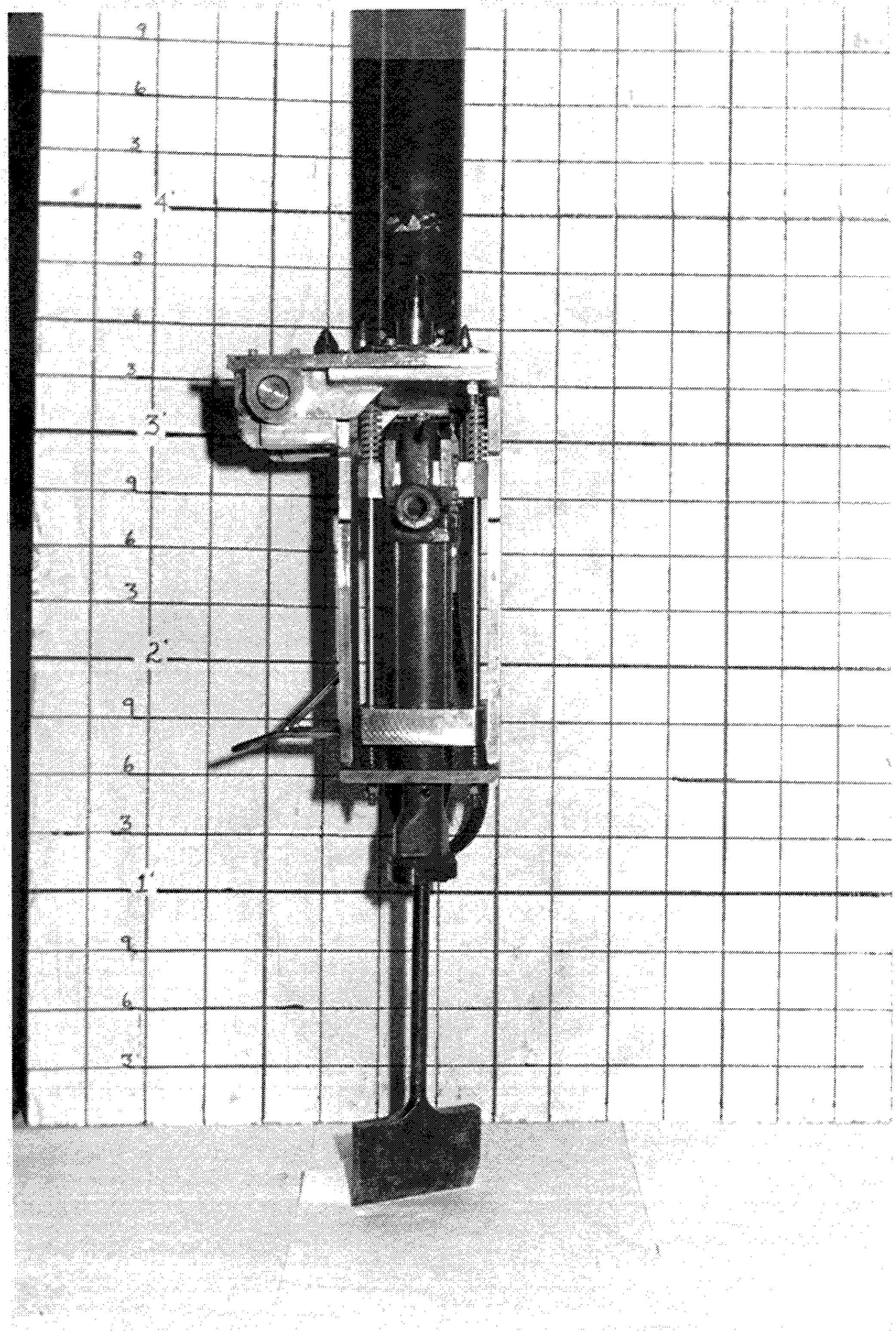


Photo 8-3. Chisel Tool

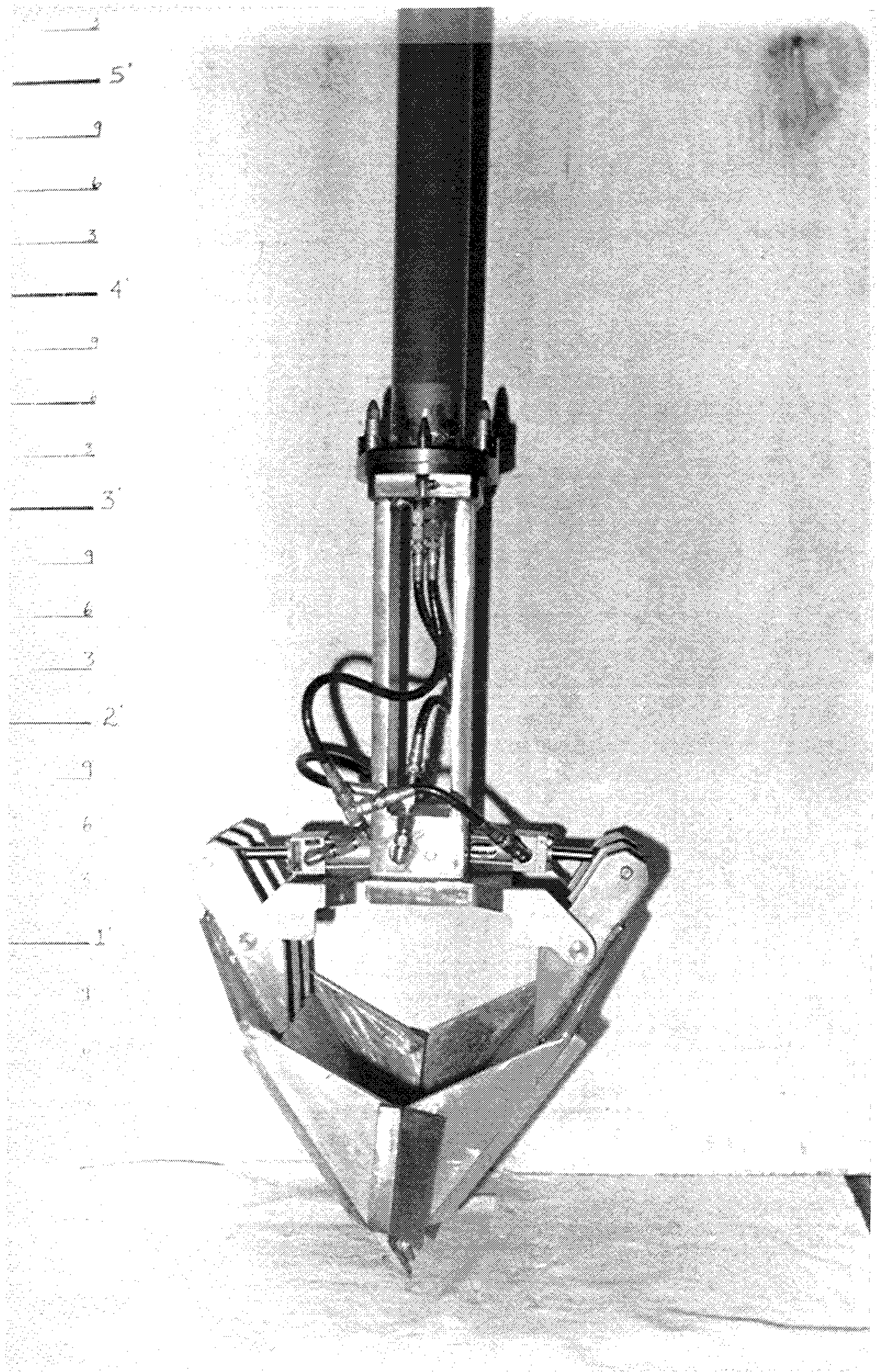


Photo 8-4. Spade Bucket Tool

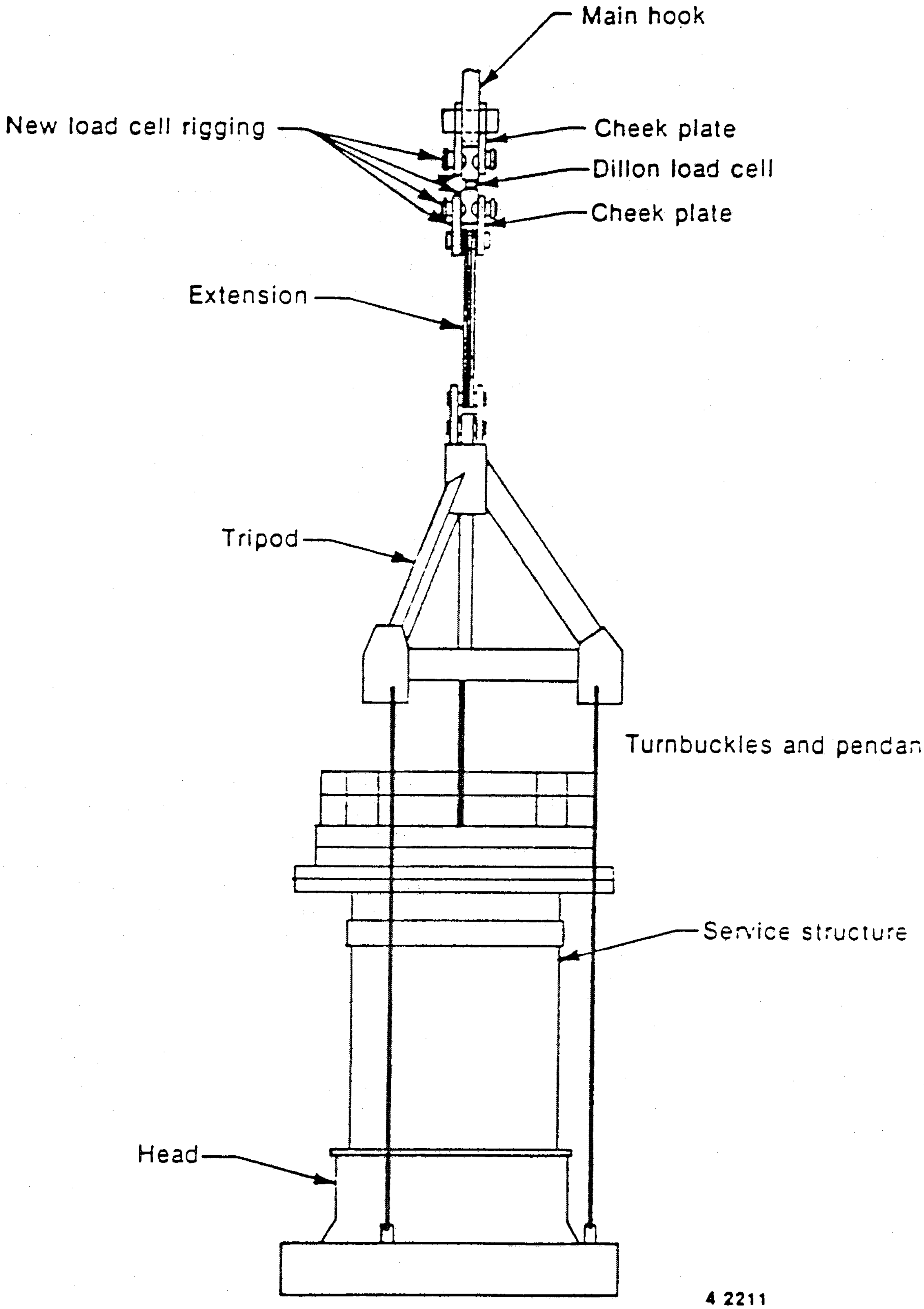


Figure 8-14. Reactor Vessel Head and Service Structure with Rigging

