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DEVELOPMENT REPORT

DEFUELING OF THE LIGHT WATER BREEDER REACTOR AT THE SHIPPINGPORT ATOMIC POWER STATION

(LWBR Development Program)

I. A. Selsley, Editor

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FOREWORD

The Shippingport Atomic Power Station located in Shippingport, Pennsylvania was the first large-scale, central-station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power. This program was started in 1953 to confirm the practical application of nuclear power for large-scale electric power generation. It has provided much of the technology being used for design and operation of the commercial, central-station nuclear power plants now in use.

Subsequent to development and successful operation of the Pressurized Water Reactor in the Atomic Energy Commission (now Department of Energy, DOE) owned reactor plant at the Shippingport Atomic Power Station, the Atomic Energy Commission in 1965 undertook a research and development program to design and build a Light Water Breeder Reactor core for operation in the Shippingport Station.

The objective of the Light Water Breeder Reactor (LWBR) program has been to develop a technology that would significantly improve the utilization of the nation's nuclear fuel resources employing the well-established water reactor technology. To achieve this objective, work has been directed toward analysis, design, component tests, and fabrication of a water-cooled, thorium oxide-uranium oxide fuel cycle breeder reactor for installation and operation at the Shippingport Station. The LWBR core started operation in the Shippingport Station in the Fall of 1977 and finished routine power operation on October 1, 1982. After end-of-life core testing, the core was removed and the spent fuel shipped to the Naval Reactors Expended Core Facility for detailed examination to verify core performance including an evaluation of breeding characteristics.

In 1976, with fabrication of the Shippingport LWBR core nearing completion, the Energy Research and Development Administration, now DOE, established the Advanced Water Breeder Applications (AWBA) program to develop and disseminate technical information which would assist U.S. industry in evaluating the LWBR concept for commercial-scale applications. The AWBA program, which was concluded in September, 1982, explored some of the problems that would be faced by industry in adopting technology confirmed in the LWBR program. Information developed includes concepts for commercial-scale prebreeder cores which would produce uranium-233 for light water breeder cores while producing electric power, improvements for breeder cores based on the technology developed to fabricate and operate the Shippingport LWBR core, and other information and technology to aid in evaluating commercial-scale application of the LWBR concept.

All three development programs (Pressurized Water Reactor, Light Water Breeder Reactor, and Advanced Water Breeder Applications) have been conducted under the technical direction of the Office of the Deputy Assistant Secretary for Naval Reactors of DOE.

Technical information developed under the Shippingport, LWBR, and AWBA programs has been and will continue to be published in technical memoranda, one of which is this present report.

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After successfully operating for 29,047 effective full power hours, the Light Water Breeder Reactor was totally defueled prior to decommissioning of the Shippingport Atomic Power Station. Total defueling included removal of all head area attachments, internal instrumentation and control equipment, and 39 fuel modules from the reactor vessel. Heavily borated water in the canal and reactor vessel was used to ensure that no inadvertent criticality could occur under worst-case accident conditions. Fuel removed from the reactor vessel was either placed in storage for later disassembly, or directly disassembled and prepared for shipping to the Naval Reactors Expended Core Facility in Idaho. No significant problems or accidents occurred during defueling operations. Radiation and personnel exposure levels were carefully controlled.

DEFUELING OF THE LIGHT WATER BREEDER REACTOR AT THE SHIPPINGPORT ATOMIC POWER STATION

(LWBR Development Program)

SECTION 1 - INTRODUCTION

The Light Water Breeder Reactor (LWBR) core was defueled after successfully operating for 29,047 effective full power hours (EFPH). This report describes operations performed to remove fuel from the reactor, the tools required to perform these operations, and the components that were removed. Defueling of LWBR was a joint effort by personnel from Westinghouse Electric Corporation's Bettis Atomic Power Laboratory and Duquesne Light Company, which had prime responsibility for operations at Shippingport.

Removal of nuclear fuel from the LWBR core, along with many nonfuel components, was the first stage of total decommissioning of the Shippingport Atomic Power Station. The objective was to remove the 39 fuel modules comprising the LWBR core and transfer them to the Naval Reactors Expended Core

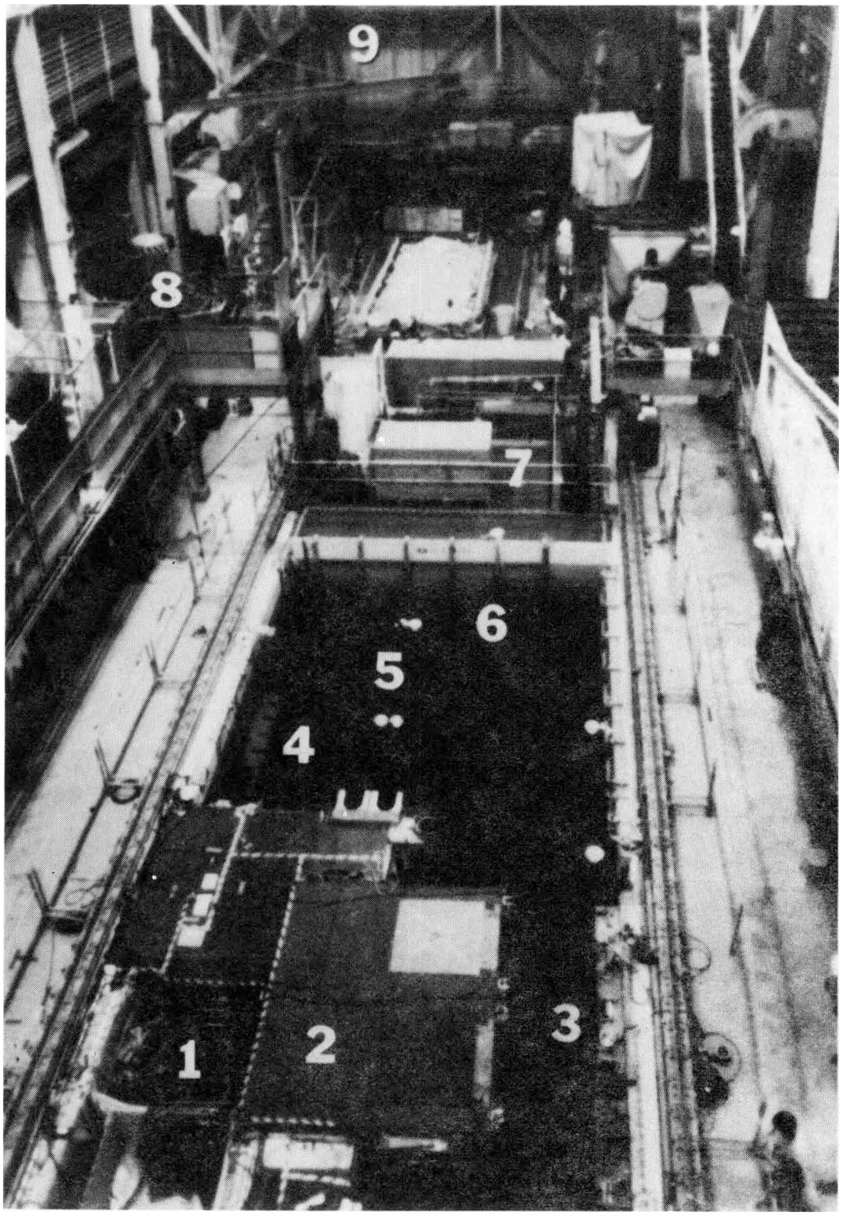
Facility (ECF) in Idaho for analysis and evaluation of the breeding concept in a thorium-based fuel cycle.

A brief overview of defueling operations is presented in this section, along with a description of the Fuel Handing Building and the site facilities that aided the defueling effort. Section 2 provides a brief summary of the LWBR operating history from startup in 1977 to shutdown in 1982 after completing 29,047 EFPH of power generation and prototype testing. Section 3 provides detailed accounts of operations performed to remove all fuel modules from the LWBR reactor vessel. The main emphasis is on component removal, but tools used and problems encountered are also described. Defueling support activities, including administration, preparation, training, and planning, are discussed in Section 4. Significant defueling tools, methods, and problems encountered are discussed in greater detail in the Appendices.

In addition to removing fuel from the reactor vessel, operations were also performed in conjunction with disassembly of fuel modules and shipment of fuel and reactor components to ECF in Idaho or to burial sites. Disassembly operations are described in Reference 1 and shipping operations are detailed in Reference 2.

1.1 - FACILITY DESCRIPTION

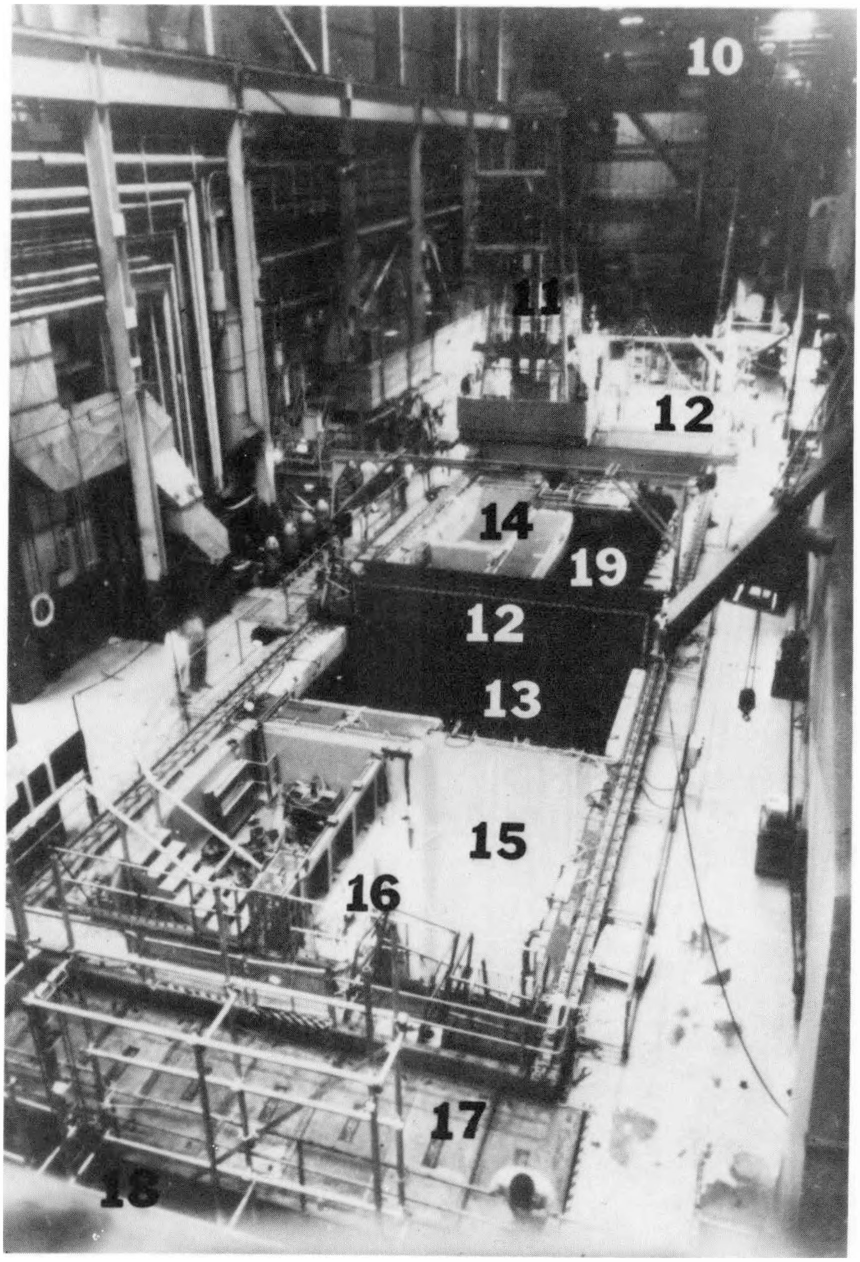
The reactor was located in the Fuel Handling Building (Figures 1A and 1B), within an underground steel chamber (see Figures 40 and 45 through 47 for elevation and plan diagrams of the facilities). Following shutdown, access to the reactor for defueling was obtained by draining the shielding water from the reactor pit above the chamber and removing the steel chamber dome which isolated the reactor from the water in the reactor pit during normal reactor operation. Existing facilities within the building were adapted as storage areas for the major reactor components prior to their removal from Shippingport. A 26-foot deep dry storage pit immediately north of the reactor pit was used initially as a tool staging area, then as a storage area for the reactor closure head. Underwater storage racks for the fuel modules were installed in the deep pit area south of the reactor pit. A 32-foot deep underwater storage pit was dried out and used as a support area for M-130 shipping operations.



LEGEND:

Item	Description	Item	Description
1	Tool Storage	5	Reactor Pit
2	Seed/Blanket Disassembly Stand (DAS)	6	CNS 3-55 Liners and Rack
		7	Closure Head Storage Pit
3	Disassembly Tools	8	Bolt Cutting Machine Air Compressor
4	Seed Support Shaft Storage Rack	9	Jib Crane

Figure 1A. The Fuel Handling Building During Refueling (Disassembly Stand and Reactor Pit)



LEGEND:

Item	Description	Item	Description
10	Main Crane	15	Dry Area (M-130 Support)
11	Extraction Crane	16	M-130 Support System
12	Movable Work Bridge	17	Cask Pit No. 4 (Motor Tube and Compression Sleeve Storage)
13	M-130 Loading Area (Deep Pit)	18	M-130 Shipping Area
14	Dry Pit (Training Area and Bolt Cutting Machine Support)	19	Fuel Storage Racks (Under Water)

Figure 1B. The Fuel Handling Building During Defueling (Fuel Shipping Facilities)

Additional underwater storage for tools and reactor components was provided by attaching specialized storage racks to the canal walls; these tool and component storage racks utilized nearly the entire periphery of the deep pit and the reactor pit.

The Fuel Handling Building was serviced by an overhead bridge crane, with single 125- and 25-ton capacity hoists. Several 3/4-ton, boom-type jib cranes attached to the building columns were available also. One of these was moved to a more strategic location near the disassembly stand. A new jib crane was installed at the south end of the Fuel Handling Building to support fuel shipping operations. Access to tools and work areas was provided by two work bridges and a movable extraction crane. The extraction crane was equipped with an additional jib crane and modified specifically for defueling work by adding personnel work platforms.

1.2 - DEFUELING SAFETY

Throughout LWBR defueling, the prime consideration was personnel safety, both for the technicians performing the defueling operations and for the general public outside of the defueling area. As a part of defueling preparations, a Defueling Safety Assessment was formally issued following reviews by the Bettis Laboratory Reactor Operations Safeguards Committee and the Fuel Handling Safeguards Committee, and approval by the Naval Reactors Division of the Department of Energy. Safety features included careful control of personnel radiation exposure, protection against uncontrolled nuclear criticality and spread of radioactive contamination, and use of specially designed and tested defueling equipment to protect personnel from injury and to prevent damage to fuel. The safety aspect was an inherent feature of equipment and facility designs and was enhanced by an extensive program of personnel training and check-out of equipment and procedures prior to beginning defueling operations. As a direct result of the emphasis placed on safety, all defueling operations, including disassembly of fuel modules after removal from the reactor and subsequent shipment of the modules to ECF, were completed with no serious injury to personnel, no damage to fuel or equipment, and no release of radioactive contamination to the environment.

Defueling was completed with total personnel radiation exposure approximately 40 percent of that calculated during defueling planning; no individual worker exceeded 10 percent of the permissible yearly dose of 5 Rem.

Nuclear safety was assured through several features of the defueling program. Protection against nuclear criticality was obtained by heavily borating the reactor vessel and canal water to ensure a minimum margin to criticality of 10 percent during the most reactive defueling condition. This also ensured ample margin under worst-case accident conditions. A detailed discussion of boration as a means of criticality control is presented in Appendix A4. Personnel safety was controlled by administrative controls and use of local containments to prevent spread of radioactive contamination. Detailed discussions of these subjects are presented in Section 4.1 and Appendix A2, respectively.

1.3 - LWBR REACTOR DESCRIPTION

The LWBR core (Figure 2*) was contained in a reactor vessel approximately 33 feet high with an inner diameter of 9 feet and a nominal wall thickness of 8-7/8 inches. Within the vessel was a core barrel, which is a long cylinder that locates the fuel assemblies within the vessel. The core barrel was supported in the vessel by a large doughnut-shaped weldment, called the support flange, that rested on top of the vessel. This support flange also served as an entry point for various types of core instrumentation and safety injection piping. The support flange was clamped in position by the 50-inch thick steel closure head using 42 six-inch diameter studs; the studs were installed in the mating bolting flanges of the closure head and reactor vessel. The joints between these major components were sealed by welding a preformed seal membrane all around the reactor at the vessel-to-flange and flange-to-closure head interfaces.

The fueled section of the LWBR core consisted of 39 modules. Fifteen reflector modules comprised the periphery and 12 blanket modules filled up the

*See Figure 38 for a schematic diagram of the LWBR arrangement.

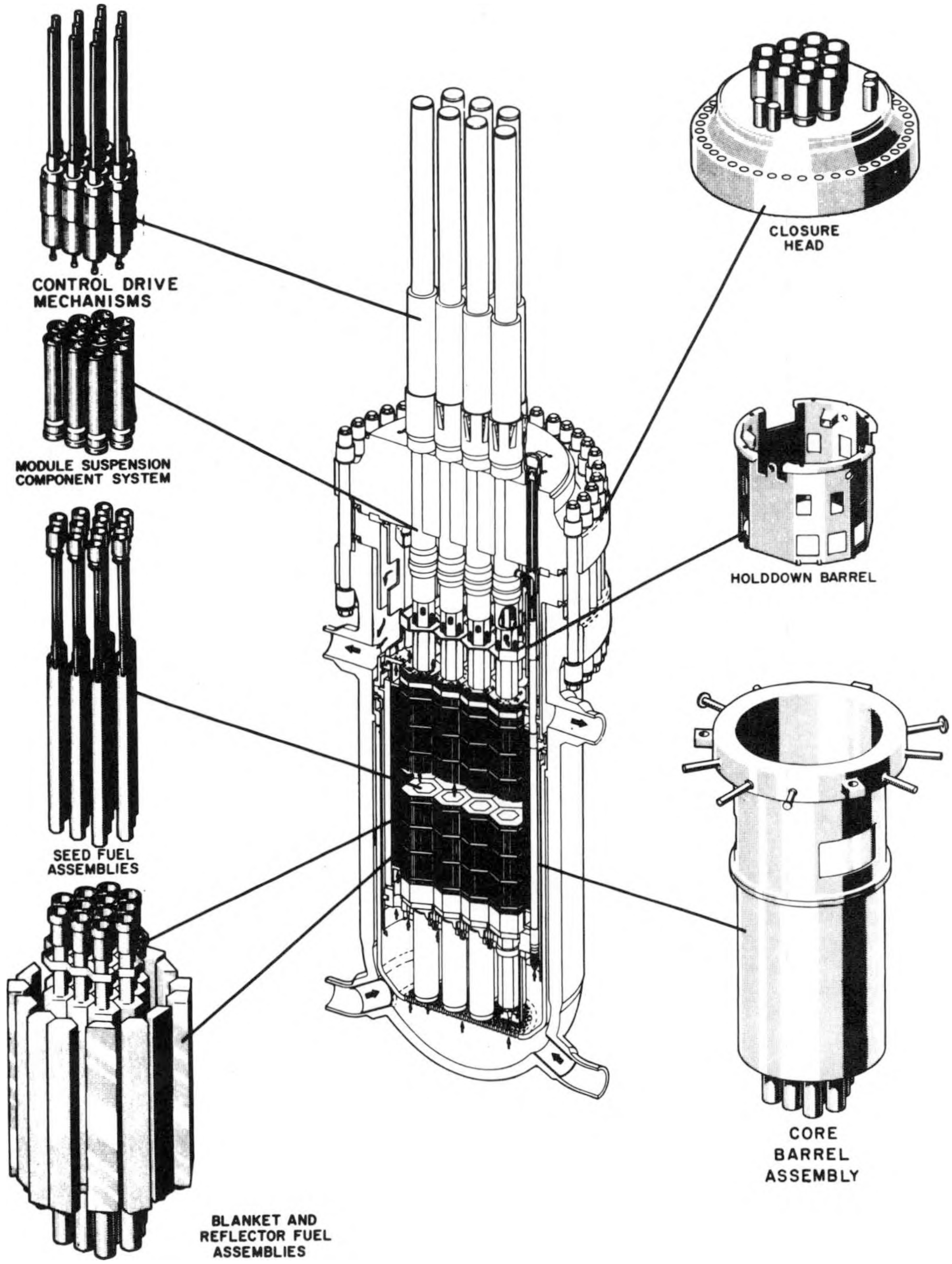


Figure 2. LWBR Component Parts

central part of the core. Within each blanket module was a vertically adjustable seed module that was used to control reactivity during reactor operation. There were two geometric variations of reflector modules, and three variations of blanket modules that provided the requisite geometry. These variations are apparent in Figure 38. Details of these modules important to defueling are shown in Figures 3 through 5 (see Reference 4 for further details of the core assembly).

Reflector fuel assemblies formed the periphery of the reactor core. They were suspended within the core barrel by a flanged lip on their top structural member (seal block), and were clamped in position by the holddown barrel. The holddown barrel rested on top of the reflector seal blocks and transmitted a clamping force to the reflector assemblies, which was imposed by the closure head bearing against the top of the holddown barrel. The hexagonal-shaped blanket fuel assemblies filled the space envelope formed by the reflectors. The blanket modules were suspended within the core barrel from the closure head. Concentric cylinders were used to support blanket modules from suspension sleeves affixed to the underside of the closure head. Both the blanket and reflector assemblies engaged holes machined into the bottom plate of the core barrel, which provided both radial positioning and a channel for water to flow into the fuel assemblies.

A seed fuel assembly was installed inside the hexagonal opening in the center of each of the 12 blanket assemblies. One of the unique aspects of the LWBR core was that seed assemblies were moved up and down within blanket modules to control reactivity during reactor operation. In earlier pressurized water reactor (PWR) designs used at Shippingport, reactivity was controlled by changing the position of neutron-absorbing control rods in the reactor core.

Each LWBR seed assembly was suspended within the reactor by a long support shaft extending from the top of the fuel assembly. In turn, this support shaft was secured to the leadscrew of the control drive mechanism (CDM) by means of the tie rod adapter and nut. The leadscrew was a long threaded shaft

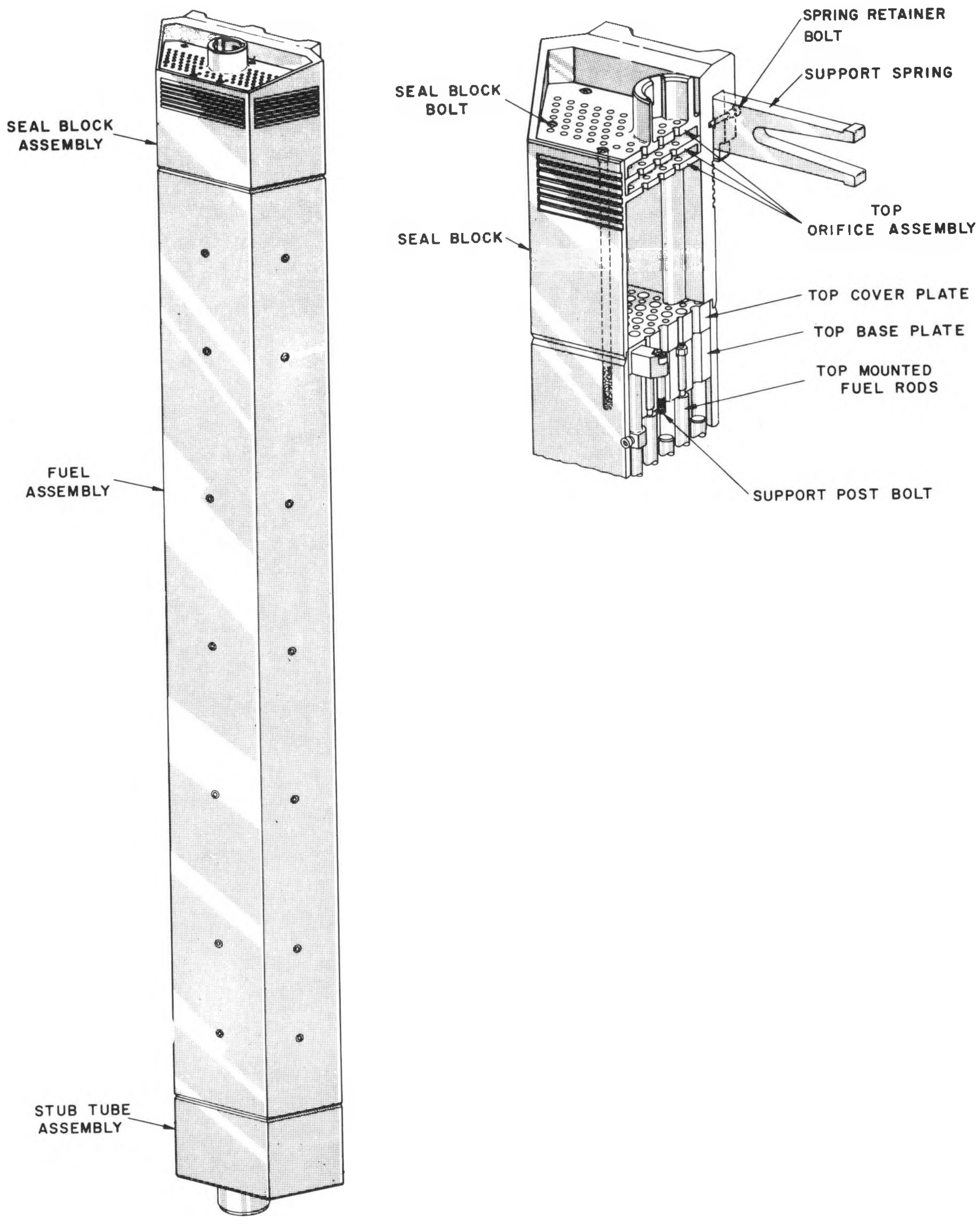


Figure 3. Reflector Fuel Assembly

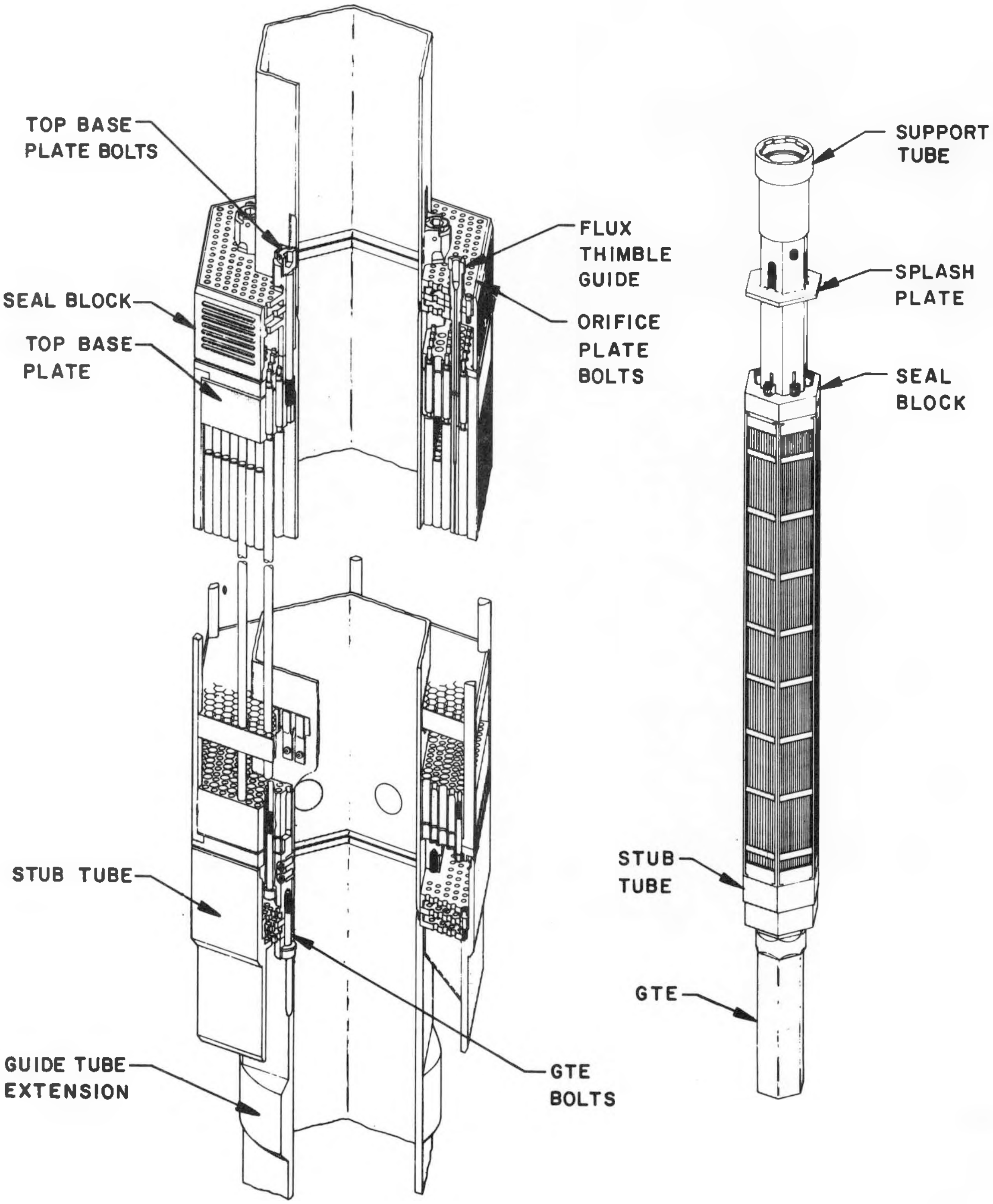


Figure 4. Blanket Fuel Assembly

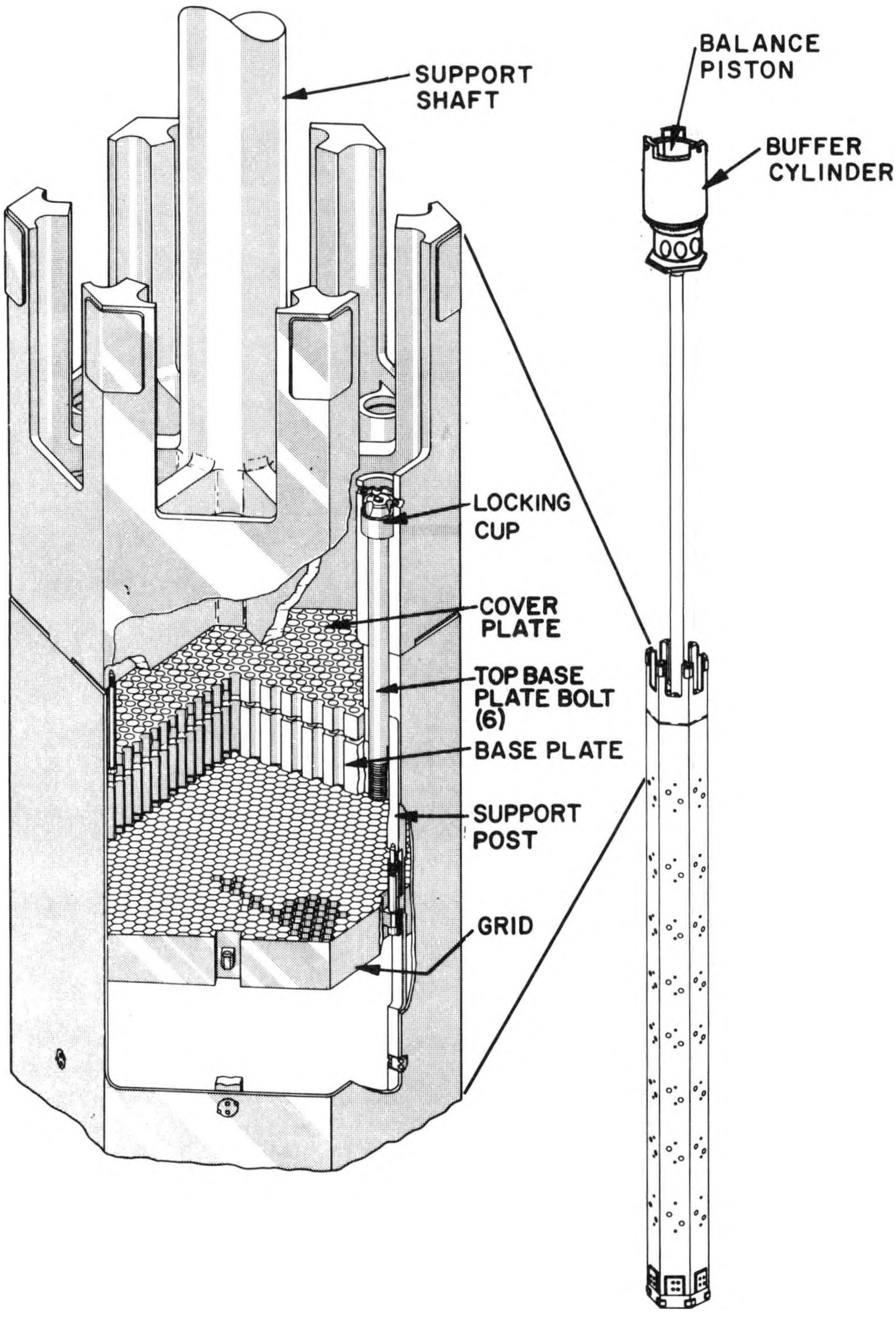


Figure 5. Seed Fuel Assembly

which was driven up or down by the rotation of the roller nut assembly within the CDM's motor tube assembly.

The CDM consisted of a reluctance electric motor which rotated a roller nut assembly to raise or lower the leadscrew; the movable seed fuel assembly was attached to the leadscrew. The motor rotor containing the roller nut assembly was located within the reactor pressure boundary formed by the motor tube and the CDM, with the stator external to the motor tube. The motor tube was threaded into the mechanism housing of the closure head and was welded in place to provide a pressure-tight seal.

An adjunct to each seed fuel module was the bypass inlet flow (BIF) system (Reference 3), which equalized the differential pressure from the bottom to the top of a seed module resulting from coolant flow so that the module could drop from its own weight in the event of a scram.

1.4 - SUMMARY OF DEFUELING OPERATIONS

Defueling operations commenced with draining the reactor pit and removing the dome covering the reactor. Insulation and ventilation equipment were removed first, followed by instrumentation and piping which penetrated the closure head, then the reactor vessel closure head studs. This provided access to the welds that sealed the reactor. Cutting of these welds and those sealing the CDM motor tube vent valves, the CDM-to-housing gap, the BIF system, and the main closure head permitted removal of head area components. Cutting operations are detailed in Section 3.4, and Appendix A1 presents a description of some equipment used to perform cutting operations.

After removing head area components, such as CDMs and instrumentation, a critical series of operations was performed to detach the blanket modules from the closure head and to lower the assemblies to rest on the core barrel bottom plate. The closure head was then removed and stored, and the reactor pit was refilled with borated water. The last nonfuel item removed from the reactor vessel was the holddown barrel, which was placed in a shipping container and sent to a disposal site. The 39 fuel modules comprising the core were then removed, one at a time, and either placed in storage or partially disassembled in preparation for shipping. Fuel removal from the reactor was performed in parallel with disassembly and shipping operations due to limited out-of-reactor storage space for the fuel. Section 3 describes the preceding defueling activities, along with a discussion of the tools used and problems encountered.

Defueling was completed with no major problems, and few minor problems, largely due to the conservative approach taken during the planning stages by anticipating possible problem areas and providing contingency procedures to surmount them. Two major evolutions where problems were anticipated were the operations for detaching the blanket modules from the closure head and lowering them to seat on the bottom plate and the removal of reflector and blanket modules from the reactor vessel.

During reactor assembly, the fuel assemblies, consisting of a blanket module and its mated seed module, were raised from the core barrel bottom plate and latched onto the closure head by using one tool to raise each assembly approximately 3 inches in a single, continuous lift (Reference 4). At that time, there was clearance between modules to ensure that exposed grids on adjacent blanket modules would not hang up on each other. For module lowering at end of life, clearance was no longer assured due to predicted radiation-induced growth and swelling. To allow the modules to be lowered without damage due to grid interference and hangup, a plan was developed to lower all 12 blanket modules incrementally and simultaneously. Additional contingency plans were developed and tooling procured to take into account that, even with conservative primary operation, hangups could develop due to uncertainties about the actual condition of the fuel assemblies. As noted in Section 3.10, primary plans were sufficient for module lowering, and contingency operations and tools were not used.