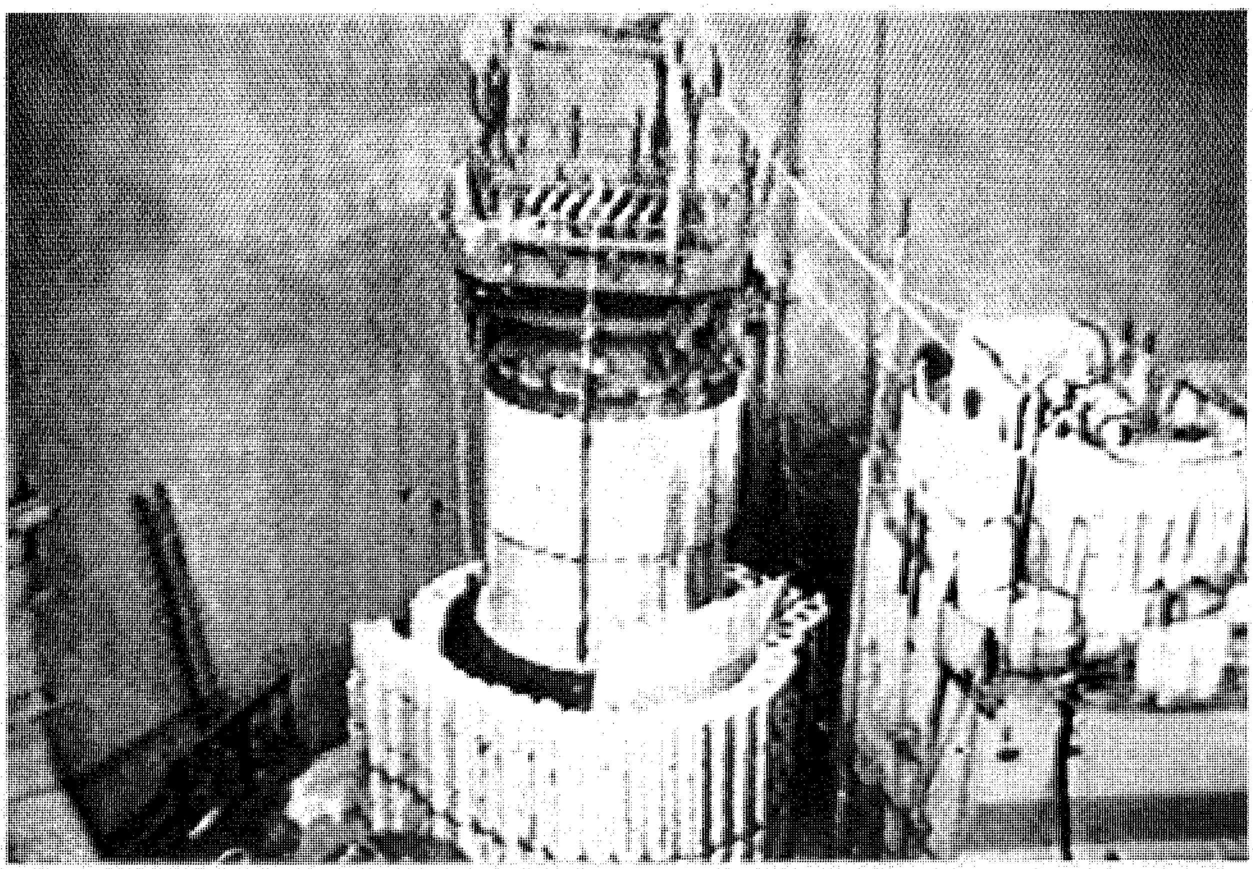


Photo 8-5. Reactor Vessel Head Being Lowered onto Storage Stand

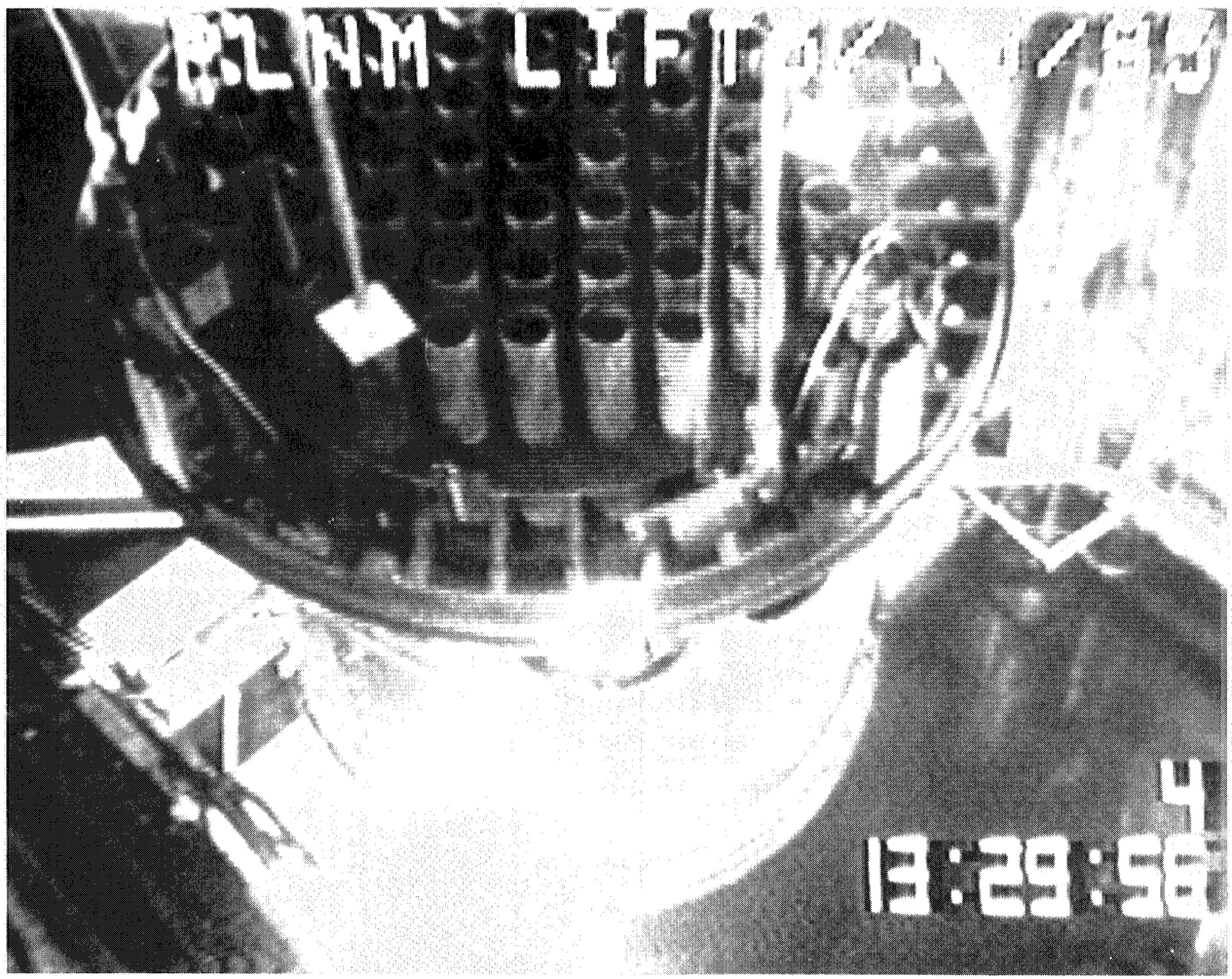


Photo 8-6. Plenum Removal

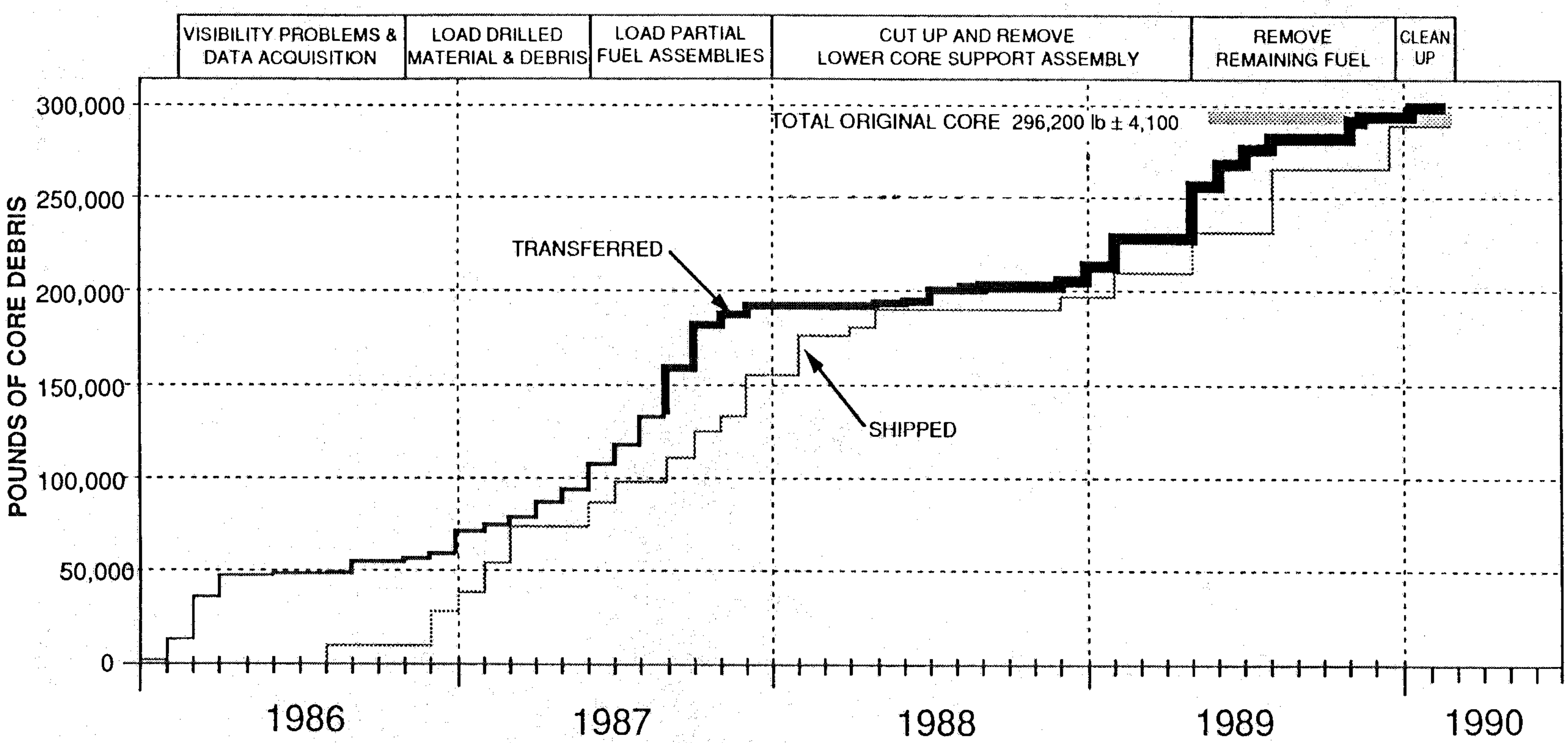