The same considerations affected planning for blanket and reflector module removal from the reactor. It was judged that estimated dimensional changes in fuel modules could have reduced intermodular clearances sufficiently to cause damage to modules if they were raised in a straight lift. Tools were developed to reposition adjacent modules to provide maximum clearances and to avoid obstacles. In addition, a study of potential hangups resulted in a fuel removal sequence that contributed to maximum utilization of space. Fuel removal operations are discussed in Sections 3.14 and 3.15, and details of the module repositioning equipment are presented in Appendix A3.

1.5 - DEFUELING PREPARATIONS

Preparations for defueling LWBR began before LWBR was assembled and on-line. A program of tool development started several years before plant shutdown. Tools and equipment were checked out at Bettis Laboratory under simulated conditions. This provided ample opportunity to develop, modify, and refine tooling, containments, and procedures, as well as to develop a core of experienced personnel.

To prepare personnel for defueling operations an extensive training program was initiated several months before the anticipated reactor shutdown. Training was conducted using actual defueling tools, fuel module mock-ups, and systems designed to simulate actual conditions as much as possible. The major objective in defueling training was to familiarize personnel with tools and methods so that actual defueling would proceed smoothly and safely, and would minimize radiation exposure. This objective was accomplished.

Another important aspect of the training program was checkout of defueling tools and procedures. Adequacy of tools was determined and changes made as needed prior to the start of actual defueling. This part of the program was particularly successful in that several defueling operations were changed to reduce tool handling and the time required to perform the operations. Strict compliance with detailed procedures was intended to provide safe and efficient performance of each defueling evolution. Weaknesses in the procedures were found and changed accordingly so that subsequent delays during actual operations were minimized.

The combination of careful considerations of tool design and an extensive training program for defueling personnel resulted in completing the defueling with no major problems and few minor ones. A summary discussion of these minor problems is presented in Appendix A9. The problems that resulted in the longest operational delays concerned evolutions that used the closure head containment prior to closure head removal and that installed the refueling seal prior to refilling the reactor pit. Both of these operations were considered straightforward since they required only the positioning of components; hence, there was no formal mock-up training before actual performance. The problems were unforeseen and were attributable to a leaking seal in one of the refueling seal joints and tears in the containment bag due to bag size, rather than to handling or lack of training. Other delays occurred during the first performance of an evolution (such as removal of each type of fuel module from the reactor). These delays were related to minor procedure problems that were not found during checkout because of slight differences between mock-ups and actual conditions, rather than to any insufficient personnel training.

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SECTION 2 - SUMMARY OF LWBR OPERATING HISTORY AT SHIPPINGPORT

The Shippingport Atomic Power Station with the LWBR core installed was placed in power operation as part of the Acceptance Test Program on September 7, 1977. The acceptance phase formally ended on December 2, 1977 when President Carter issued an order from the Oval Office in the White House to "Increase the Light Water Breeder Reactor Power to 100%. (signed) Jimmy Carter." Power operation continued satisfactorily for about 5 years and generated a total of 2,104,233,000 kilowatt hours of gross electrical output, with 29,047 effective full power hours (EFPH) accumulated on the LWBR core. Power operation ended on October 1, 1982 and the Shippingport Atomic Power Station was shut down for end-of-life physics testing and defueling.

The LWBR core was designed to demonstrate the capability of the thorium/uranium-233 fuel system for use as a breeder reactor in conventional pressurized water reactor (PWR) plants. Backfitted into the Shippingport PWR pressure vessel, the LWBR core demonstrated the power operating capability of this fuel system for a lifetime of over 29,000 EFPH, far beyond the design goal of 18,000 EFPH.

Core design and operation were guided by the objective of demonstrating typical utility operational capability, while simultaneously producing more fissile fuel than is consumed. This breeding objective resulted in design aspects unique to LWBR, aspects which required original development and test support. Included were the development of properties and performance capability of thorium-based oxide fuel in Zircaloy-4 cladding, design of a practical movable fuel control system to eliminate neutron-absorbing control rods, and design of a reliable fuel rod support system with minimum detrimental effect on neutron economy. The movable seed modules traveled vertically through the annuli of the blanket modules. Core reactivity was controlled by changing the axial position of seed modules within the surrounding blanket modules. During normal operations, the 12 seed modules were moved in a uniform bank, making reactivity control operationally simple and offering a favorable radial power distribution. The remainder of the core consisted of 12 stationary blanket fuel modules and 15 stationary reflector fuel modules.

During the 5 years of LWBR operation, there were no incidents that affected fuel rod integrity or that would have any impact on a normal defueling. To reduce the risk of fuel rod damage from cladding deforming into possibly unsupported sections of the fuel stack and to provide more thermal margin for fuel rods in proximity, a series of primary coolant pressure reductions was implemented during LWBR lifetime. Initial reactor operating conditions were at the design values of 2000 psia system pressure, 531F average coolant temperature, and a power rating of 72 Mw gross electrical output, equivalent to 236.6 Mw (thermal). In May 1978, eight months after initial startup, the first pressure reduction to 1940 psia was accomplished at 4325 EFPH. A second pressure reduction to 1870 psia occurred in October 1978 at 7132 EFPH. The third pressure reduction to 1815 psia at 10,932 EFPH was in July 1979. During these three pressure reductions, the average coolant temperature was maintained at 531F and the gross electric reactor power remained at 72 Mw.

During the periodic maintenance shutdown after 18,507 EFPH in October and November 1980, the final reduction in system pressure was implemented. At this point, fuel rod performance capability had been proven in achieving the design lifetime. Fuel utilization became important, although proof of breeding remained the primary objective. Fuel utilization would be demonstrated by the achievement of maximum lifetime at reasonable levels of generator output, but not necessarily at the design rated power level. To protect the fuel rods against external cladding deformation, system pressure was reduced to 1615 psia. To preserve thermal capability and reduce pellet cladding interaction effects, the maximum allowable power was decreased to 80 percent of design rated power (58 Mw) and the average coolant temperature was decreased to 521F. During the period from June to October 1982 (27,583 EFPH to the final 29,047 EFPH), the reactor power gross electric output was decreased from 54 to 43 Mw in 12 steps, while the system pressure and average temperature remained at 1615 psia and 521F.

During LWBR operation, there were 60 reactor startups (from below 1-percent power to above 20-percent power), 58 reactor scrams (unlatchings of the movable seed modules from any power level, including from 0-percent power after a normal shutdown), 14 system depressurizations, 204 planned swingload cycles (power reduction from about 90 percent to operation in the range of 30- to 60-percent power for at least 4 hours, then return to above 90-percent power), and 68 other power cycles ($\geq$20 percent).

In the same manner as for past PWR cores operated at Shippingport, chemical poison was not utilized in the reactor coolant as a means of normal reactivity control. However, a chemical shutdown system (the Safety Injection System) was installed to provide negative reactivity insertion capability and shutdown margin in the highly unlikely event of a major movable fuel system malfunction. This system provided for the addition of a chemical neutron absorber (boron) in the form of an aqueous solution of potassium tetraborate; however, the system was never required for normal operation. Potassium tetraborate was utilized for reactivity control during the defueling of the LWBR core.

At the completion of LWBR power operations, testing and evaluation of seed module reactivity worth and shutdown margins were performed prior to defueling to verify the boron poison requirements for implementation of the large shutdown method (i.e., the addition of a poison to assure at least a 10-percent shutdown margin at all times during normal defueling) and to ensure that subcritical conditions would be maintained in the event of any credible accident scenario. The minimum poison concentration to meet this large shutdown requirement was 3800 parts per million by weight (ppm) of natural boron. For contingencies and fluctuations in boron concentration due to evaporation and makeup water, a minimum of 4200 ppm boron was utilized. The reactor plant and canal were borated separately, then interconnected in preparation for defueling.

In summary, the Shippingport Atomic Power Station with LWBR operation continued to demonstrate the flexibility and load change response characteristics of previous PWR reactor cores. The core operated for 5 years without any serious plant problems. At the end of this period, the core was removed and the spent fuel shipped to the Naval Reactors Expended Core Facility in Idaho for a detailed examination to verify core performance and an evaluation of breeding characteristics. Since no additional reactor cores were to be installed, the Shippingport Atomic Power Station was subsequently decommissioned. Detailed information on LWBR plant operations, including a complete chronology, operating incidents, maintenance, core physics, thermal and hydraulic performance, chemistry, and plant aspects of LWBR defueling can be found in Reference 5.

SECTION 3 - DEFUELING OPERATIONS

Defueling consisted of preparing the Shippingport Atomic Power Station for defueling operations; removal of external reactor components from the reactor head area (such as control drive mechanisms, electrical and piping connections, and structural items); removal of the reactor vessel head; removal of all fuel modules from the reactor vessel; and shipment of the modules to core examination facilities for evaluation of the breeding concept. The reactor vessel itself and many of its internal structural components were not removed in this program, but were left for removal as part of the complete decommissioning of the Shippingport site (Reference 6).

3.1 - REACTOR PIT DRAINING

The initial evolution of LWBR defueling was draining the reactor pit (Figure 1A). As the pit was drained, the pit walls and the outer surface of the reactor container dome were cleaned and decontaminated. Prior to the start of draining, long-handled cleaning brushes were used to scrub down the pit and dome surfaces to remove as much dirt and contamination as possible. To provide personnel access to the walls and dome, a floating platform (Figure 6) was placed on the water surface in the reactor pit surrounding the dome.

Water level in the pit was lowered in approximately 4-foot increments to allow decontamination and cleaning of the pit walls and dome surface as the water level was decreased. Decontamination was performed using rags, mops, and a detergent solution to reduce the contamination level to less than 450 pCi/100 cm^2 loose surface contamination. Areas of the pit walls that were not reduced to this level after a minimum of three attempts were covered with yellow plastic sheeting.

Following this, the floor of the reactor pit was decontaminated as previously described. A floor covering of canvas and a complete liner made of vinyl plastic sheet (Figure 7) were installed in the pit. A second layer of floor covering made of vinyl plastic was also installed on top of the canvas floor covering. In the event that radioactive contamination originating from dry reactor pit surfaces became airborne, another cover made of plastic sheeting and supported by a structural frame made of pipe was provided for the

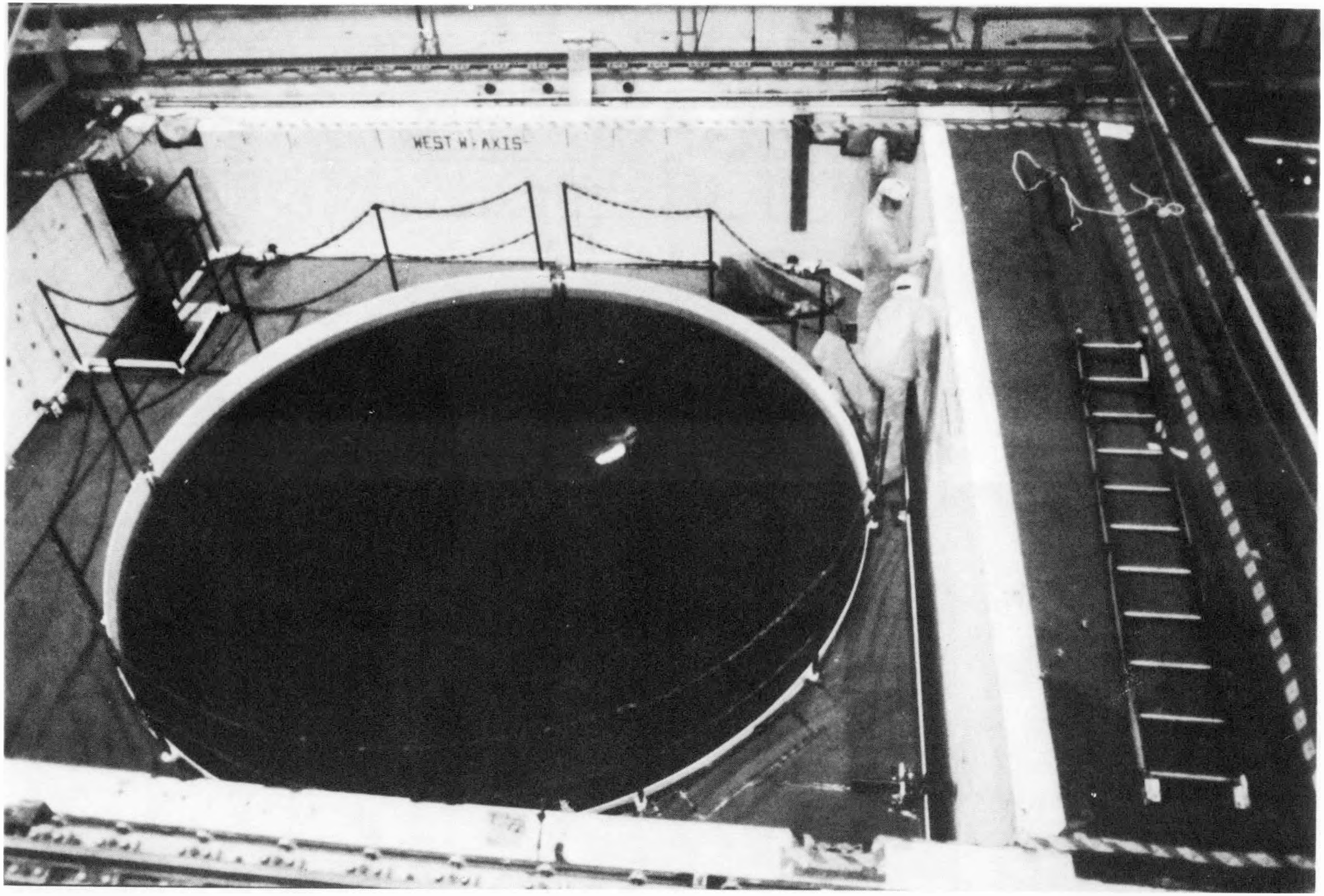

Figure 6. Floating Platform for Decontaminating the Reactor Pit

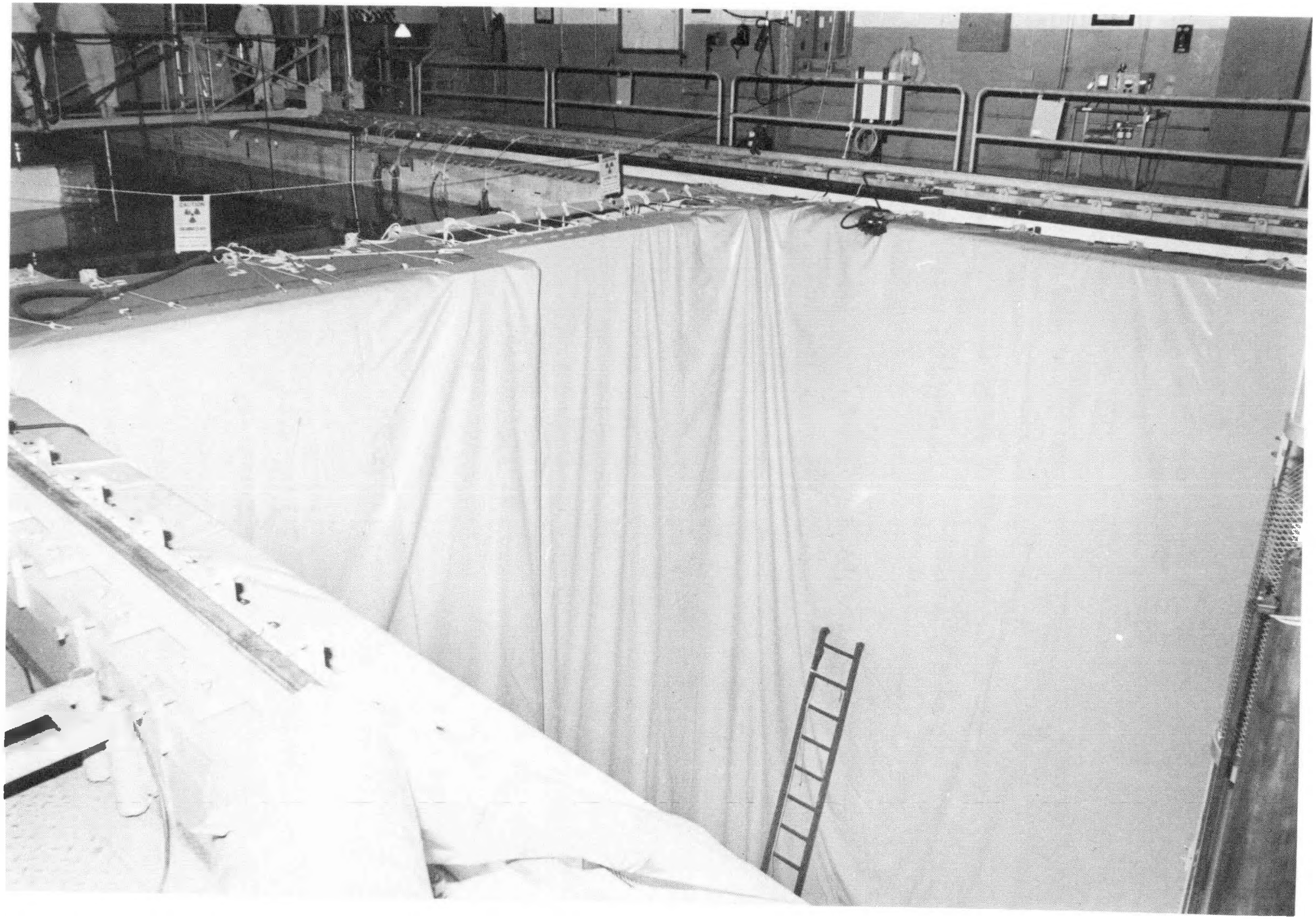

Figure 7. Reactor Pit Radiological Control Liner

reactor pit, rolled up, and stored at the north end of the reactor pit. This cover was never needed during the defueling.

3.2 - REACTOR CHAMBER DOME REMOVAL

The reactor chamber dome was a large cap, approximately 20 feet high by 19 feet in diameter, that was bolted to a flange at the top of the reactor chamber at the reactor pit floor elevation. The dome completely enclosed the reactor vessel head and its external components, and was part of the reactor plant containment. A gasket seal at the reactor pit floor permitted flooding of the reactor pit without allowing canal water to enter the area below the reactor pit floor. Following draining of the reactor pit, the dome was removed to permit access to the reactor vessel and associated LWBR components.

Preparations for dome removal included removing bolts at the flanged connection between the dome and the reactor chamber, clearing a path in the Fuel Handling Building to allow passage of the dome from the reactor pit to the south end of the building, and preparing an area for decontamination of dome surfaces. The dome was lifted out of the reactor pit and transported to the decontamination area prepared at the south end of the Fuel Handling Building. Exterior and interior dome surfaces were cleaned and decontaminated to less than 450 pCi/100 cm^2 loose surface contamination. A large plastic containment was installed and secured in place to completely cover the dome (Figure 8). Following this, the dome was transported from the Fuel Handling Building to a storage area for final disposal.

3.3 - REMOVAL OF HEAD AREA EXTERNAL COMPONENTS

The first group of reactor components to be removed included head area externals such as instrumentation and piping attachments, reactor compartment ventilation ducts, the service lead support structure, holddown structure, and components of the control drive mechanisms (CDMs).

The service lead support structure (Figure 9) was a circular framework which supported the reactor head area electrical and plumbing components and attached directly to the LWBR closure head. The support structure included three platform levels which provided access to head area components during

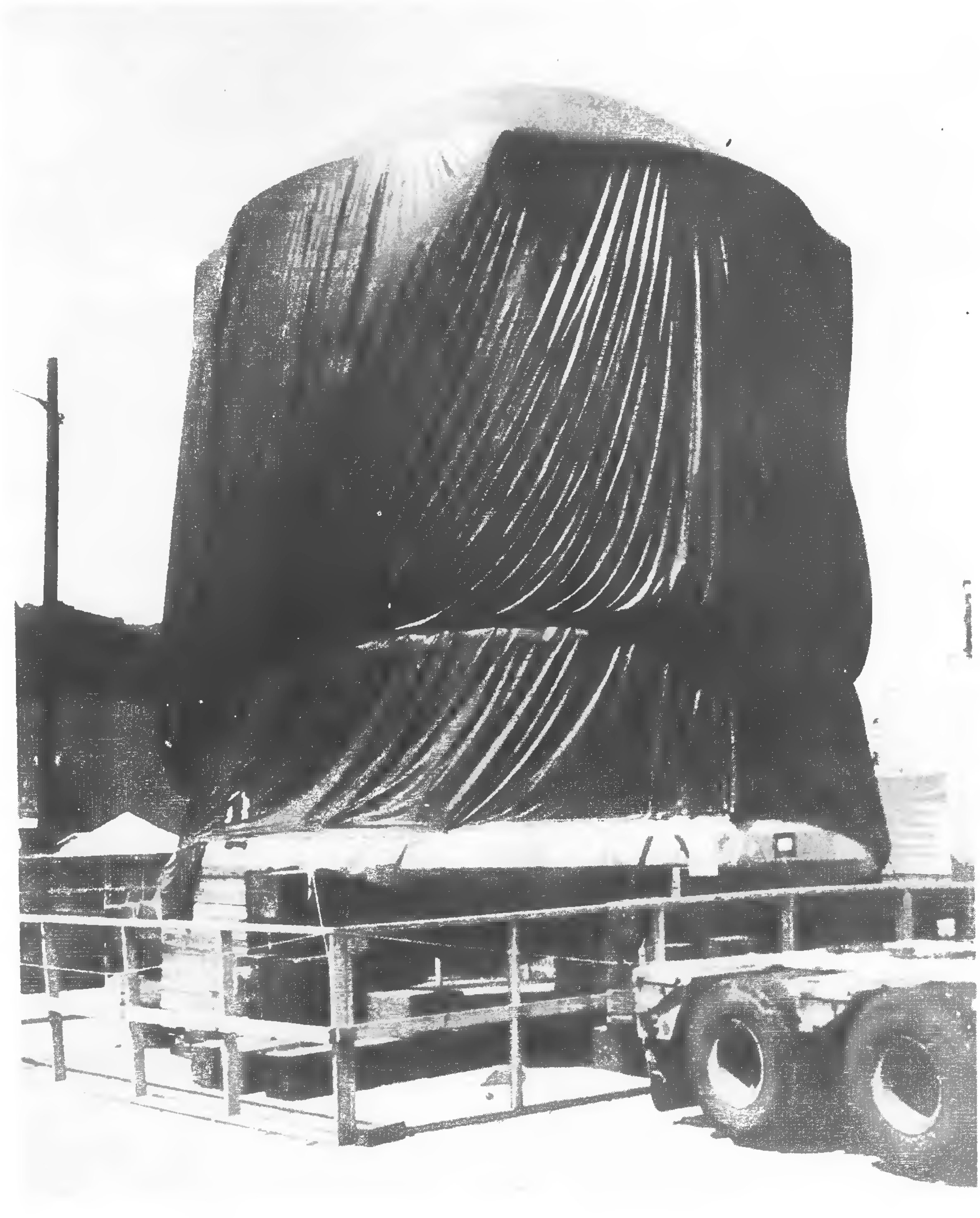

Figure 8. Reactor Chamber Dome with Containment Cover Installed

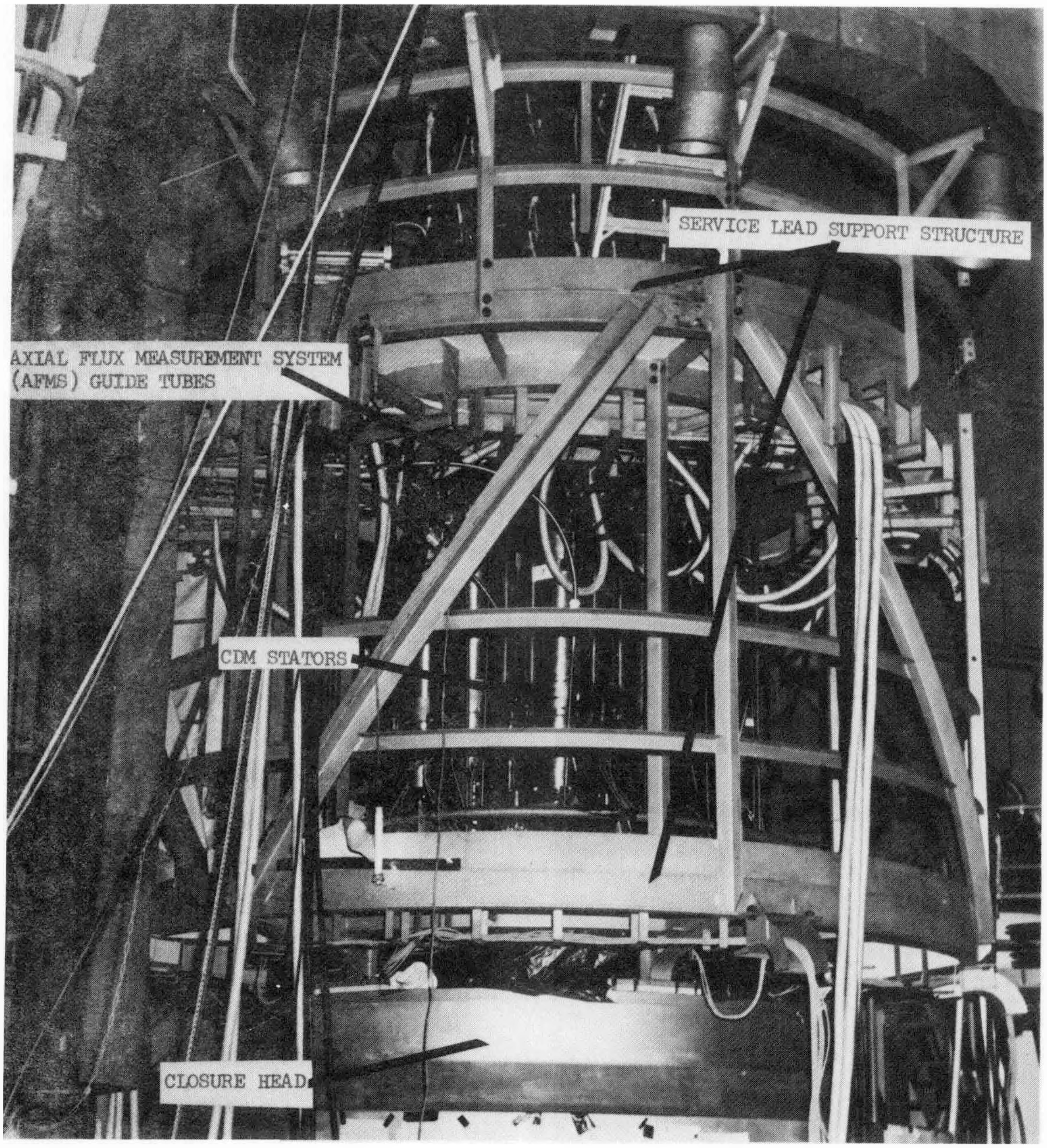

Figure 9. Service Lead Support Structure

assembly, disassembly, and routine maintenance. The framework was also used for attaching cable trays and mounting brackets for the electrical and cooling water lines that were connected to the reactor and reactor components. Reactor chamber ventilation ducts were also secured to the framework in various locations. The holddown structure consisted of a steel beam framework which was attached to the closure head and which bridged the CDMs to provide protection in the event of failure of threaded connections on the motor tubes. The CDMs are described in Section 3.5 and illustrated in Figure 15. Maximum radiation levels on top of the closure head for these operations was 12 mR/hr.

The support structure was removed in three sections: the top platform, the access ladder, and the bottom two platforms. The top platform was removed to gain access for removal of the CDM leadscrew position indicator coils, holddown beam structures and energy absorbers, and the stator water jacket assemblies which included the CDM stator (Figure 15). The access ladder and bottom two platforms were removed after the structure was freed from the instrumentation and cooling water lines. All components removed were packaged as low specific activity material and sent to disposal sites (except for two sets of CDM components which were saved for the end-of-life examination program).

3.4 - HEAD AREA WELD CUTTING AND MAIN CLOSURE SEAL GRINDING

After removing the head area external components, several components were removed to permit removal of the closure head. These included CDM motor tubes and translating assemblies, piping which was used to monitor pressure in the bypass inlet flow (BIF) system, thermocouples, flux thimbles, and BIF supply tubes. Access to most of these components required cutting of welds or omega seals at the primary system pressure boundary. Cutting of these welds provided an opening to the primary system and represented potential paths for the spread of radioactive contamination. Also, because the cuts were to be made in the top-most regions of the reactor, there was a potential for an explosion from the accumulated hydrogen within the reactor. Thus, some of the cuts were made within contamination containments using a nitrogen gas purge to prevent buildup of hydrogen within the containment. Figure 10 shows the locations for

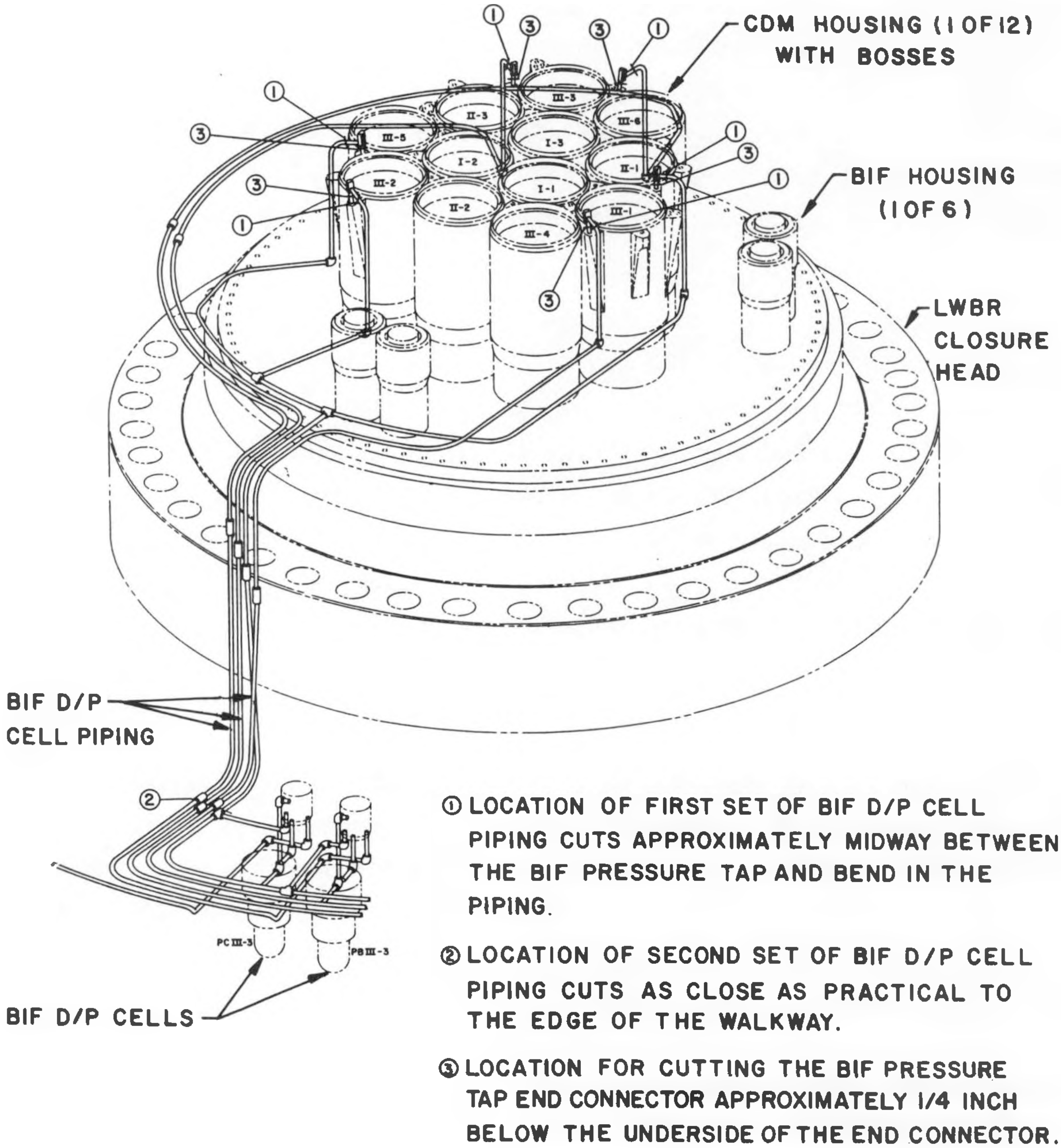

Figure 10. Locations for Cutting of the BIF Differential Pressure Cell Bypass Piping

cutting of the BIF pressure monitoring piping, and Figure 11 shows the locations of the 65 welds which were cut. The first weld cuts were performed on two of the 12 CDM vent valve plugs because they were at the highest point in the reactor and could be used for venting and as a nitrogen flow path to provide a safety blanket after the internal water level was lowered below the closure head. Subsequent cuts were performed on the 12 CDM motor tube-to-housing omega seals, six BIF plug-to-housing omega seals, 44 instrumentation port seals, and the upper main closure head seal. Cutting methods included using a simple hacksaw (for the piping), counterboring, machining, and grinding. Maximum radiation levels ranged from 6 mR/hr for CDM vent valve plug weld cutting to 130 mR/hr on contact for BIF omega seals.

3.4.1 - Control Drive Mechanism Motor Tube Vent Valve Plug Weld Cutting

The CDM vent valves (Figure 12) were used to vent air from the reactor during initial fill. Before initial criticality, a plug was inserted into the vent and welded into place. Two of the 12 sealed vents were opened for defueling to vent the reactor and to provide an inlet for nitrogen gas. This purged the reactor vessel of hydrogen and provided a blanket of nitrogen within the reactor after the water level was lowered.

The plug cutting operation used an electric hand drill with a special boring tip and jig, which was bolted to the top of the motor tube extension. A nitrogen gas purge of the containment enclosure (Appendix A2) was maintained to prevent possible buildup of hydrogen in this cutting area; as an added safety precaution, hydrogen levels within the containment were monitored also. When weld cutting was complete, the vent valve plug was removed and a nitrogen purge gas line was attached in its place. Nitrogen purging continued until the closure head was removed.

3.4.2 - Bypass Inlet Flow Differential Pressure Cell Piping Cutting

The BIF differential pressure (D/P) 1/2-inch Schedule 160 stainless steel pipe (Figure 10) connected BIF D/P cells to three low-pressure taps and three high-pressure taps mounted on CDM housing bosses. This BIF D/P cell piping system provided measurements of primary coolant differential pressure across the balance pistons of three fuel modules.