Figure 8-15. TMI-2 Defueling Progress

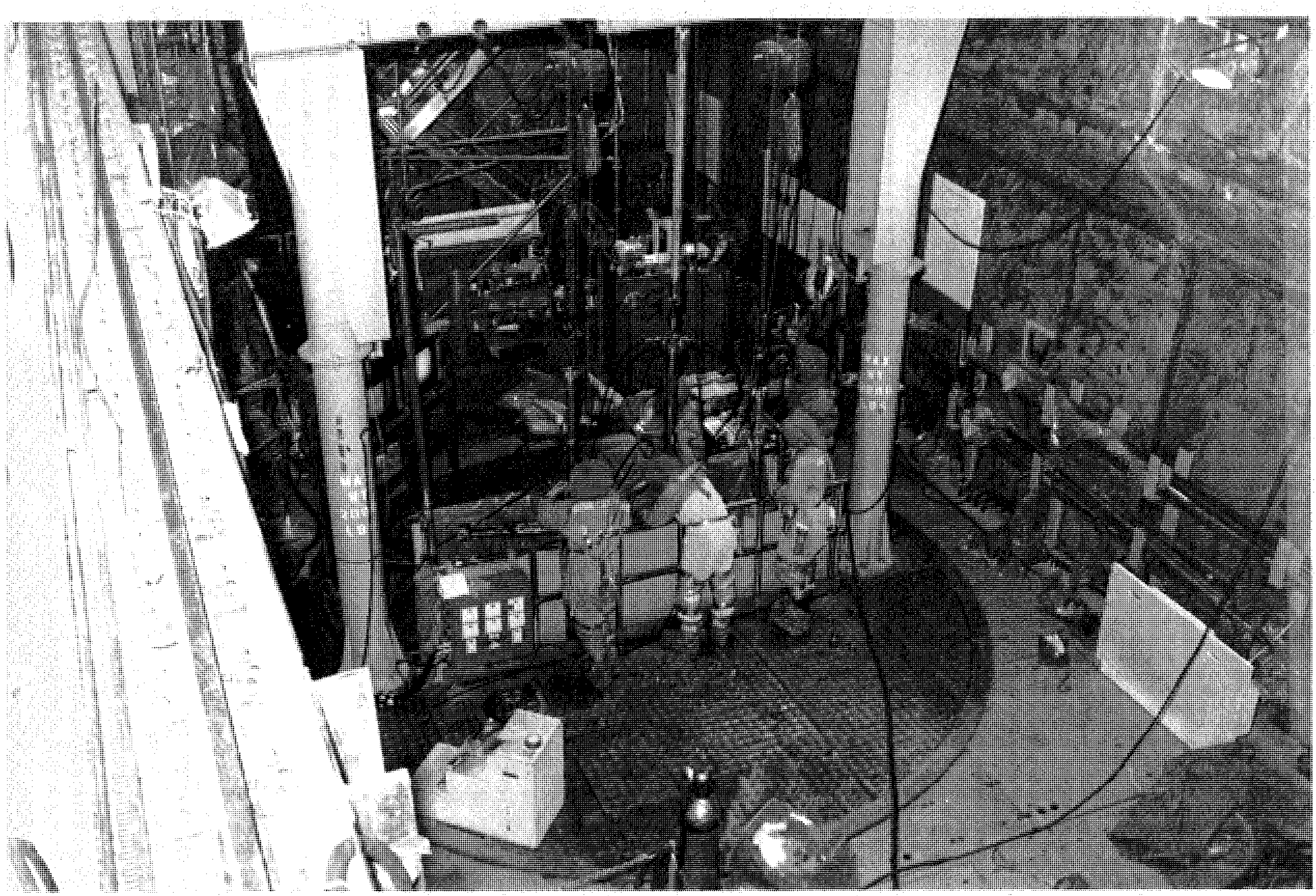


Photo 8-7. Operators on the Defueling Work Platform

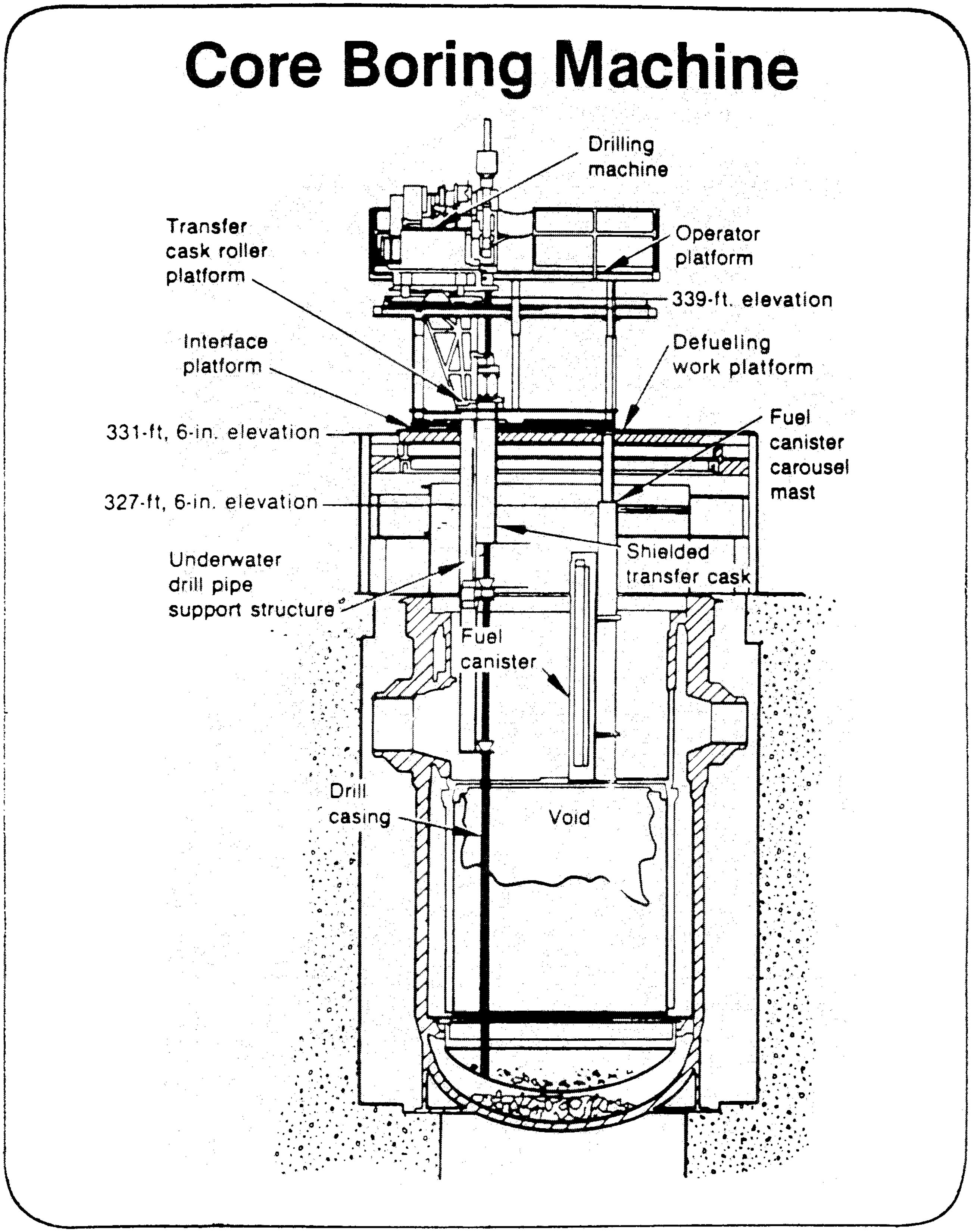


Figure 8-16. Core Boring Machine