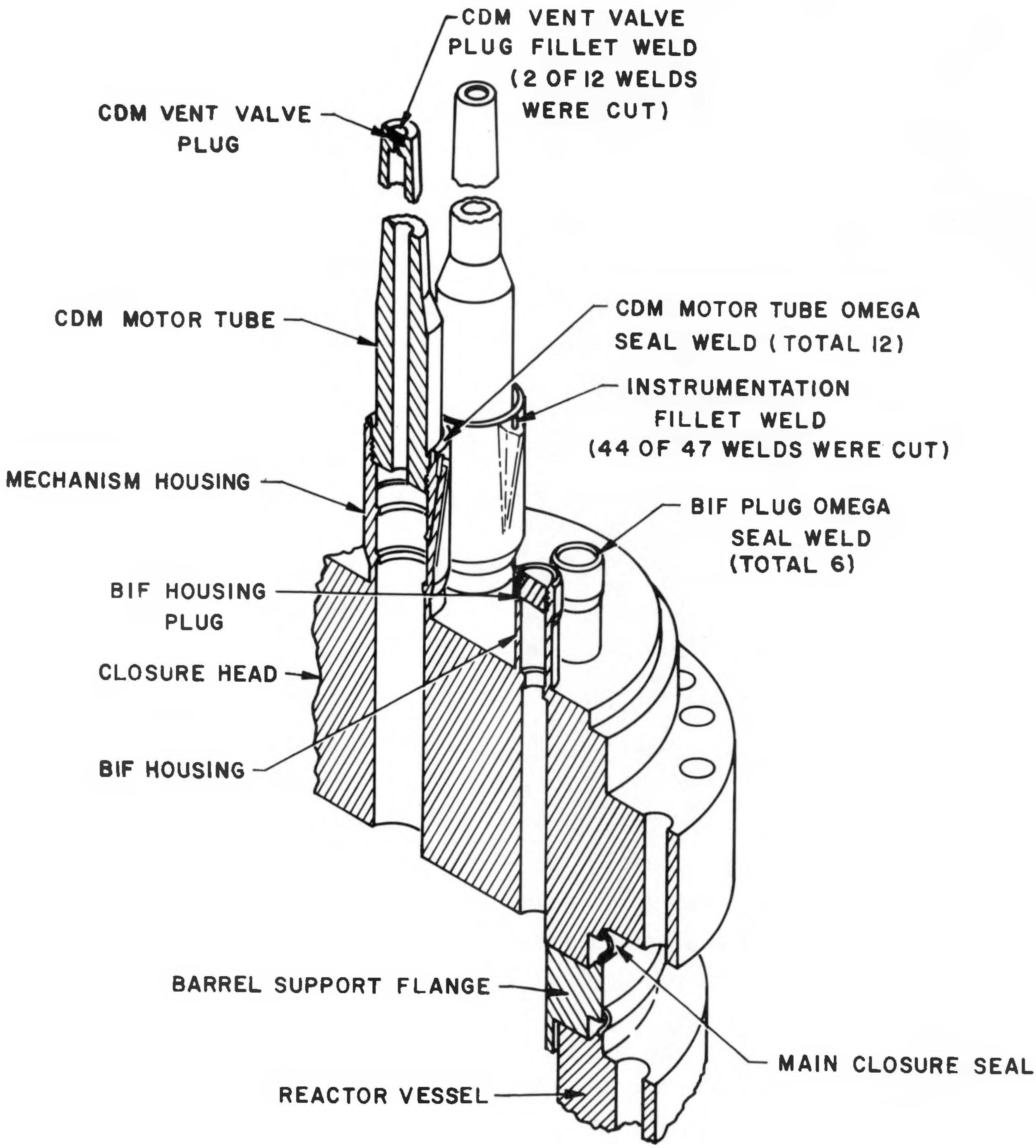

Figure 11. Locations for Cutting of the Pressure Boundary Welds on LWBR

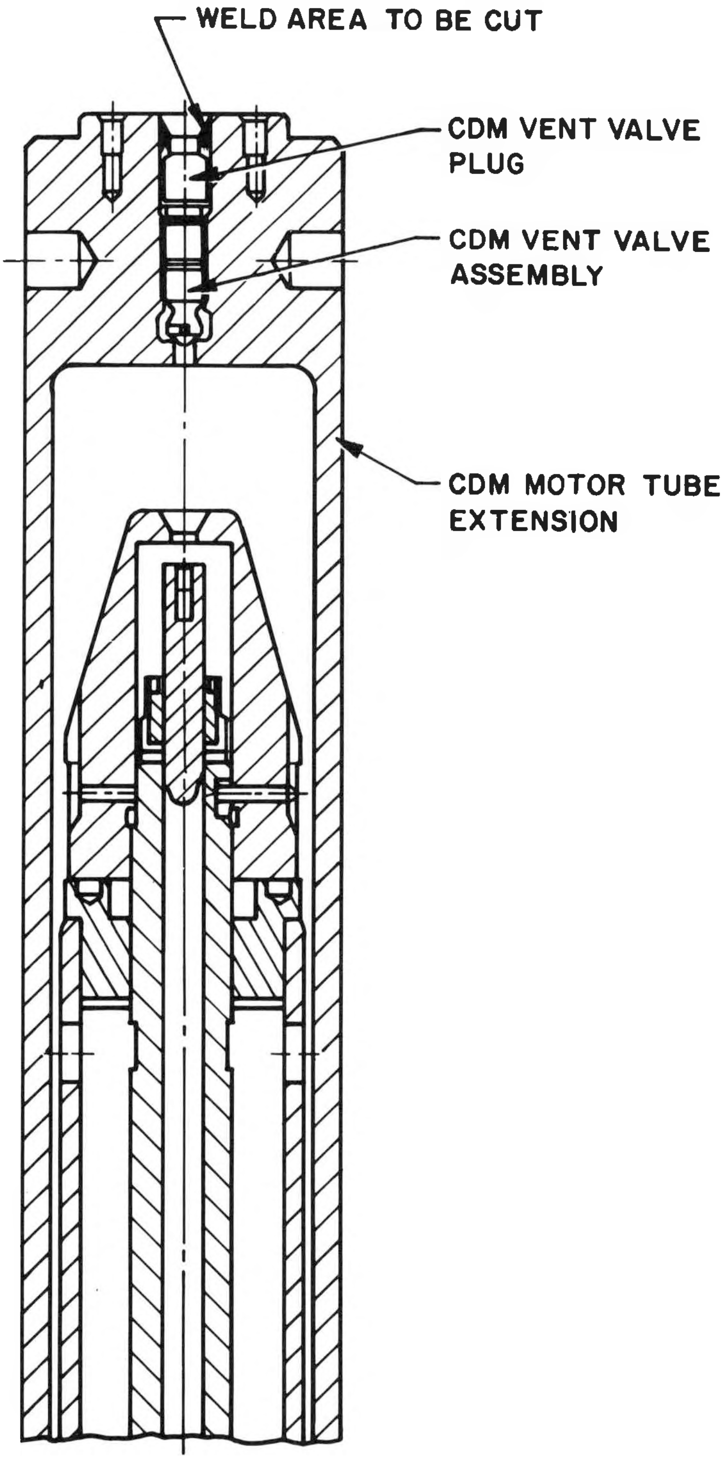

Figure 12. CDM Vent Valve Plug Cutting Location

The BIF D/P cell piping cutting was performed inside of a containment enclosure with a nitrogen purge; the cuts were made manually using either a miniature hand hacksaw or a regular hand hacksaw. The cut locations were chosen to minimize the number of cuts required, and the severed ends of the pipe sections were sealed with pipe caps and tape.

3.4.3 - Control Drive Mechanism Motor Tube Omega Seal Weld Cutting

Control drive mechanism motor tube omega seals were welded during reactor assembly by an automatic welder to provide a pressure boundary between each CDM and its associated housing after assembly. The CDM motor tube Alloy 600 omega seal has a nominal diameter of 14.873 inches and a nominal unwelded thickness of 0.100 inch.

An air-operated cutting machine (Appendix A1) was used to cut each of the 12 CDM motor tube omega seal welds. A facing tool was used first, followed by narrow- and wide-grooving tools used in tandem; the wide-grooving tool was positioned in front of the narrow-grooving tool. The seating surface for the cutting machine was a horizontal surface with three index holes, located outboard of the CDM omega seal. The index holes engaged three cutting machine centering pins. The cutting machine was held in place on the motor tube by a spring-loaded breechlock ring which engaged keyways in the motor tube and by tightening three jackscrews. With the cutting machine rotating about the motor tube at 9 to 12 rpm, a mechanism on the cutting machine advanced the tool cartridge into the groove 0.0014 inch for each rotation. The cutting operations were performed without a lubricant*. Plastic sheets were positioned to confine chips to the cutting area, and the cutting machine was designed to ensure that chips did not spread in an uncontrolled manner.

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*Most cutting operations were performed without coolant or lubricant because all commercial compounds for this purpose contain materials which may be harmful to reactor materials; therefore, they were prohibited in the defueling area. The exception was for closure head omega seal grinding, which required a coolant to protect the grinding wheel and reduce grinding dust (a radiological control concern). The location of the cut kept the coolant out of the primary system, and all used coolant was collected by a filtered vacuum system.

After the omega seal was severed, the cutting chips were cleaned up and the cut was sealed pending motor tube removal.

3.4.4 - Bypass Inlet Flow Housing Omega Seal Weld Cutting

The BIF housing omega seals were manually welded during reactor assembly to provide a pressure boundary between each BIF housing plug and its associated housing on the closure head. The omega seal had an outside diameter of 8.073 inches and an unwelded thickness of 0.100 inch.

The air-operated BIF housing omega seal weld cutting machine (Appendix A1) had operating characteristics and a sequence of operations similar to the CDM motor tube omega seal weld cutting machine, except that it was smaller in size. The BIF cutting machine had two locating pins which engaged pilot holes in the top of the BIF housing plug and two captured mounting bolts to secure the machine to the BIF closure plug. The cutting operations were performed without a lubricant. Plastic sheeting was used to confine chips to the work area. After the cutting operations were complete, cutting chips were cleaned up and the cut was sealed pending BIF component removal.

3.4.5 - Instrumentation Plug Cutting

The LWBR closure head area instrumentation cutting operations included 33 thermocouple plug welds, three BIF low-pressure tap plug welds, and eight flux thimble plug welds. All of the instrumentation plugs were located on bosses attached to the CDM housings (Figure 13), except for one flux thimble plug which was welded to a BIF housing closure plug. These plugs had been manually welded to provide a primary pressure boundary between instrumentation plugs and CDM housing bosses or BIF closure plug. All of the instrumentation plugs were made of Inconel Alloy 600. The thermocouple and BIF low-pressure tap plugs were approximately 0.5 inch in diameter, and the flux thimble plug was approximately 0.75 inch in diameter. All plugs extended approximately 2.0 to 2.7 inches from the surface of the bosses. The fillet welds penetrated below the surface of the boss about 0.10 inch.

An air-operated cutting machine with a hollow end mill cutter was used to skim cut the outside diameter of the instrumentation plug and sever the weld

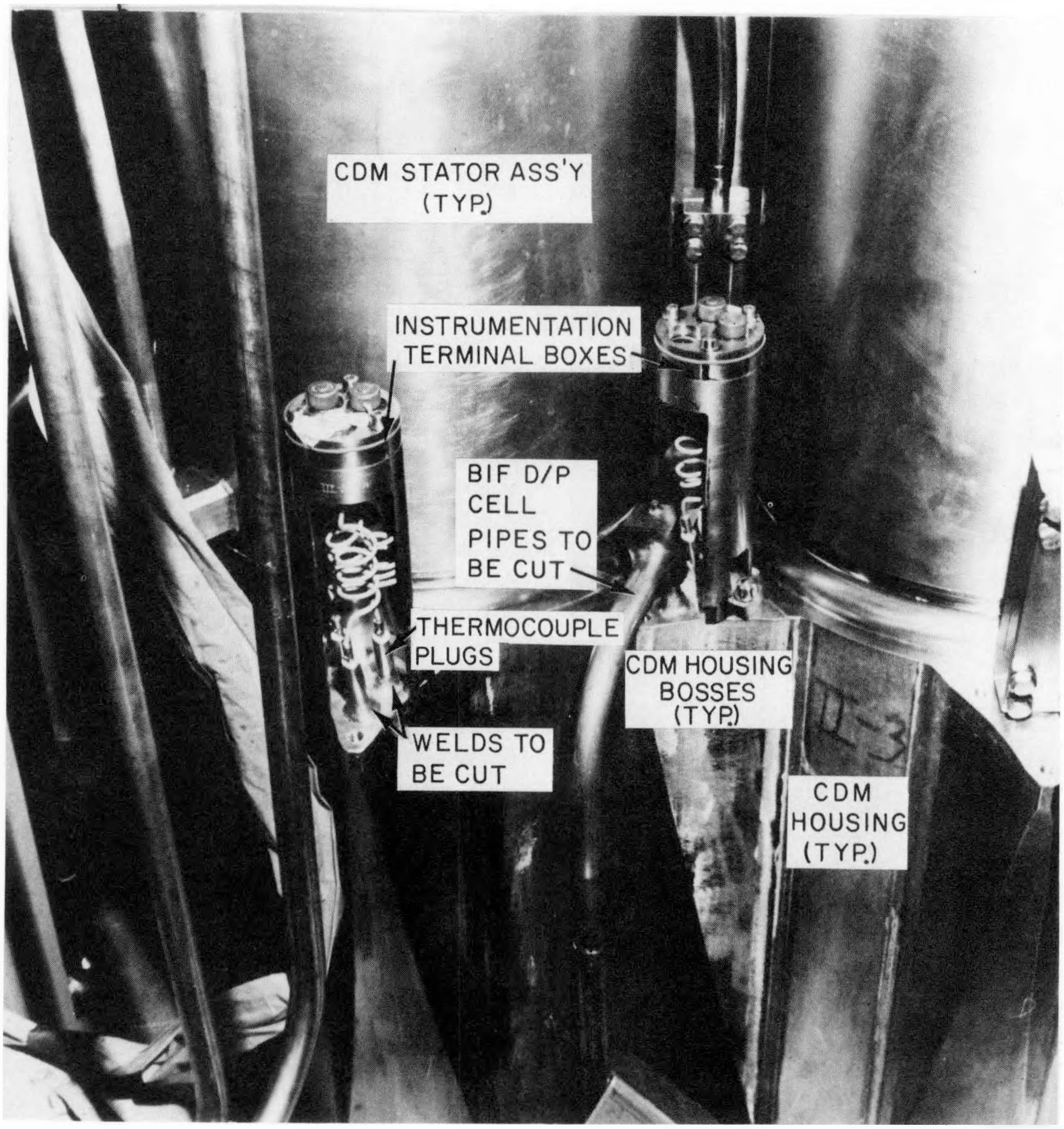


Figure 13. Instrumentation Terminal Boxes on CDM Housing Bosses Showing Thermocouple Instrumentation and BIF Pressure Tap Plug Welds

between the plug and CDM housing or BIF housing. Two diameters of cutters were used; the smaller diameter cutter for thermocouple and BIF low-pressure tap plugs, and the larger diameter cutter for the flux thimble plug. After the terminal boxes were removed and the electric wires were cut away, the cutting machine was bolted to the boss on the CDM housing. The cutting operations were performed without a lubricant. After the cutting operation was complete, cutting chips were removed with a vacuum cleaner and the parted weld joint was filled with sealant around the entire circumference, pending removal of each item.

A couple of difficulties were encountered during instrumentation plug cutting operations. Part of the problem was a result of cutting Inconel welds without a lubricant or coolant. As a result of work-hardening of the weld metal during cutting, cutter wear and breakage was so great that some cutting cycles required as many as four cutters to complete weld removal. A sufficient supply of cutters was maintained so that no operational delays occurred due to a shortage of cutters. It was also found that plug distortion due to manual welding variations resulted in off-center cuts and incomplete removal of weld metal. For the few plugs affected by this problem, the remaining weld bridge was manually broken by firmly attaching locking pliers to the plug and twisting until the plug turned freely.

3.4.6 - Main Closure Seal Grinding

The LWBR reactor assembly contained two main closure seals. The upper main closure seal (Figure 11) was welded to form a flexible primary pressure boundary between the closure head and the barrel support flange. The lower main closure was welded to form a flexible primary pressure boundary between the barrel support flange and the reactor vessel. Only the upper main closure seal was severed to permit removal of the closure head and the LWBR fuel modules. The outside diameter of the upper main closure seal was approximately 132.50 inches. The closure seal was fabricated from 2.75-inch outside diameter Type 348 stainless steel pipe with a 0.193-inch nominal wall thickness.

Operations using the main closure seal grinder (Appendix A1) began by attaching the machine to the closure head. (Figure 14 shows the grinder attached to a mock-up of the closure head during checkout.) The cut was started by a manual plunge cut. Water trapped within the seal drained out of the cut and was captured within the grinder containment. There was much more water than expected, but it was not contaminated. Rags and a wet/dry vacuum cleaner were used to control water around the cut area. When drainage stopped, the cutting wheel was restarted and the air motor was turned on to automatically drive the grinder around the closure head at a rate of between 5 and 12 inches per minute.

Because of the circular cross section of the seal, a minor problem occurred in which the grinding wheel was deflected off a horizontal track, causing deflection and breakage of one grinding wheel. This problem was not encountered during mock-up training because only plunge cuts and short traverses were made to familiarize a sufficient number of operators with the equipment. After the first occurrence, this deflection was controlled by noting the start of the deviation, withdrawing the grinder, and reinitiating the cut a few inches away. Uncut lengths were severed subsequently by running the drive motor in reverse or by manually using a chisel and hammer. As a further precaution, a new grinding wheel was installed at approximately 90-degree intervals around the circumference. Total time required to perform closure head grinding, from installing the machine to removing the machine from the reactor pit, was five working shifts. General radiation levels in the work area were kept under 15 mR/hr by using lead shielding on exposed pipes.

3.5 - CONTROL DRIVE MECHANISM MOTOR TUBE REMOVAL

Twelve CDMs (Figure 15) were used in the LWBR reactor as the means of adjusting elevation of the movable fuel assemblies (seed modules) to control reactivity. The major functional components of the CDM are the stator, the motor tube, and the translating assembly. Inside the motor tube was the roller nut assembly, which surrounded the leadscrew of the translating assembly from which the seed modules were suspended. The rotating field of the

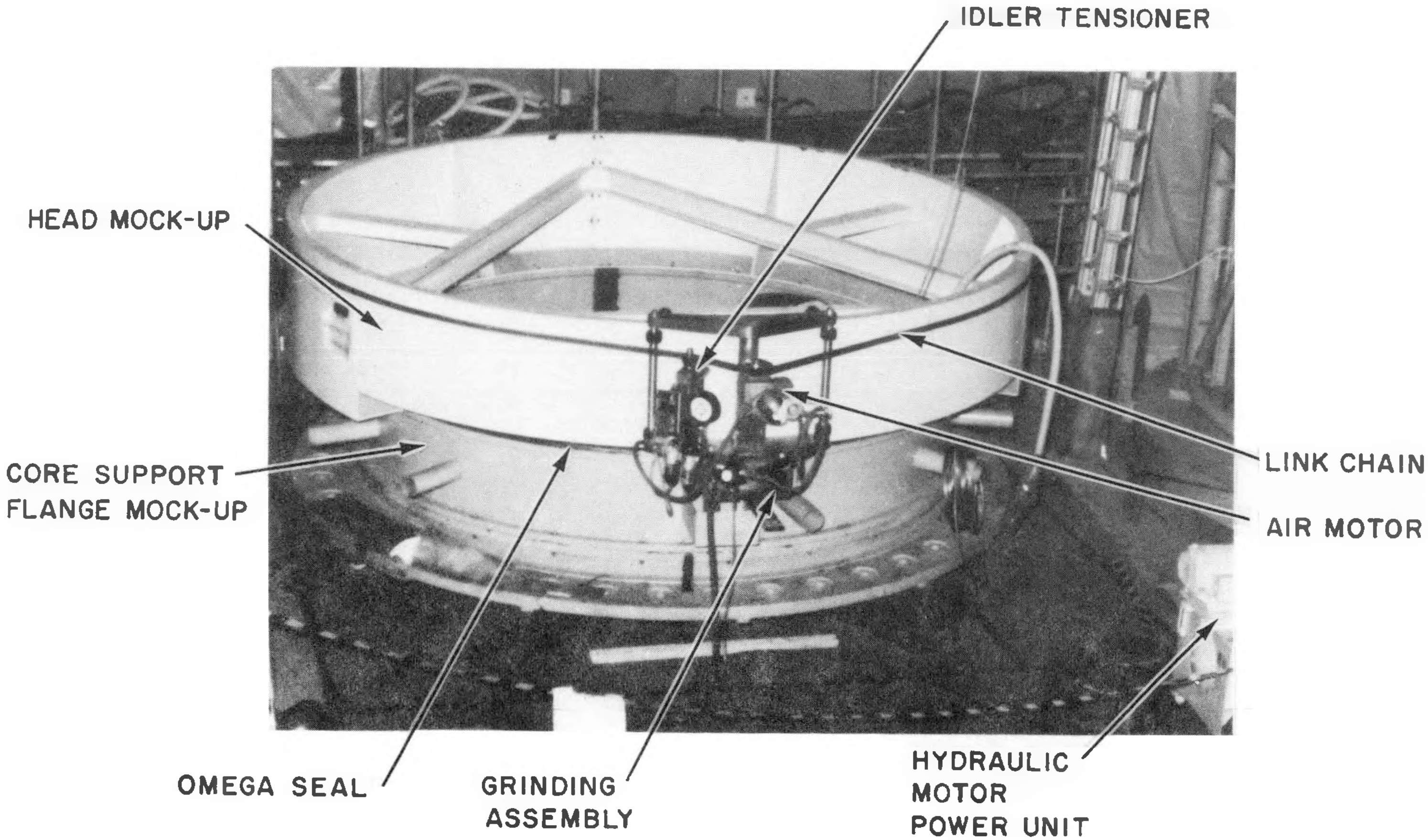


Figure 14. Closure Head Grinding Machine Attached to Mock-up During Checkout

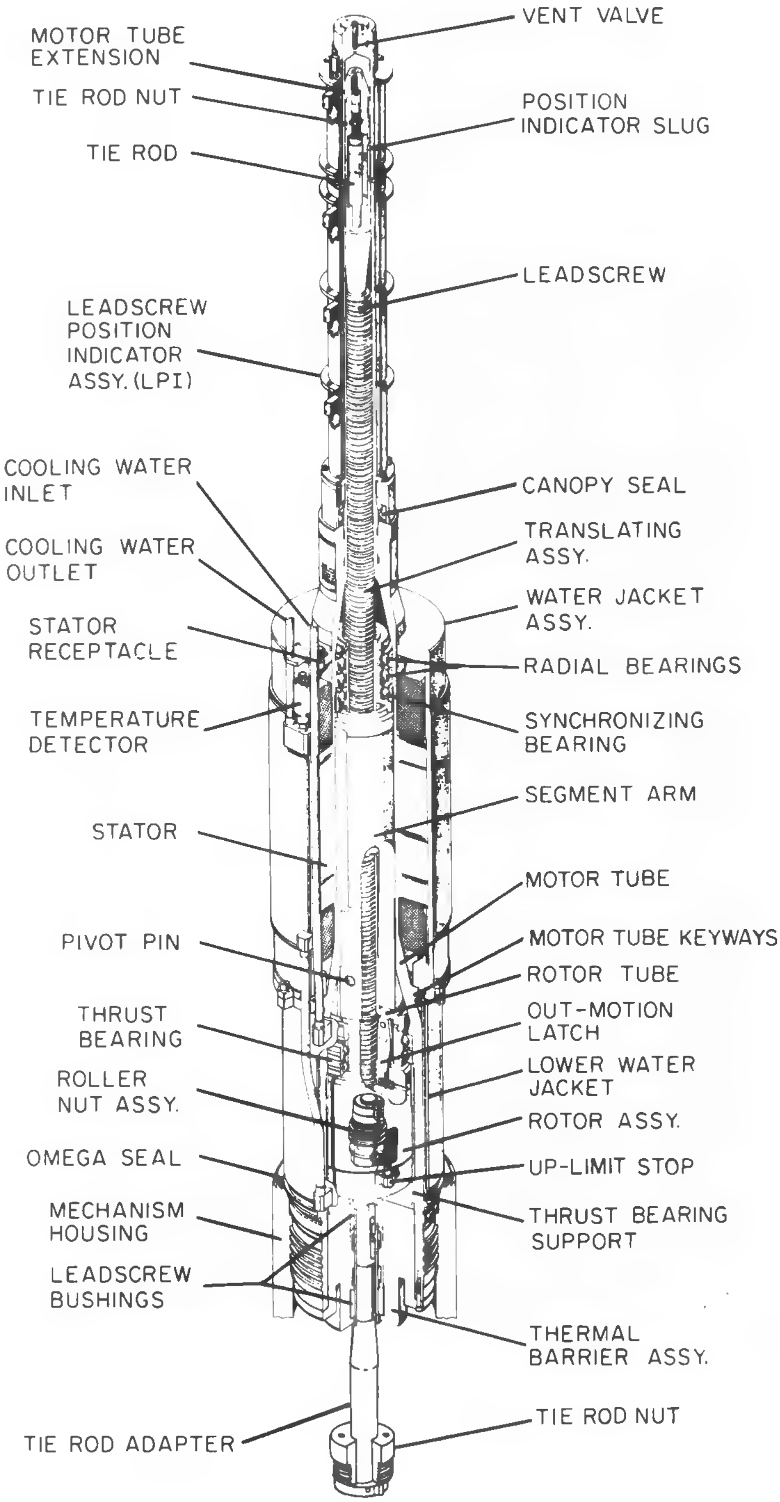


Figure 15. RN-70A Control Drive Mechanism

stator which fitted around the motor tube, caused the roller nut assembly to rotate with the field, thus adjusting the elevation of the seed module through the translating assembly leadscrew. A comprehensive discussion of the CDM is presented in Reference 8.

The CDM motor tube functioned as a primary system boundary. The top of a motor tube extension contained a vent valve which was used to breach the primary system boundary to vent and purge the primary system of combustible hydrogen prior to the beginning of head area disassembly operations (Section 3.4.1).

The CDM motor tube was attached to the closure head through the CDM housing. The base of the motor tube was threaded into the CDM housing, and the gap between the motor tube and CDM housing was sealed with an omega seal.

Motor tubes and translating assemblies were removed separately, but in an integrated operation to maintain radiological containment (i.e., a motor tube and translating assembly were removed from one location before proceeding to the next location). Motor tube removal operations began after the CDM housing omega seal had been cut (Section 3.4.3) and after the primary system had been purged with nitrogen. The motor tube lifting tool (Figure 16) was used to unthread the motor tube from the CDM housing. The motor tube lifting tool was attached to the top of the motor tube extension, and the handles of the lifting tool were used to unthread the motor tube while rigging suspended the weight of the motor tube to ensure that galling of the motor tube threads would not occur. A method for providing a breakaway torque was initially sequenced into the unthreading operations to accommodate the possibility of galled threads on the motor tube. To provide breakaway torque, a long-handled spanner wrench was installed on the motor tube keyways (Figure 15) and torque was applied to rotate the motor tube the first few degrees of travel, after which normal unthreading operations resumed. The mandatory initial high-torque operation was deleted after removal of the first two motor tubes proved

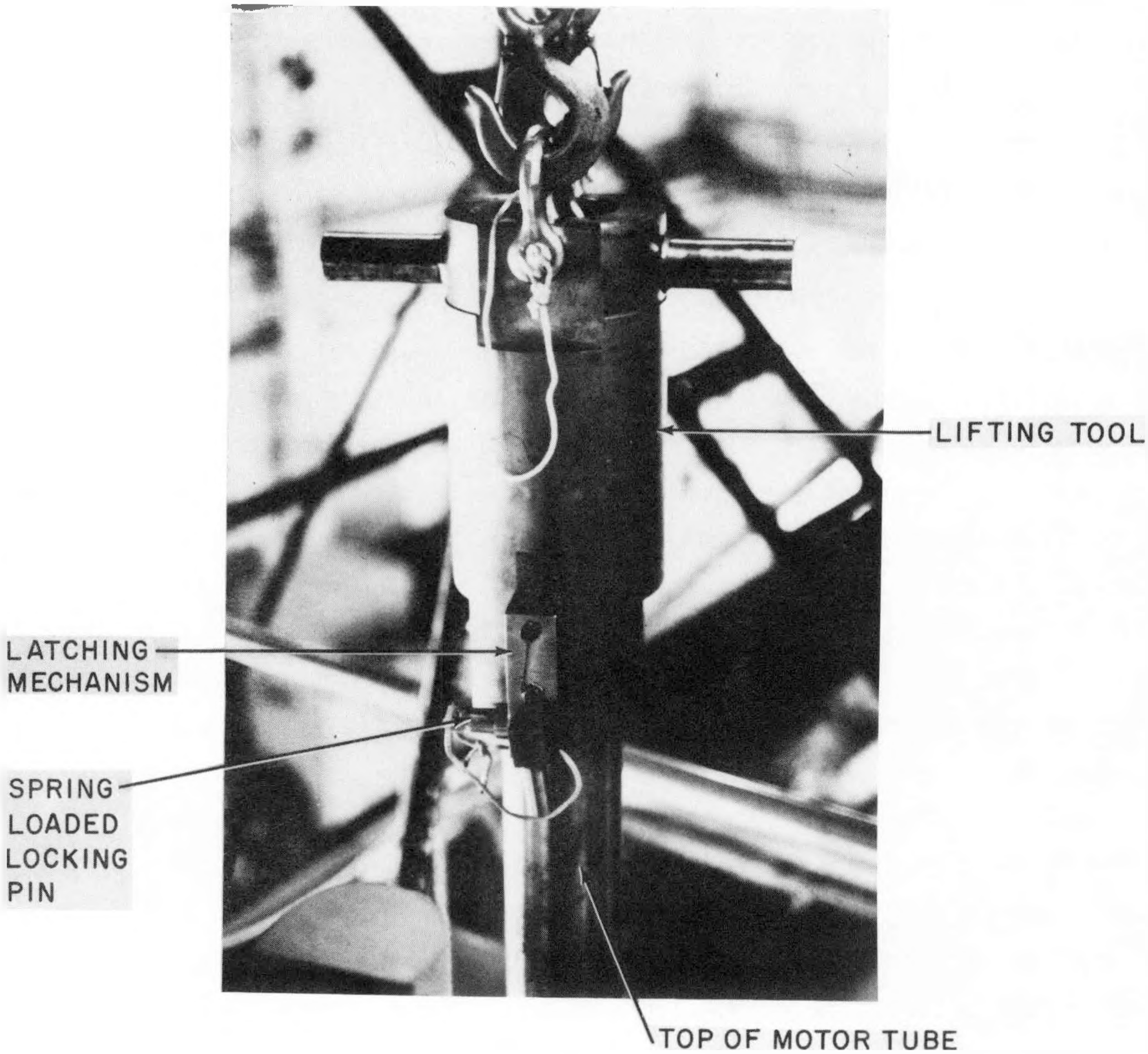


Figure 16. Motor Tube Lifting Tool Latched Onto Motor Tube

that enough torque could be applied to the lifting tool (Figure 16) to begin unthreading the motor tubes.

After the motor tube was unthreaded from the mechanism housing, it was necessary to carefully raise it high enough to clear the translating assembly. The motor tube was raised slowly using a chain hoist while constantly monitoring the lifted load to ensure that the motor tube did not bind up on the translating assembly. The translating assembly was connected to the seed module, which had to remain seated on the reactor baseplate to ensure maximum radiation shielding. Thus, a limit of 200 pounds over the weight of the motor tube was imposed on the motor tube removal operation. When the motor tube was raised high enough to clear the translating assembly, it was wrapped in its plastic radiological containment bag and transported to storage.

All motor tube removal operations were performed in radiological containment (Appendix A2). Maximum radiation levels of 130 mR/hr occurred on contact with the base of the motor tubes after removal from the closure head. The general radiation level on the closure head during operations was 30 mR/hr.

3.6 - TRANSLATING ASSEMBLY REMOVAL

The CDM translating assembly provided suspension for the LWBR movable fuel assemblies (seed modules) and permitted adjustment of the seed module elevation to control the core reactivity. The bottom of each translating assembly was attached to the support shaft of a seed module through a balance piston/tie rod nut assembly (Figure 17). To remove the translating assembly from the CDM housing, the translating assembly tie rod nut had to be unthreaded from the balance piston. The translating assembly removal tool (Figure 18) was designed to fit into the open CDM housing, restrain the balance piston, rotate the tie rod nut and, when the tie rod nut was fully disengaged from the balance piston, engage the translating assembly and remove it from the CDM housing.

The translating assembly removal tool consisted of two concentric pipe sections with 2.00-inch long, 0.25-inch diameter pins at the bottom of each section to engage holes in the balance piston and tie rod nut. The outer section of the removal tool engaged the balance piston, while the inner section

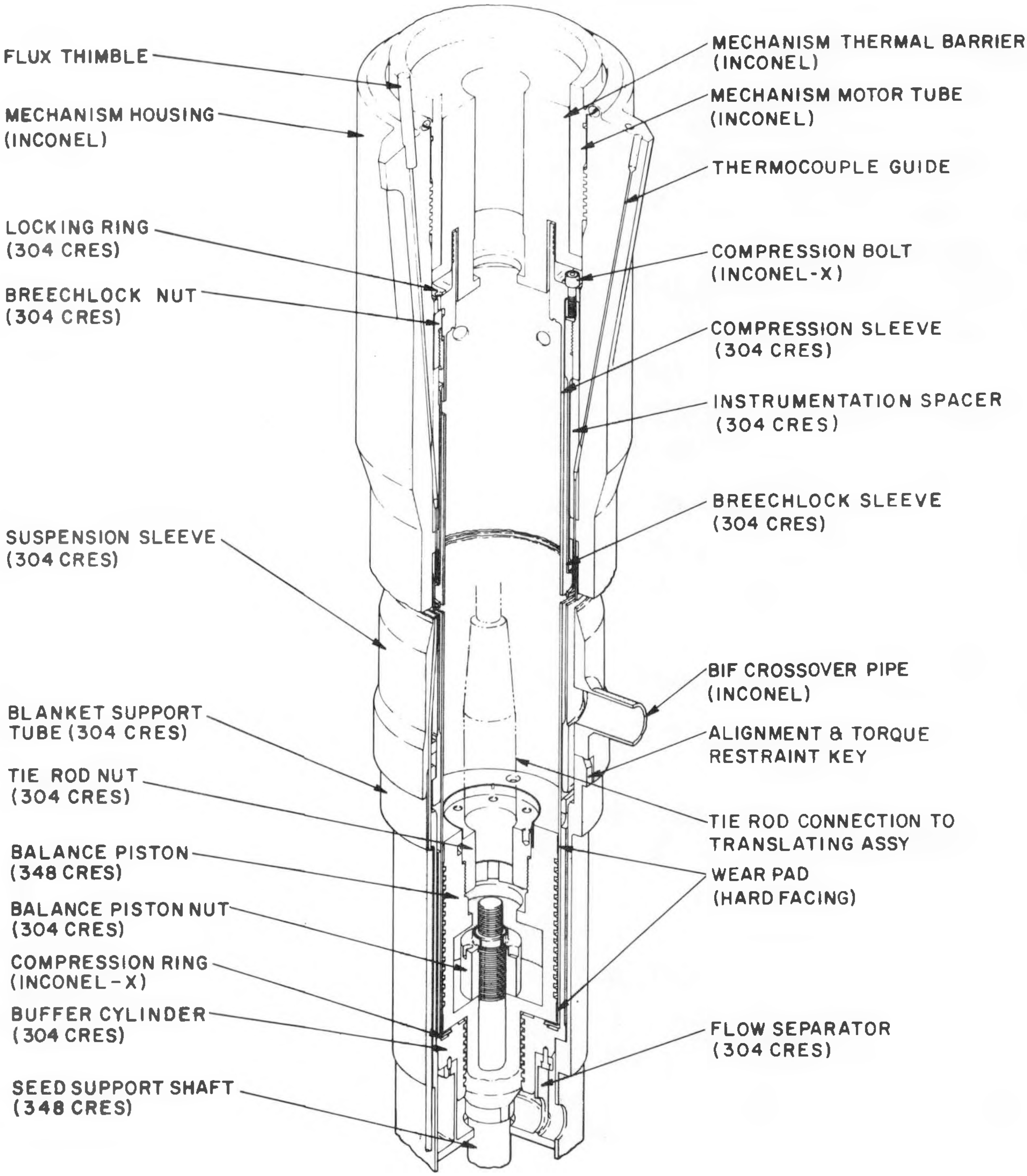


Figure 17. Fuel Module Suspension System

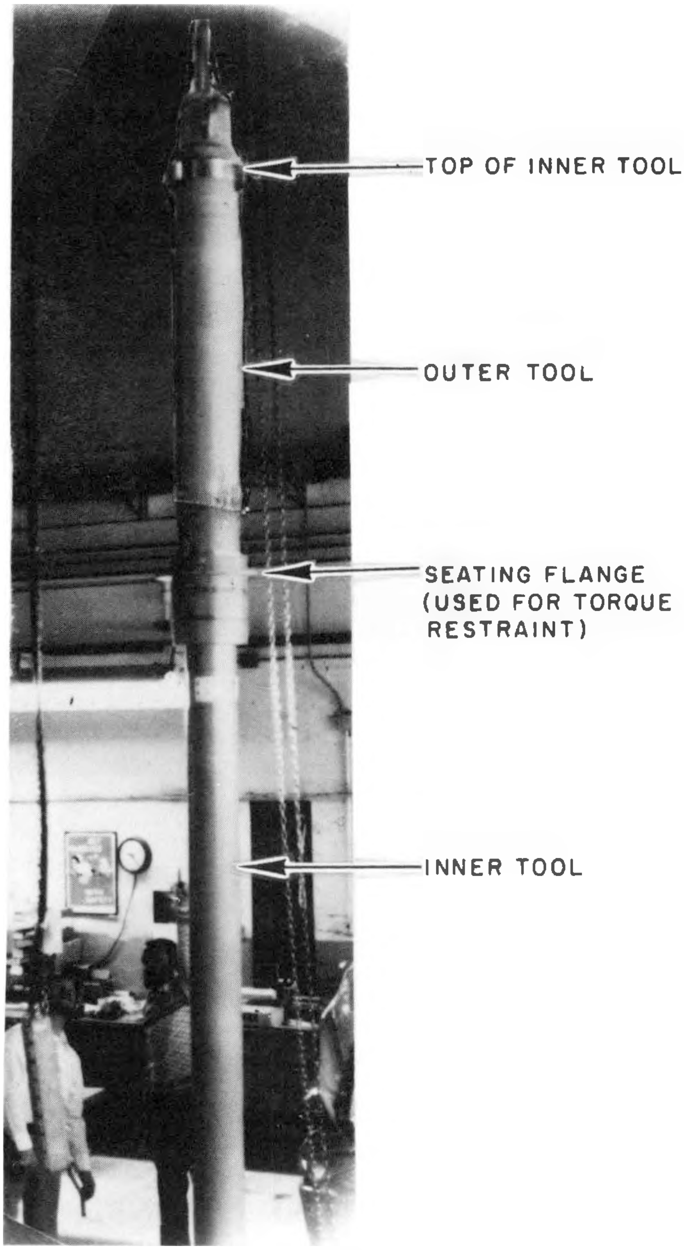


Figure 18. Translating Assembly Removal Tool

engaged the tie rod nut. Torque was applied to the tie rod nut through a wrench which fitted over the lifting ears of the inner tool. Torque applied to the tie rod nut was countered by one of two methods. If the tie rod nut would break free and unthread with applied torque below 300 lb-ft, torque was countered through the unrestrained seed support shaft. Torque above the cut-off could damage the seed module; therefore, the balance piston was restrained through the outer tool by attaching a torque restraint cam to the flange on the outer tool (Figure 18) and reacting it against the CDM housing. In practice, the second method was used on all translating assemblies, and torques up to 750 lb-ft were applied. Once tie rod nut unthreading was complete, the wrench was removed from the tool lifting ears and replaced by a translating assembly lifting bracket (Figure 19). The translating assembly and removal tool were removed from the head area for disposal of the translating assembly. The removal tool was reused for all 12 CDM housing locations.