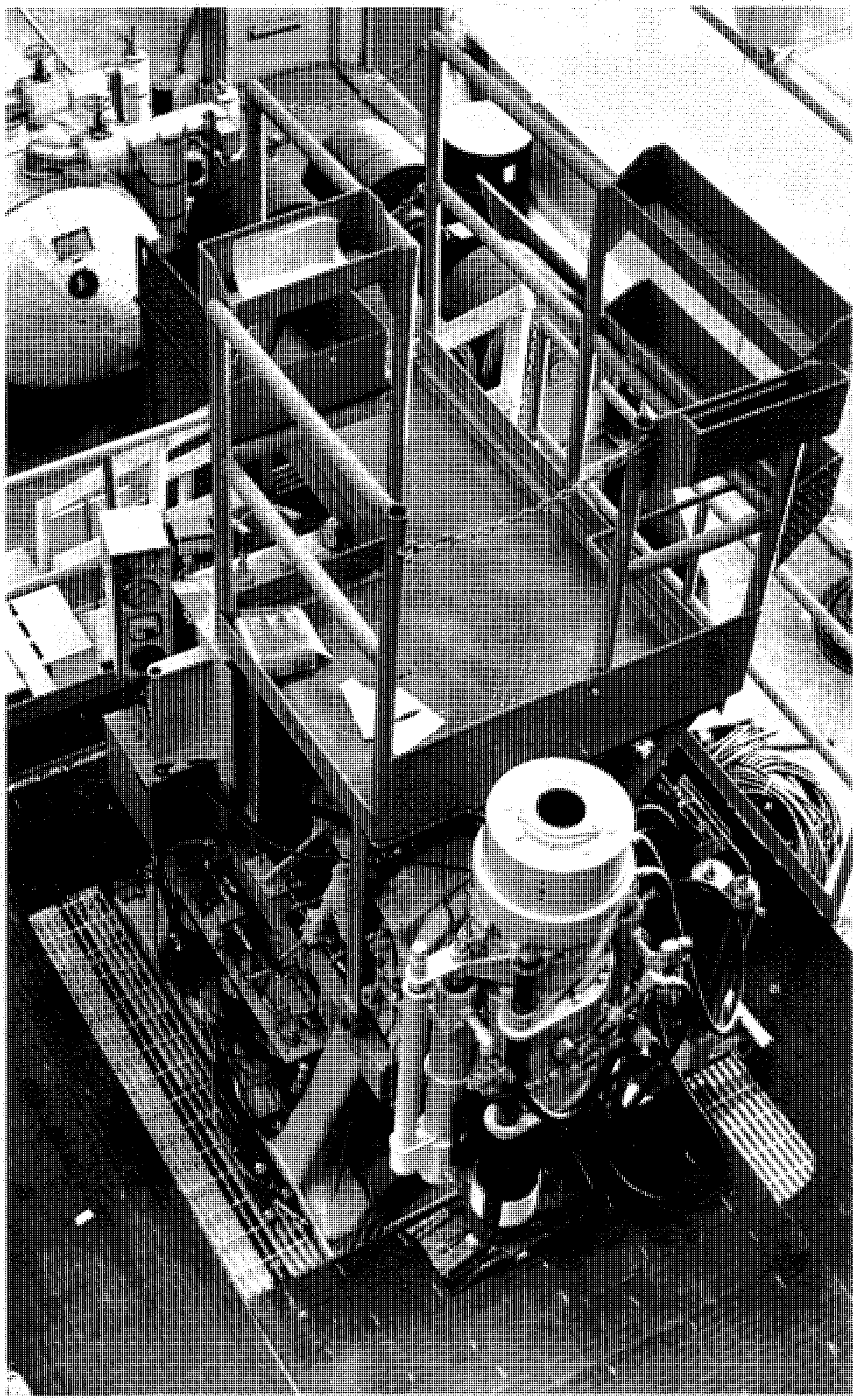


Photo 8-8. Core Boring Machine in Turbine Building

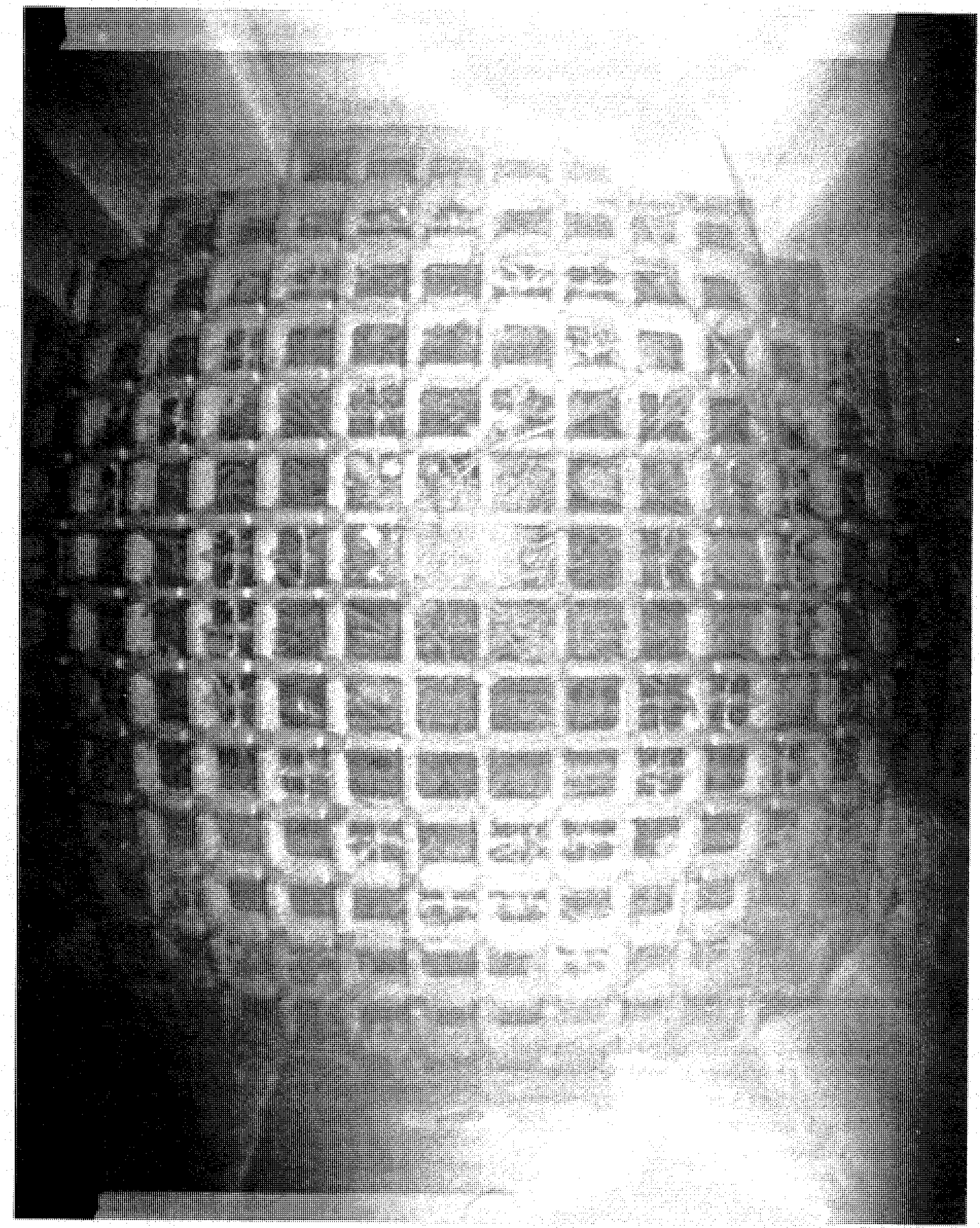


Photo 8-9. Reactor Core Region Looking Down from the Work Platform to the Lower Grid Rib Assembly