All disassembly operations involving the CDM housing were performed in radiological containments to prevent the spread of radioactivity (Appendix A2). Radiation levels up to 2580 mR/hr were estimated to exist on contact with the translating assembly. Therefore, the removal tool was made as thick as possible to provide shielding while transporting a translating assembly to its storage location. Expected radiation level on contact with the tool was 1850 mR/hr. The maximum radiation level on contact with the base of the tool measured during actual defueling operations was 600 mR/hr. Radiation levels where personnel were standing did not exceed 100 mR/hr during discharge of the translating assemblies into underwater storage because work was performed at the top of the tool as the assembly was discharged out of the bottom.

In planning for tie rod nut removal, consideration was given to the possibility that a galled tie rod nut might not be loosened using the maximum torque limit of the removal tool, about 1500 ft-lbs. Tools for compression sleeve removal, breechlock sleeve detensioning, and blanket module lowering were designed with hollow centers to prepare for this situation. A special shield was designed that would fit over the translating assembly to permit completing operations through closure head removal with the translating

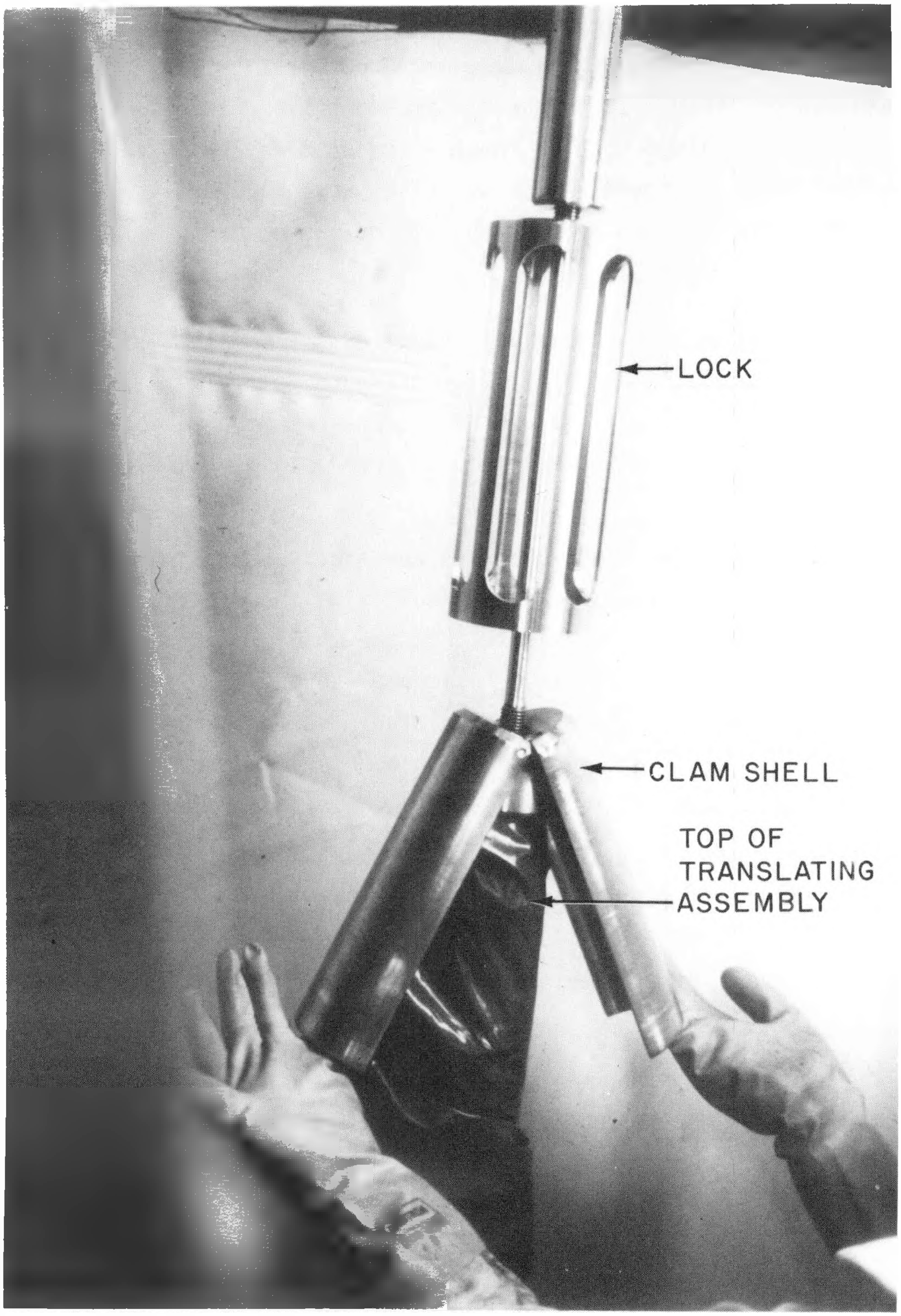


Figure 19. Translating Assembly Lifting Bracket

assembly in place. Contingency operations for closure head removal with one or more translating assemblies in place included visual verification that a seed module was not being raised due to binding between the closure head and the translating assembly. None of the tie rod nuts galled during normal removal operations; the translating assemblies were all easily removed and none of the contingency equipment or operations was used.

3.7 - BYPASS INLET FLOW COMPONENT REMOVAL

To permit closure head removal it was necessary to remove three components of the bypass inlet flow (BIF) system (Figure 20). These components were the BIF housing closure plug, the BIF tension/compression tube, and the BIF supply tube. These components were removed from each of the six BIF locations.

The main component of the system was the supply tube assembly, the purpose of which was to provide a means of equalizing the differential pressure from bottom to top of a seed module so that the module could drop under its own weight in the event of a scram. To accomplish this, a 238-inch long by 5.0-inch diameter Type 304 stainless steel tube assembly extended from top to bottom of the core. Each BIF supply tube assembly served two fuel modules and was comprised of two concentric tubes.

The tension/compression tube assembly served as a holddown device for the supply tube. The compression tube portion of this concentric pair exerted a force on the supply tube assembly. The tension component was connected to the BIF suspension sleeve in the closure head.

The BIF housing closure plug sealed the BIF supply system by means of a 7.5-inch thick threaded plug and welded omega seal between the plug and housing. Details of seal weld cutting are given in Section 3.4.

To gain access to the BIF system, the housing plug was removed first. The removal tool was a variation of a simple wrench, which was connected to the plug by means of captive cap screws mating with threaded holes in the plug. To ease the effort required for turning the plug and minimize the potential for galling threads, the wrench remained rigged to a lifting device

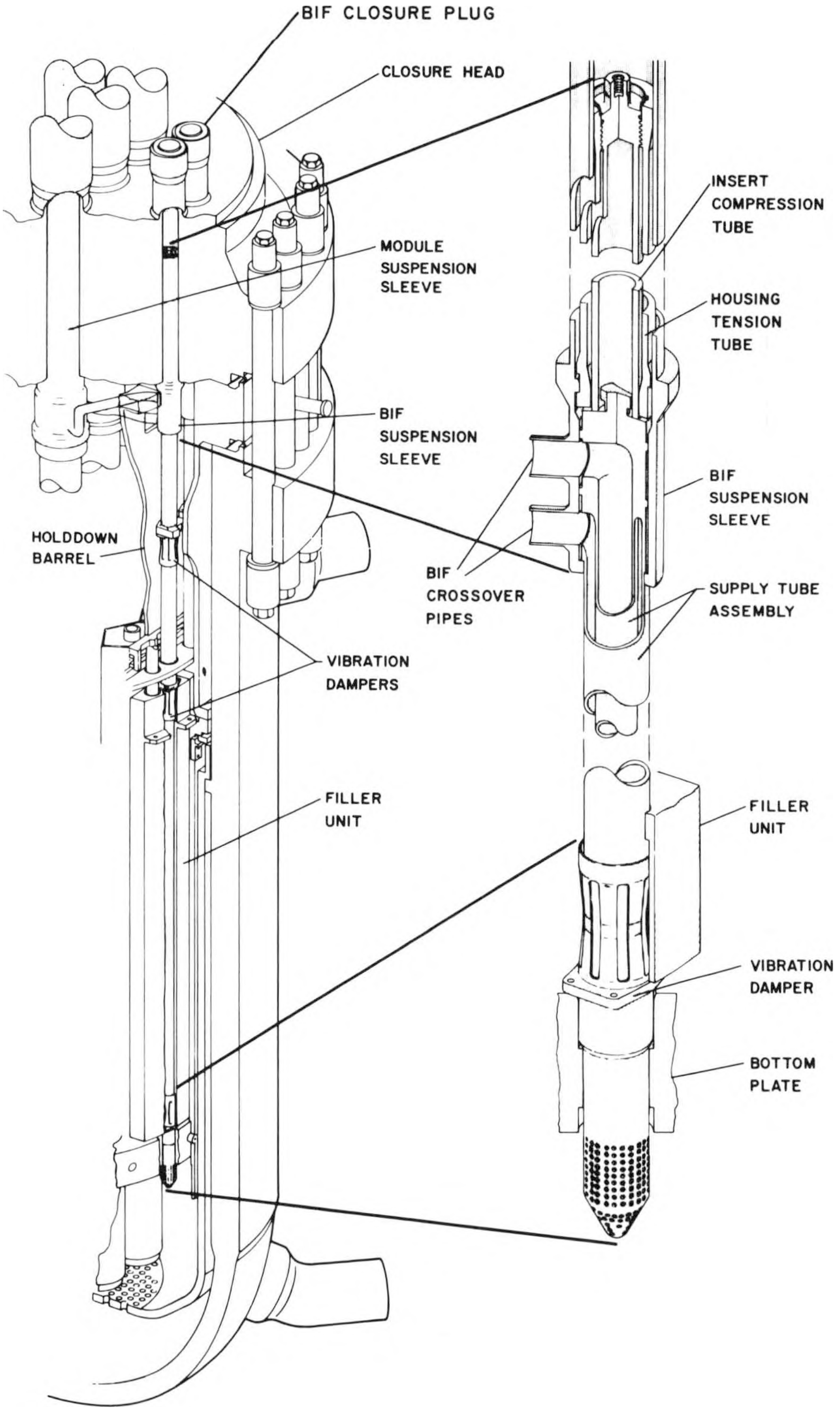


Figure 20. BIF Supply Tube Installed in Reactor Vessel

so that an upward force equal to the weight of the tool and plug could be applied. Work was accomplished in radiological containment (Appendix A2). The maximum radiation level at the top of BIF housings during plug removal operations was 20 mR/hr.

Removal of the tension/compression tube assembly required first relieving the compression force in the compression tube, then removing the assembly as a unit. To accomplish this, a two-part tool was used. The inner tool served as a wrench to apply torque of up to 1600 ft-lbs to the compression tube. The outer tool was connected to the tension tube by means of three threaded rods. The compression tube was unthreaded sufficiently to relieve the compressive forces, but not so far as to disengage it from the tension tube. The tension tube was then disengaged from the BIF suspension sleeve, and the assembly was removed from the BIF housing and placed in a shielded container. All work was accomplished in radiological containment (Appendix A2). The maximum radiation level on the tension/compression tubes during removal was 130 mR/hr.

With the removal of the tension/compression holddown sleeve, the supply tube assembly was free to be removed by a simple lifting operation. However, because of the extremely high radiation levels on the supply tube (estimated at up to 1070 R/hr), it was necessary to lift it into a heavy shielded container (Figure 21). A lifting tool with a positive locking latch was first attached to the supply tube. A lifting extension was inserted through the shield and attached to the lifting tool. The supply tube was then raised into the shielded container in containment, removed from the reactor pit, and discharged into an underwater storage area. The maximum radiation level on the surface of the shielded container was 80 mR/hr.

One minor problem occurred during removal of the first of the six supply tubes. It was not immediately recognized that the shielded transfer container, unlike the mock-up for training, was not symmetric with respect to two locating pins in its base that were designed to center the container over the BIF port. The container was installed on its support in the wrong orientation. When the first supply tube was raised, the lifting tool was far enough

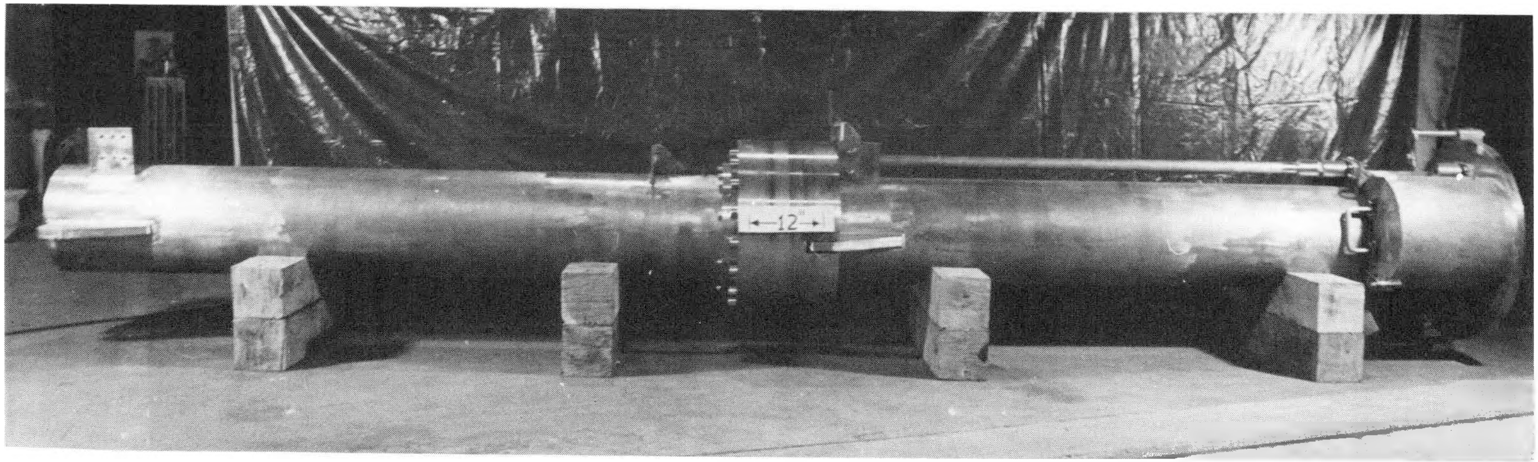


Figure 21. BIF Supply Tube Transfer Container (Shown Horizontally, But Used Vertically)

off the center line of the shielded container that the supply tube could not be pulled into the container. For this first supply tube, the container was repositioned to provide sufficient clearance to raise the supply tube into the container.

3.8 - THERMOCOUPLE, FLUX THIMBLE, AND PRESSURE TAP REMOVAL

Core instrumentation entered the reactor core through the closure head at bosses on the CDM housing and at one BIF housing (Figures 13 and 22). Instrumentation installed at these locations consisted of eight flux thimbles (one of which was on a BIF housing), 33 thermocouples, three BIF low-pressure taps, and three BIF high-pressure taps. Flux thimbles consisted of long lengths of stainless steel tubing which extended deep into the core and were highly irradiated, with radiation levels of up to 35 R/hr on contact. Thermocouples and BIF low-pressure taps also were long lengths of highly irradiated material, but radiation levels were several orders of magnitude lower than for flux thimbles. The BIF high-pressure taps consisted of short hollow plugs which did not extend into the fuel modules.

Prior to removing instrumentation, it was necessary to cut seal welds around each item (Section 3.4.5). To remove thermocouples and low-pressure taps, a wire rope was attached to the item using a hose clamp. To remove flux thimbles, a nylon rope was connected to the item through an adapter and hoist ring in a threaded hole previously used for inserting flux wires. All thermocouples and low-pressure taps (Figure 22) on a given boss were removed as a group of two or three. The flux thimbles occupied individual locations on bosses or on BIF housing location IV-2 (Figure 22) and were removed individually. All instrumentation (except the high-pressure taps) on a given boss was removed at one time using appropriately prepared wire rope pull cables running over a pulley located on the workbridge above the reactor pit. All items were pulled into containment sleeves (Appendix A2). The BIF supply tube transfer container (Figure 21) was used for flux thimble removal to reduce radiation levels.