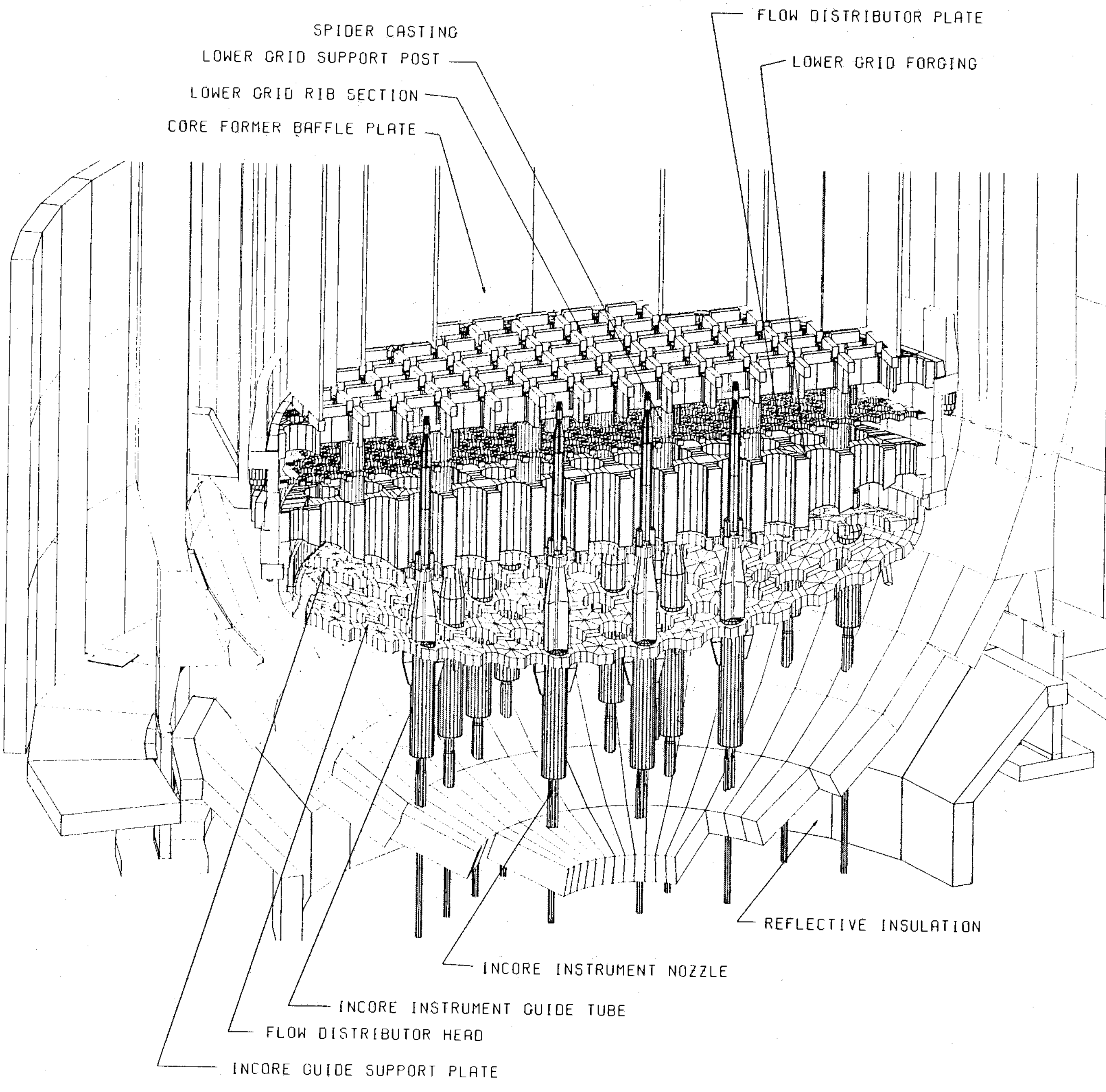


Figure 8-17. Lower Core Support Assembly

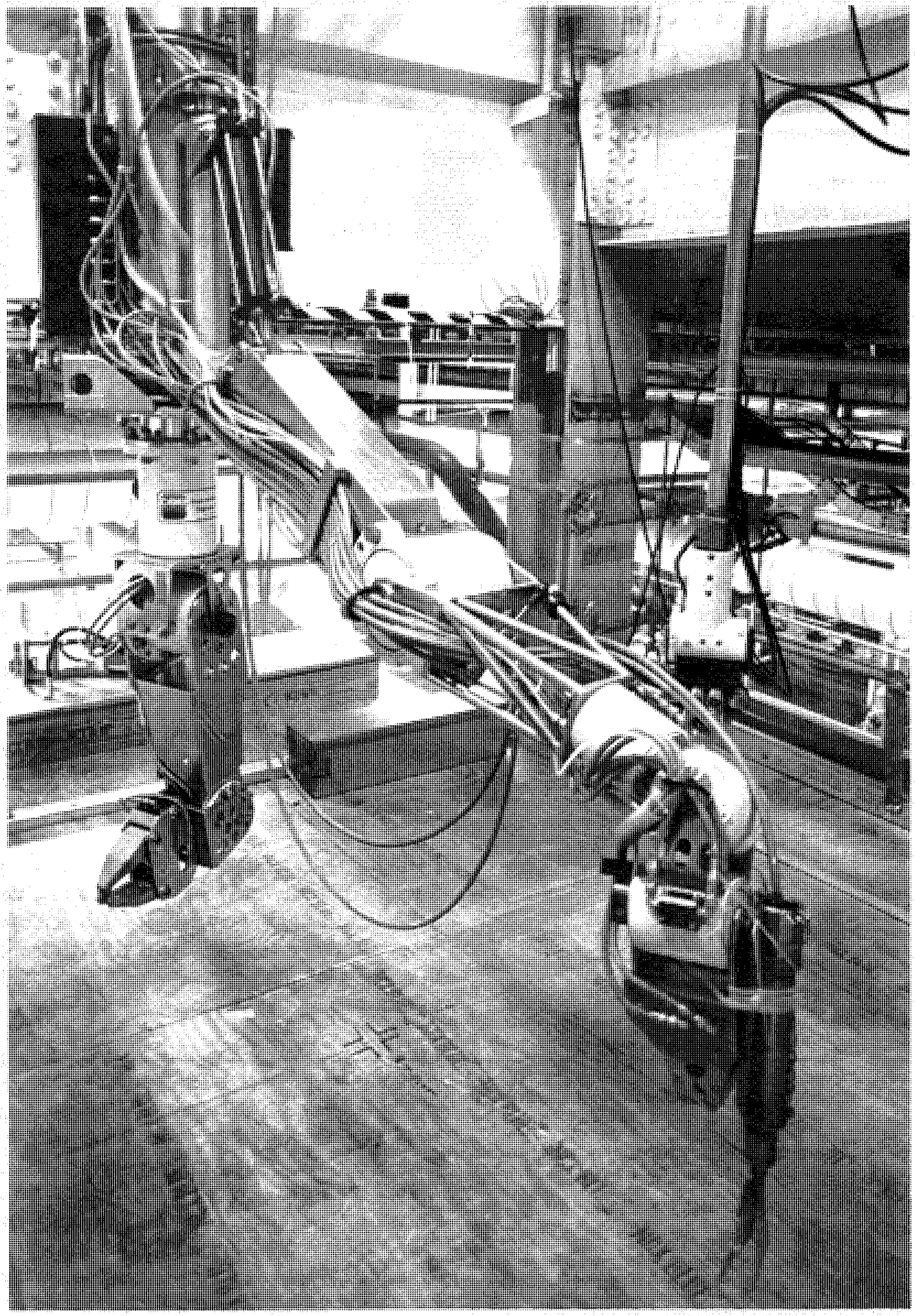


Photo 8-10. MANFRED

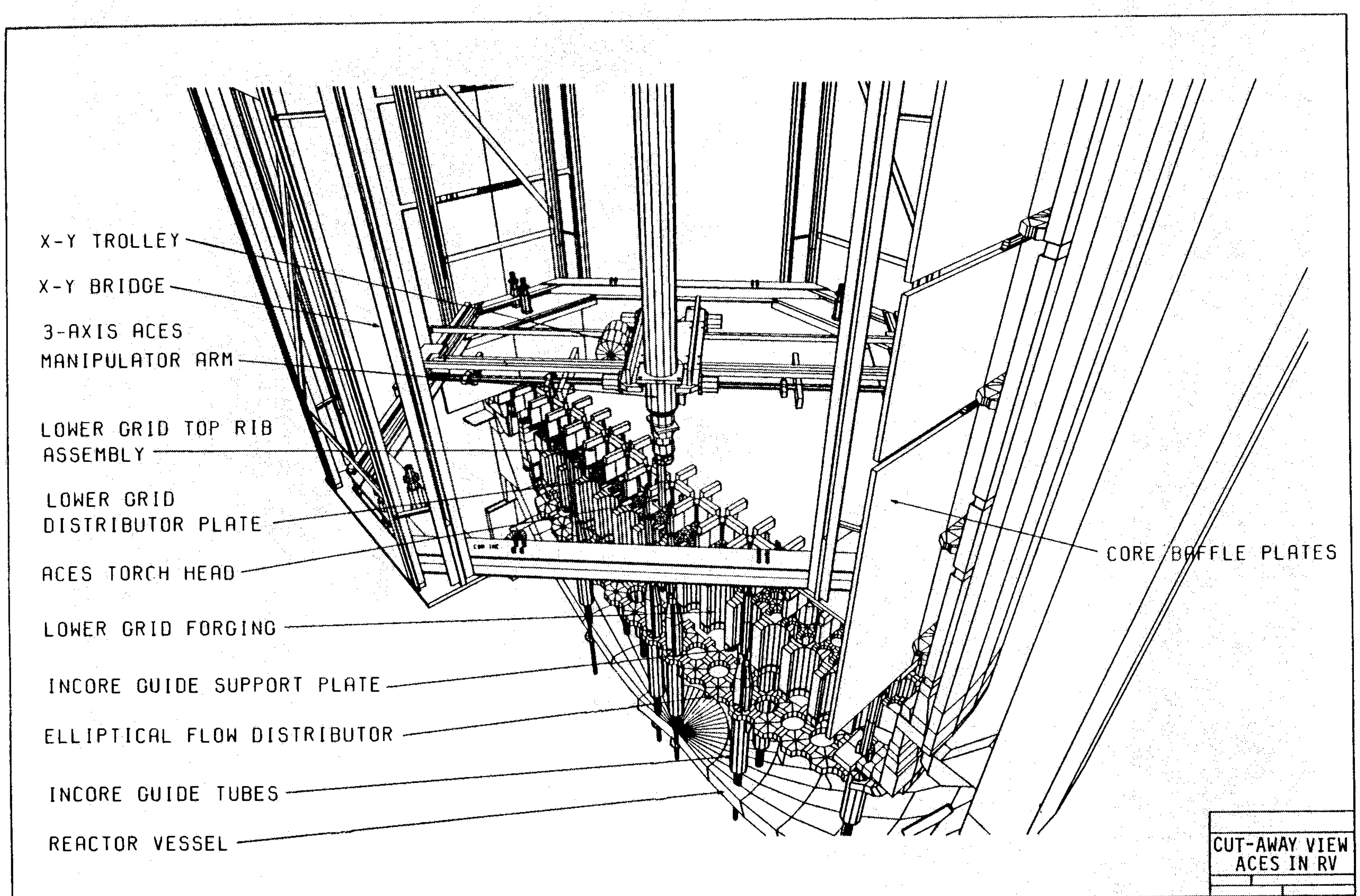


Figure 8-18. Computer View of ACES in the Reactor Vessel

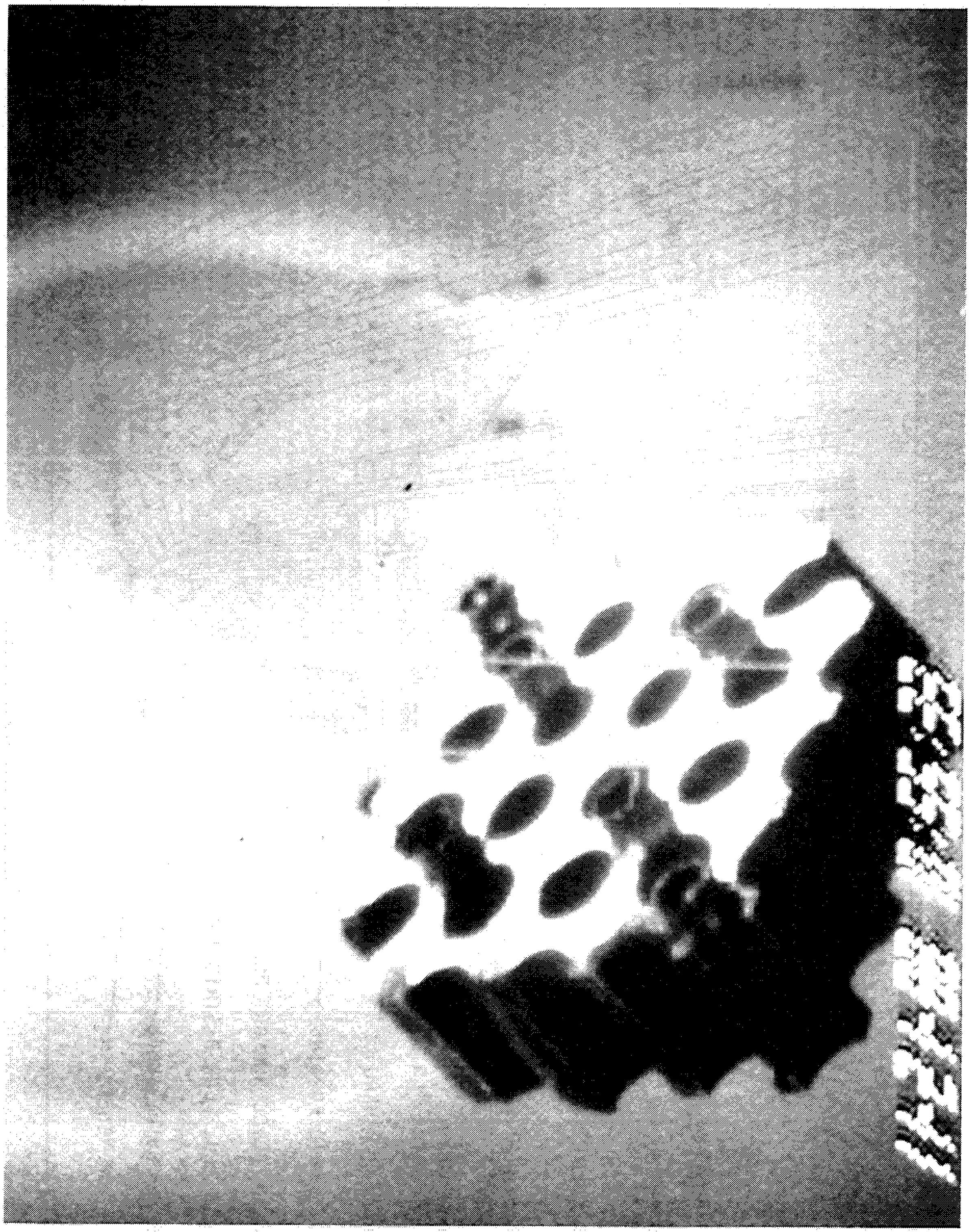


Photo 8-11. Section of the Lower Grid Forging Plate Being Transferred from the Reactor Vessel to Storage

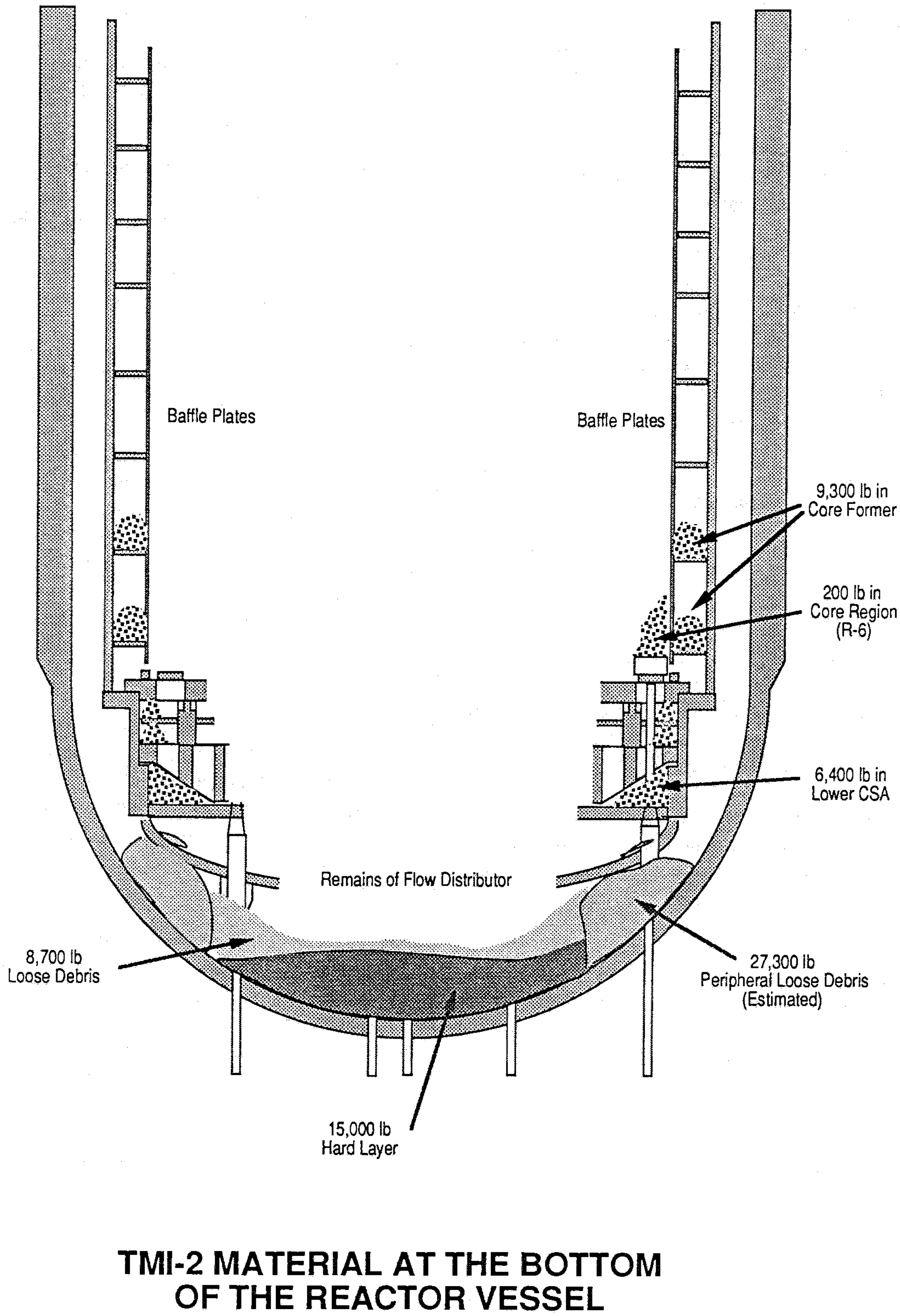


Figure 8-19. Lower Head Cross-section with LCSA Cut Out

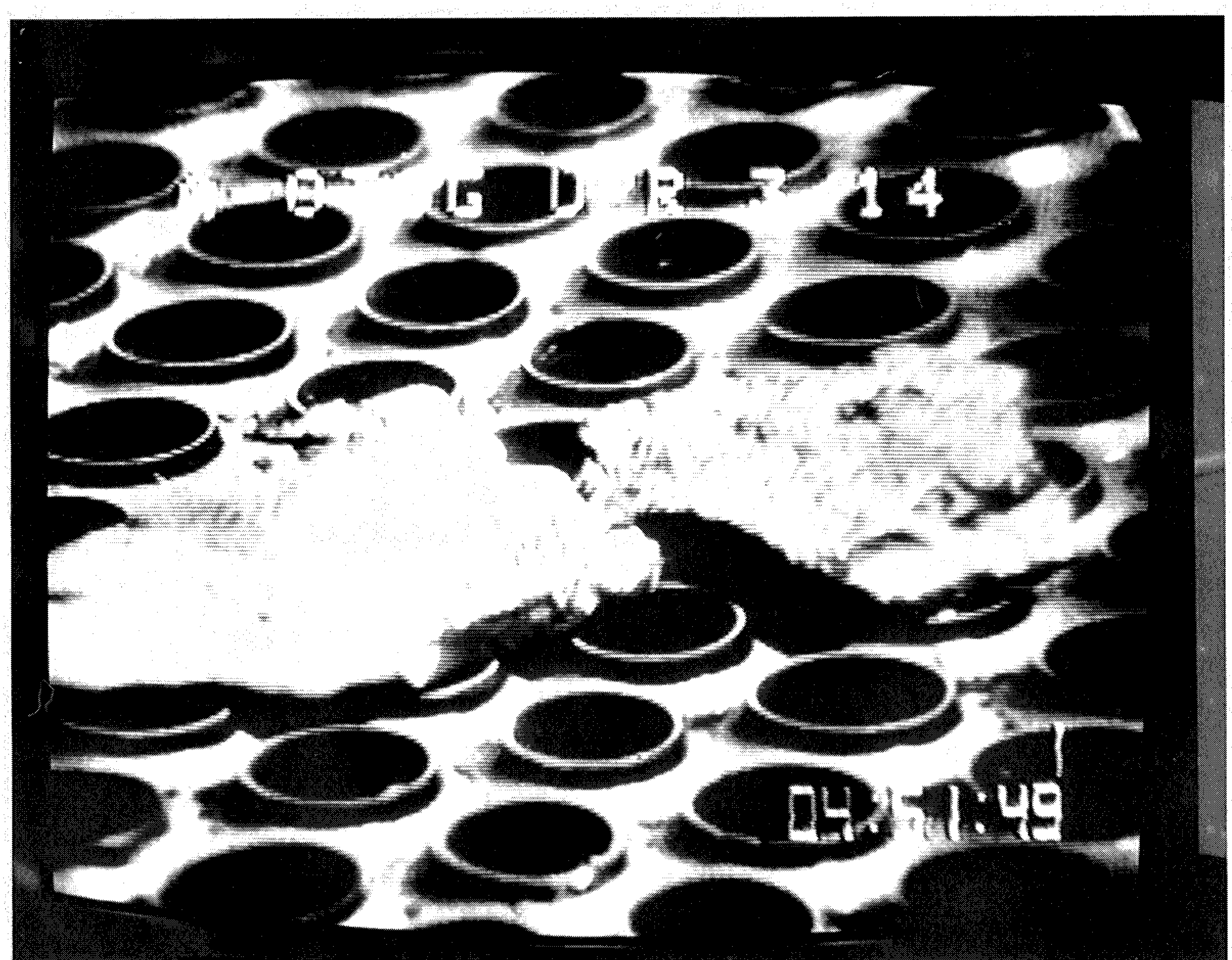
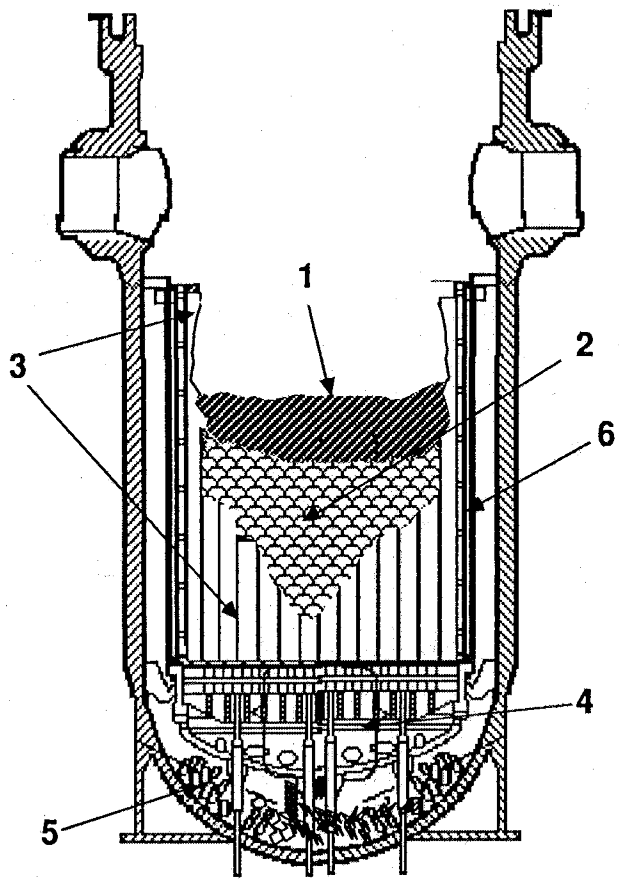


Photo 8-12. Debris on Tube Sheet of a Once-Through Steam Generator



ZONE	DESCRIPTION	ESTIMATED QUANTITY (Kg)
1	Upper Debris Bed	26,000
2	Resolidified Mass	33,000
3	Intact Assemblies (Partially or Fully Intact)	45,000
4	Lower CSA	6,000
5	Lower Head	19,000
6	Upper CSA	4,000
	TOTAL	133,000

Figure B-1. Postaccident Estimated Core Material Distribution

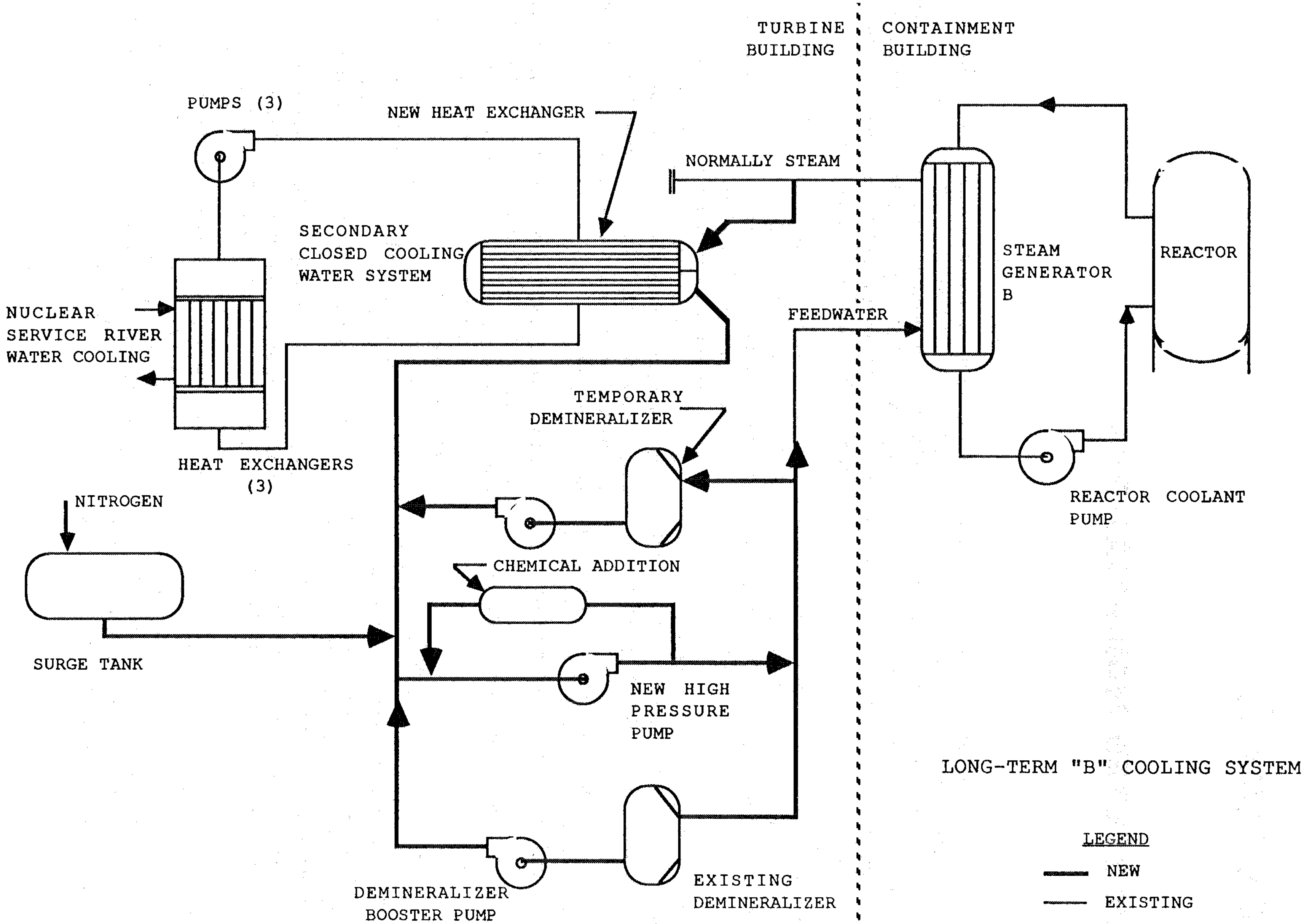


Figure E-1. Long-Term "B" Cooling System

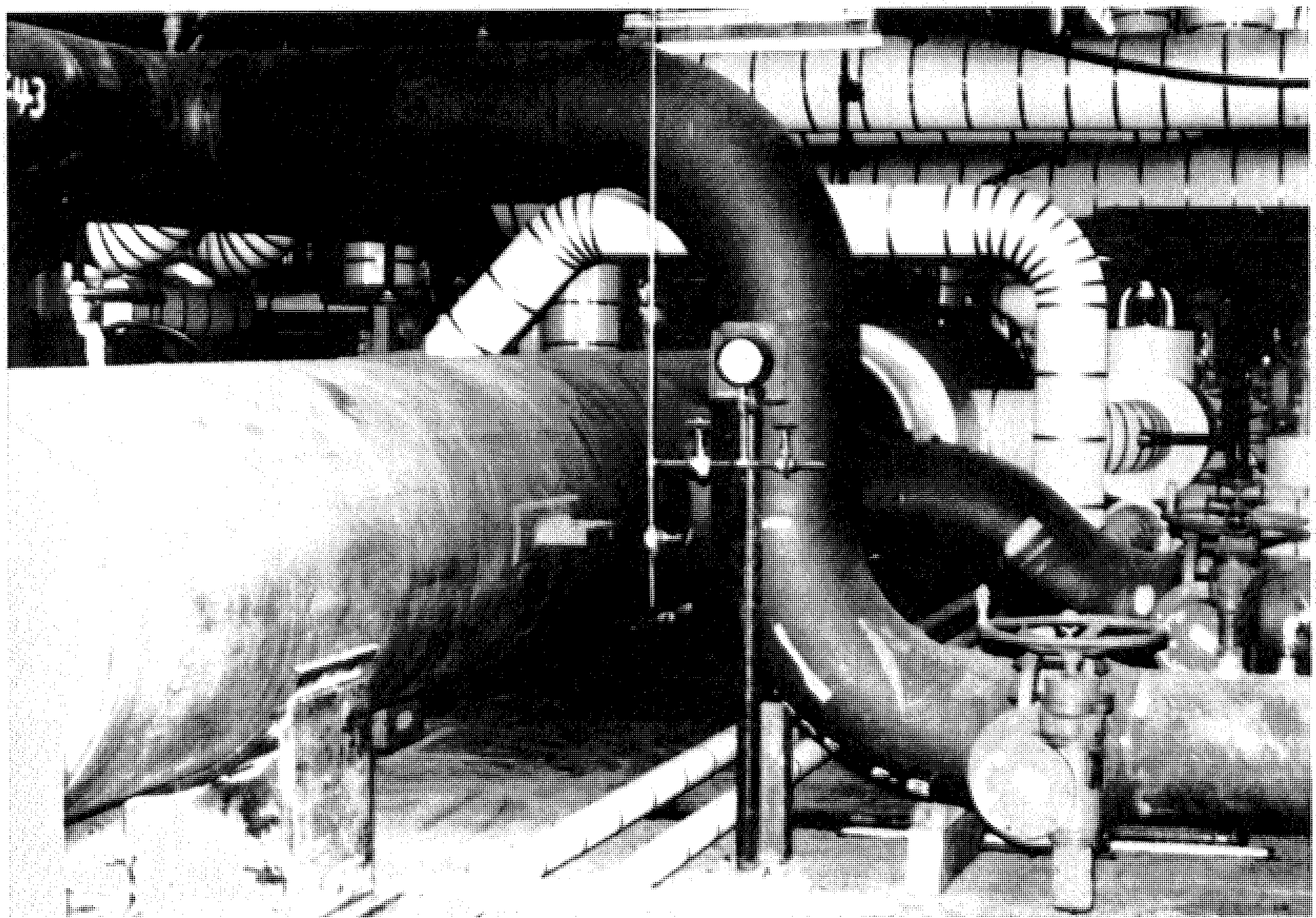


Photo E-1. Long-Term "B" Cooling System Heat Exchanger

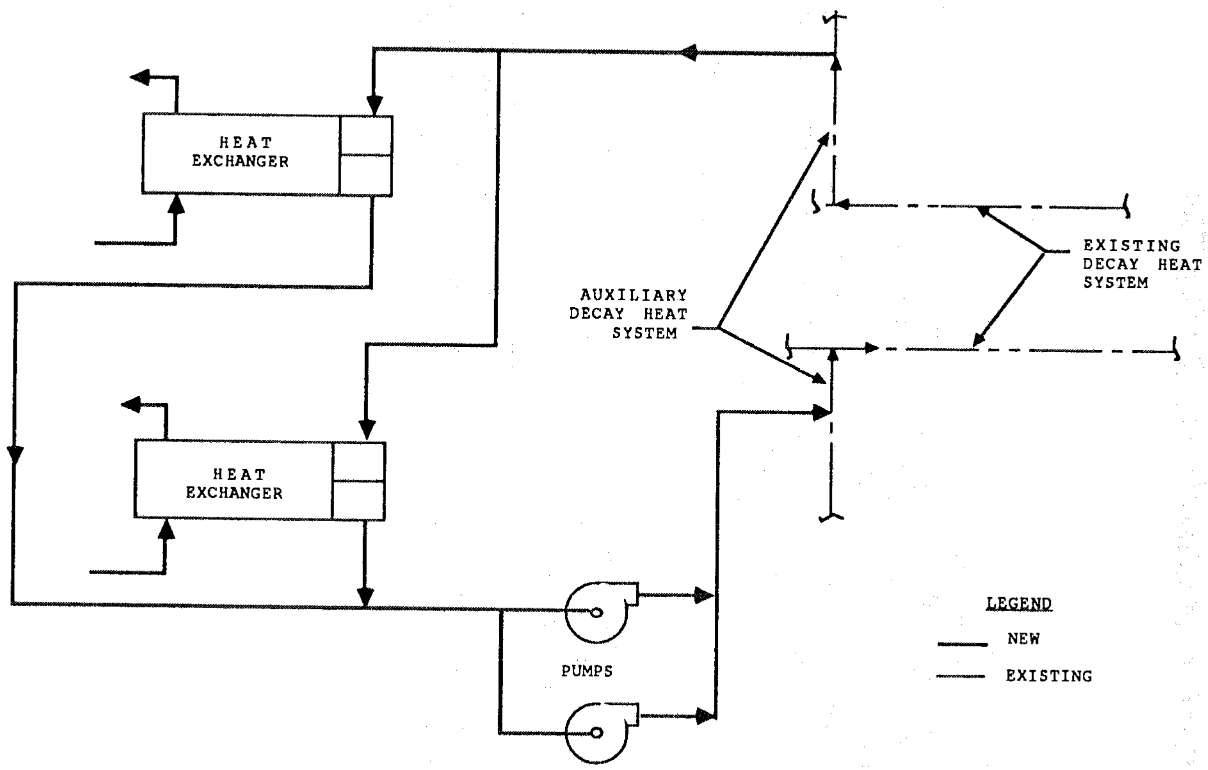


Figure F-1. Mini-Decay Heat Removal System

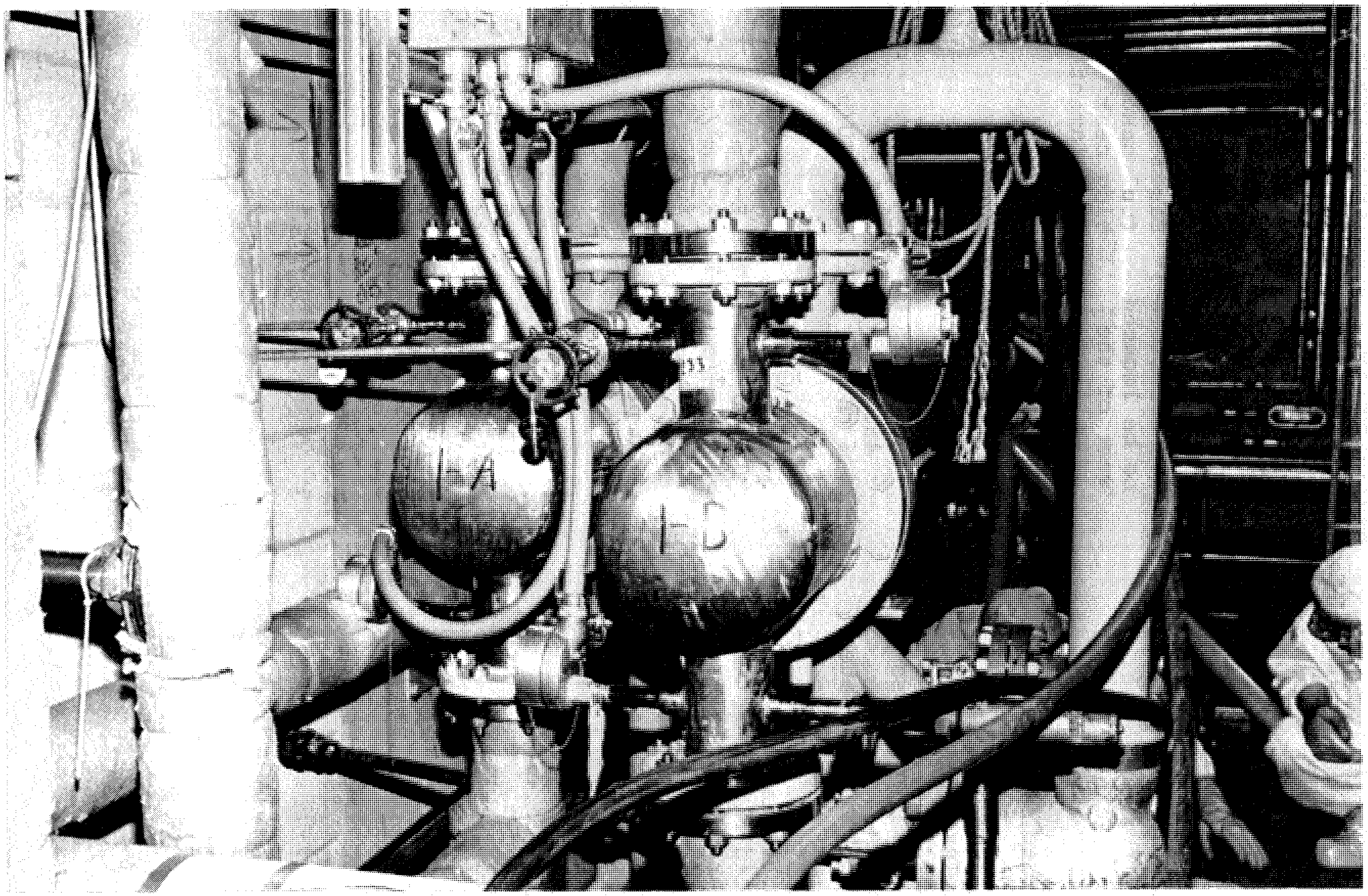


Photo F-1. MDHR Heat Exchanger