After removing thermocouples and low-pressure taps from the reactor, they were disposed of in lead-lined drums. Flux thimbles were transported in

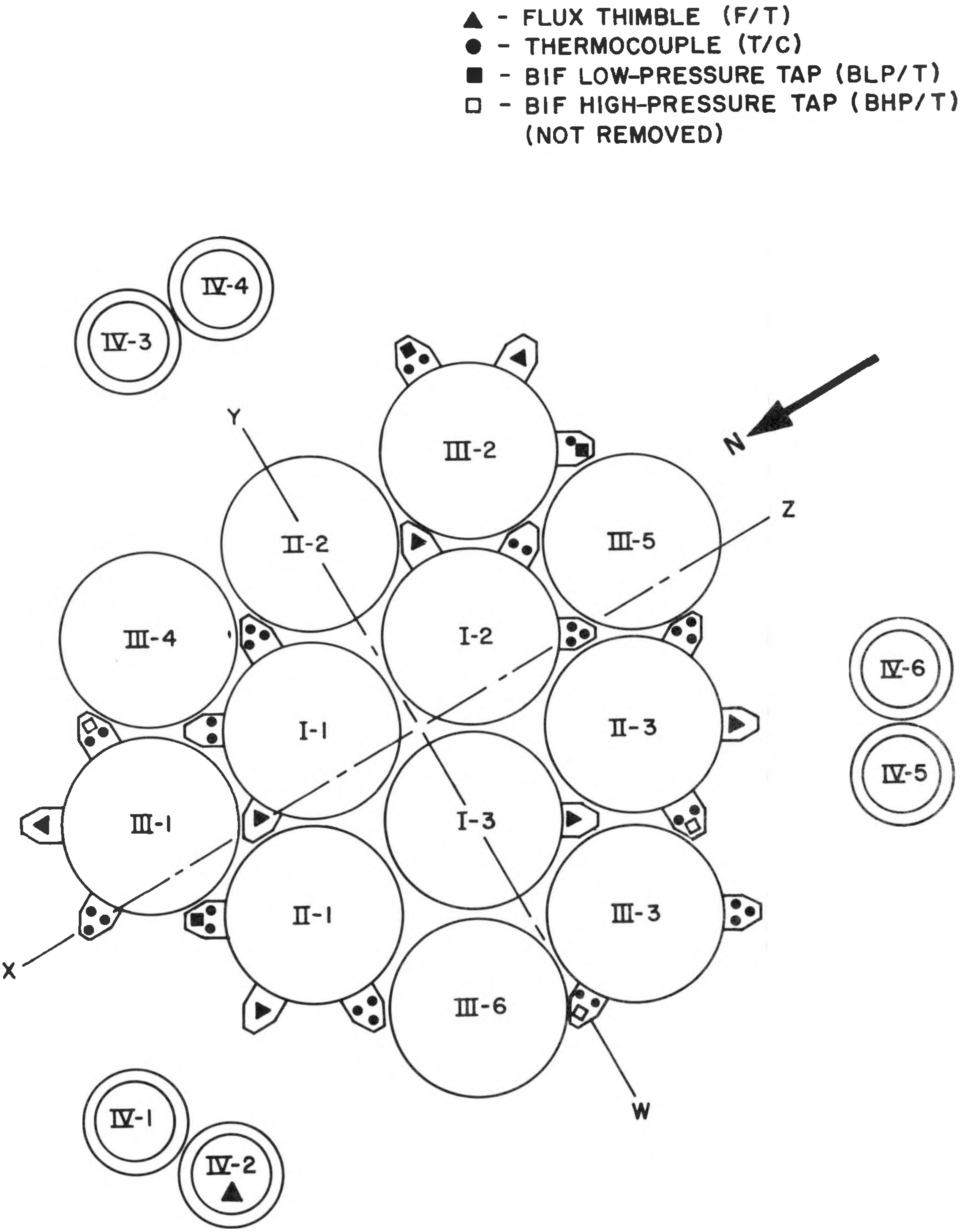


Figure 22. Schematic of Instrumentation Locations on CDM Bosses and BIF Plugs

the shielded container to a storage location in the transfer canal and stored under water until other items with high radiation levels were accumulated and disposal was arranged (Appendix A7).

During removal of the first flux thimble at the BIF housing location (IV-2 on Figure 22), both radiation levels and removal forces were much lower than expected and a problem was suspected. The flux thimble was raised from its storage location and it was noted that less than half of the total length of the thimble was in the containment bag. Flux measurement operations using this thimble had ceased several months before the LWBR was shut down when there were indications of a failed thimble. Results of an investigation into the cause of this failure indicate that it was due to tube wall thinning of the thimble material (Type 347 or 348 stainless steel) and subsequent fracture of the weakened section.

Analyses of the length of the part of the thimble removed from the reactor raised the concern that the remnant may have been partially removed from the core. If it were not fully seated, the potential for interference with further disassembly operations (especially with removal of the holddown barrel) existed. A special measuring device and procedures to use this device were developed to determine the remnant elevation within the core. It was determined that the remnant was in a safe location, and no further retrieval efforts were undertaken.

3.9 - COMPRESSION SLEEVE REMOVAL

The compression sleeve was an integral part of the blanket fuel module suspension system. The components of this system (Figure 17) are the suspension sleeve, breechlock sleeve and nut, compression sleeve and bolts (with locking ring), and the compression spring. The suspension sleeve was the outermost component of the system; it penetrated the closure head and provided connections for the BIF piping (Section 3.7). The breechlock sleeve served to clamp the blanket support tube to the suspension sleeve, thereby suspending the blanket module from the closure head. The compression sleeve fitted inside the breechlock sleeve to provide a guide for the movable seed fuel assembly balance piston and to provide the axial loading necessary to effect a watertight seal at the base of the compression sleeve through controlled deflection of the compression spring on the buffer cylinder. For reactor disassembly, it was necessary to remove the compression sleeve from the closure head to gain access to the breechlock sleeve, which had to be disengaged from the blanket support tube to permit module lowering. The breechlock sleeve remained in the closure head after fuel module lowering (Section 3.10) and was removed with the closure head.

Removal of the compression sleeve was done in two steps. First, the compression bolts were untorqued and removed along with the locking ring (Figure 23), then the compression sleeve was grappled and removed.

Removal of the compression bolts and their associated locking ring was accomplished in a straightforward manner inasmuch as the bolts were accessible from the CDM housing opening; mostly conventional hand tools, such as a torque wrench or breaker bar, square drive extension, and tongs were used. For the first compression sleeve, the eight bolts were removed one at a time. For the remaining 11 compression sleeves it was found that, once all eight bolts were unthreaded, the bolts could be lifted out at one time by using tongs to lift the locking ring. This work was accomplished through glove ports in a large containment sleeve (Appendix A2).

Removal of the compression sleeve was accomplished with the same tool that had been used to install the sleeve (Figure 24). The compression sleeve tool was inserted through the CDM housing and grappled onto the sleeve; then the sleeve was carefully raised to a transfer elevation, wrapped in its containment sleeve, and transported to Cask Storage Pit No. 4 (Figure 1B). All work was accomplished in containment, using the same tools for all 12 sleeves. The maximum radiation level on the compression sleeves was 700 mR/hr on the cylindrical surface of the sleeves. The sleeves were wrapped with tape to gather the containment around the sleeve (to prevent damage to the containment while placing the sleeve in a storage rack).

3.10 - BREECHLOCK SLEEVE DETENSIONING AND MODULE LOWERING

The final head area disassembly operation prior to removing the reactor vessel closure head was to disengage the blanket fuel assemblies from the head

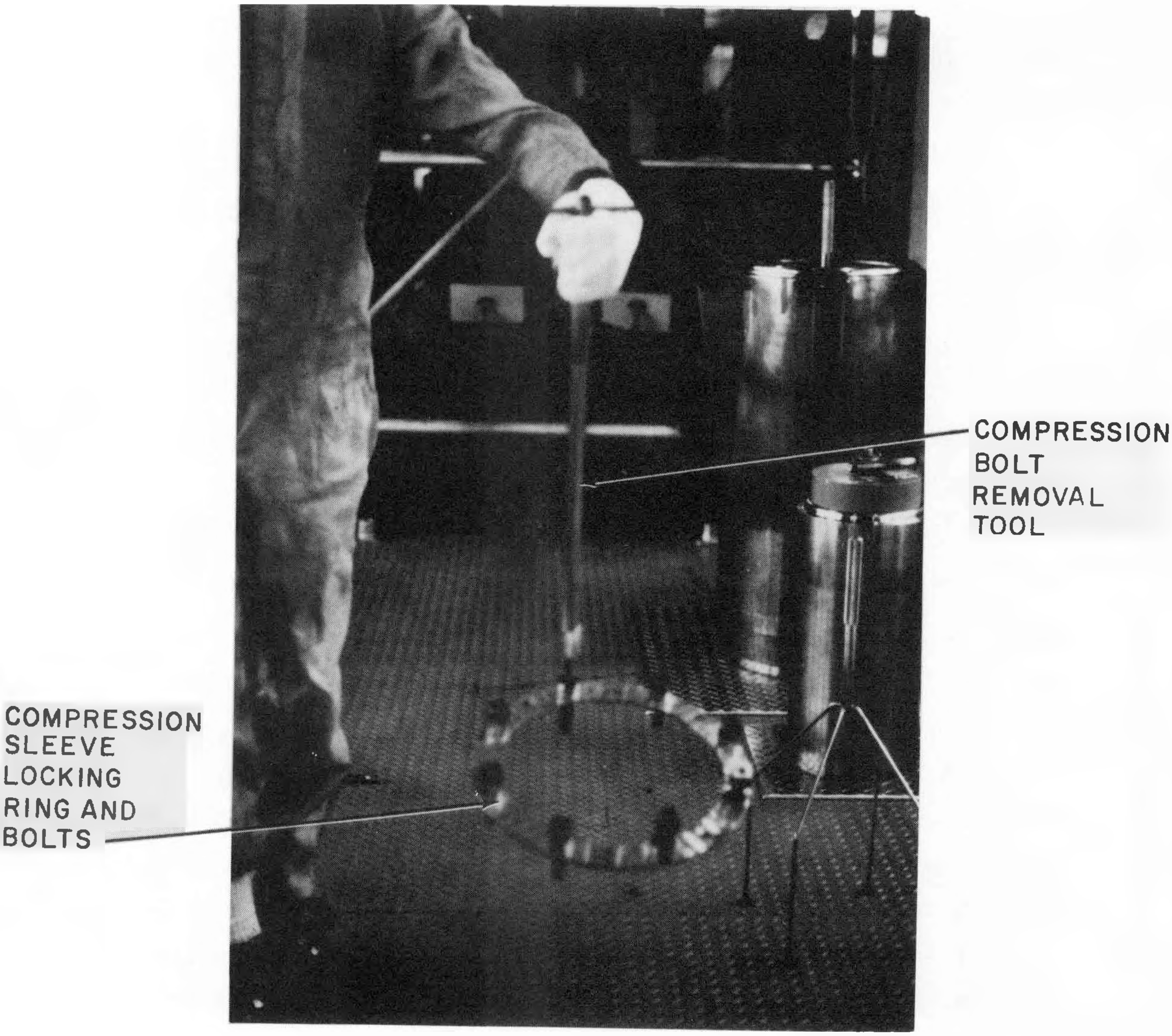


Figure 23. Compression Sleeve Bolt Removal Tool Demonstration

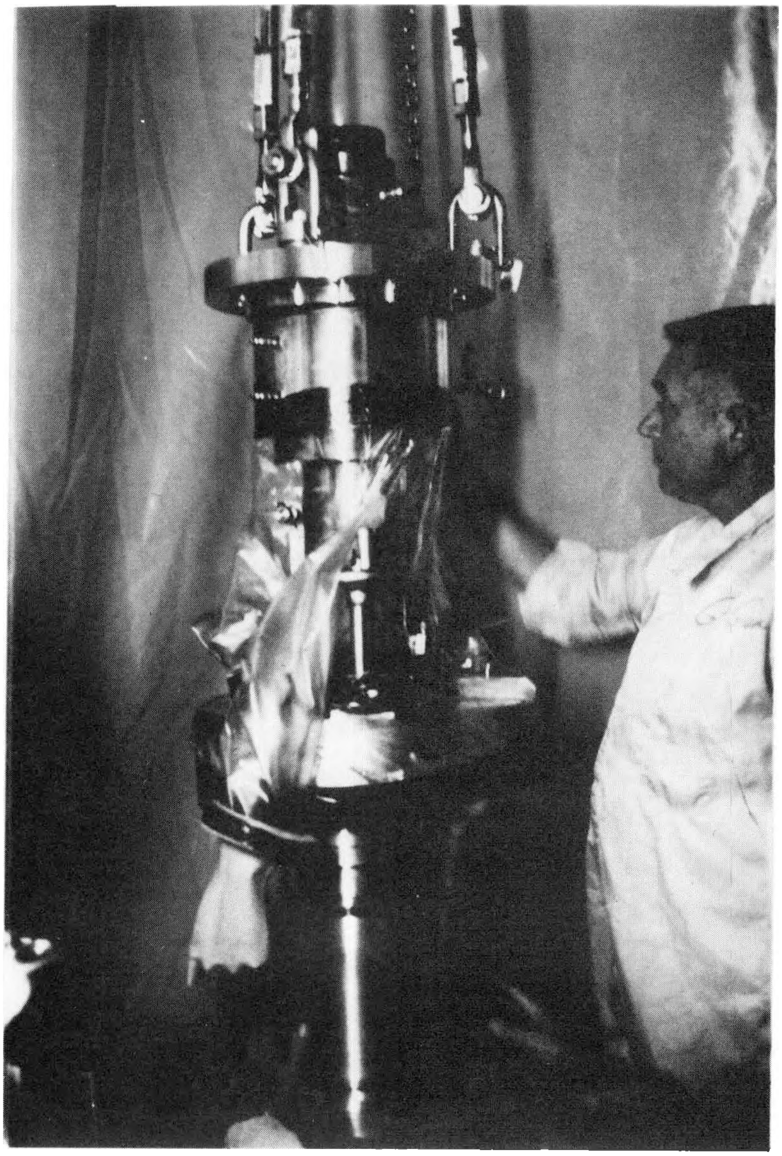


Figure 24. Compression Sleeve Installation Tool

and lower them to seat on the core barrel bottom plate. All 12 fuel assemblies were incrementally lowered in a predetermined sequence to reduce the chances for hangup of exposed grids on adjacent modules because module growth and distortion during reactor operation reduced the clearance between modules.

The 12 blanket modules were suspended from the reactor vessel closure head by means of the breechlock sleeves (Figure 25). Each breechlock sleeve was held in tension by a breechlock nut, which seated on an instrumentation spacer and ledge inside the CDM housing. The breechlock sleeve held the blanket support tube in contact with an internal ledge at the base of the suspension sleeve. In turn, the suspension sleeve was bolted to the bottom of a ledge in the CDM housing.

3.10.1 - Requirements and Constraints

Six lugs were located on the outside diameter at the base of the breechlock sleeve. Six mating lugs were also located on the inside diameter at the top of the blanket support tube. These two sets of lugs were segmented so that they could pass through one another and could be fully aligned or fully misaligned by a 30-degree rotation of the breechlock sleeve relative to the blanket support tube (Figure 26). In addition, two locking keys were located above one of the lugs on the breechlock sleeve. These locking keys engaged another key on the inside diameter of the suspension sleeve and prevented the breechlock sleeve from rotating.

During core installation, the breechlock sleeve tensioner was used to preload the breechlock sleeves to 67,500 pounds prior to tightening the breechlock nuts. The breechlock nuts held the breechlock sleeves in place with a final elongation of 0.067 inch. Consequently, a residual preload existed in the breechlock sleeves which had to be removed before the breechlock nuts could be loosened and the breechlock sleeves unlocked from the suspension sleeves.

During core installation, each of the fuel assemblies was lifted from the core bottom plate to seat the blanket support tube in the suspension sleeve by one continuous lift of approximately 3 inches. A single increment lift was possible at beginning of core life because the fuel assemblies were straight

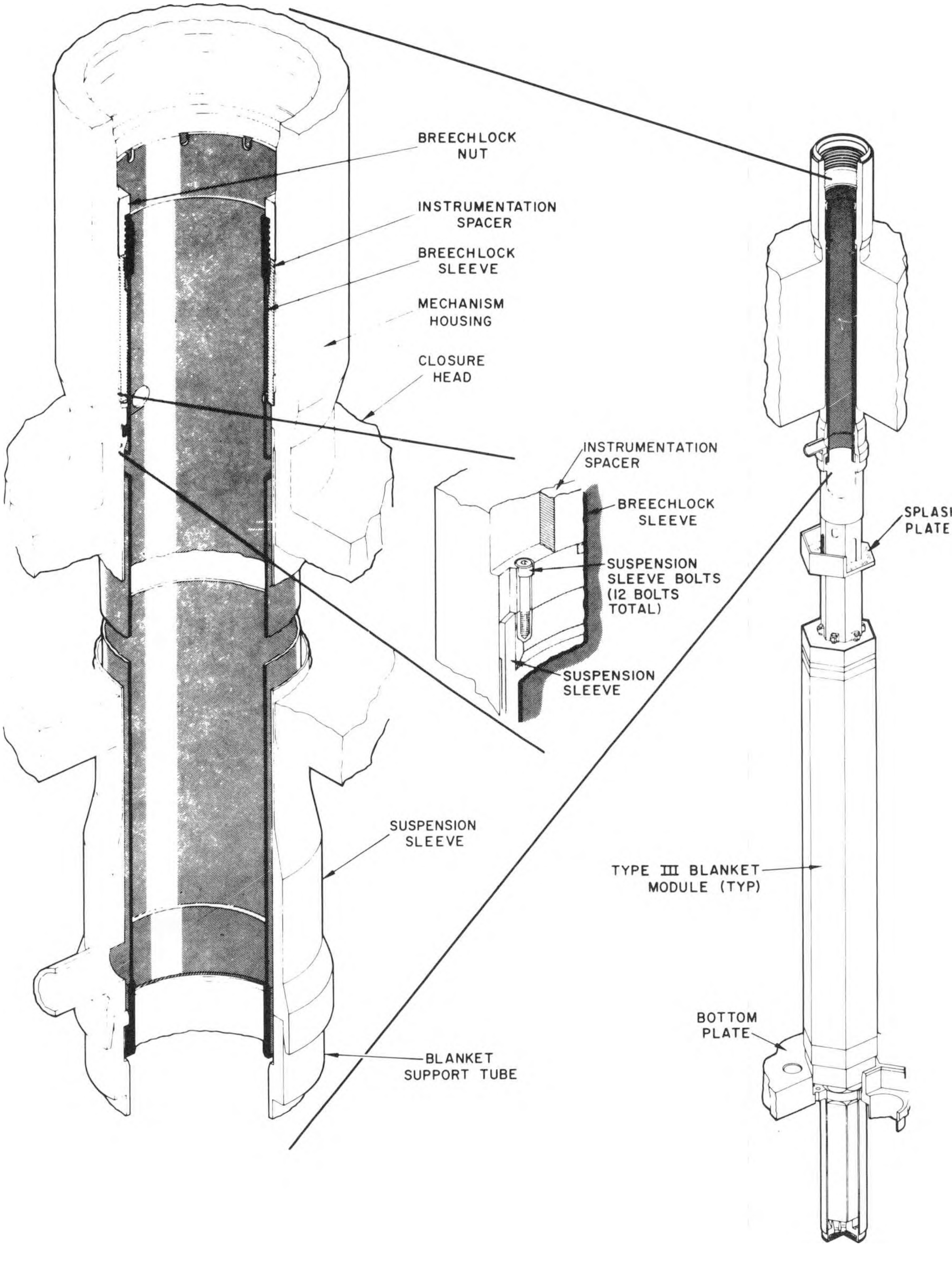


Figure 25. Blanket Module Suspension System

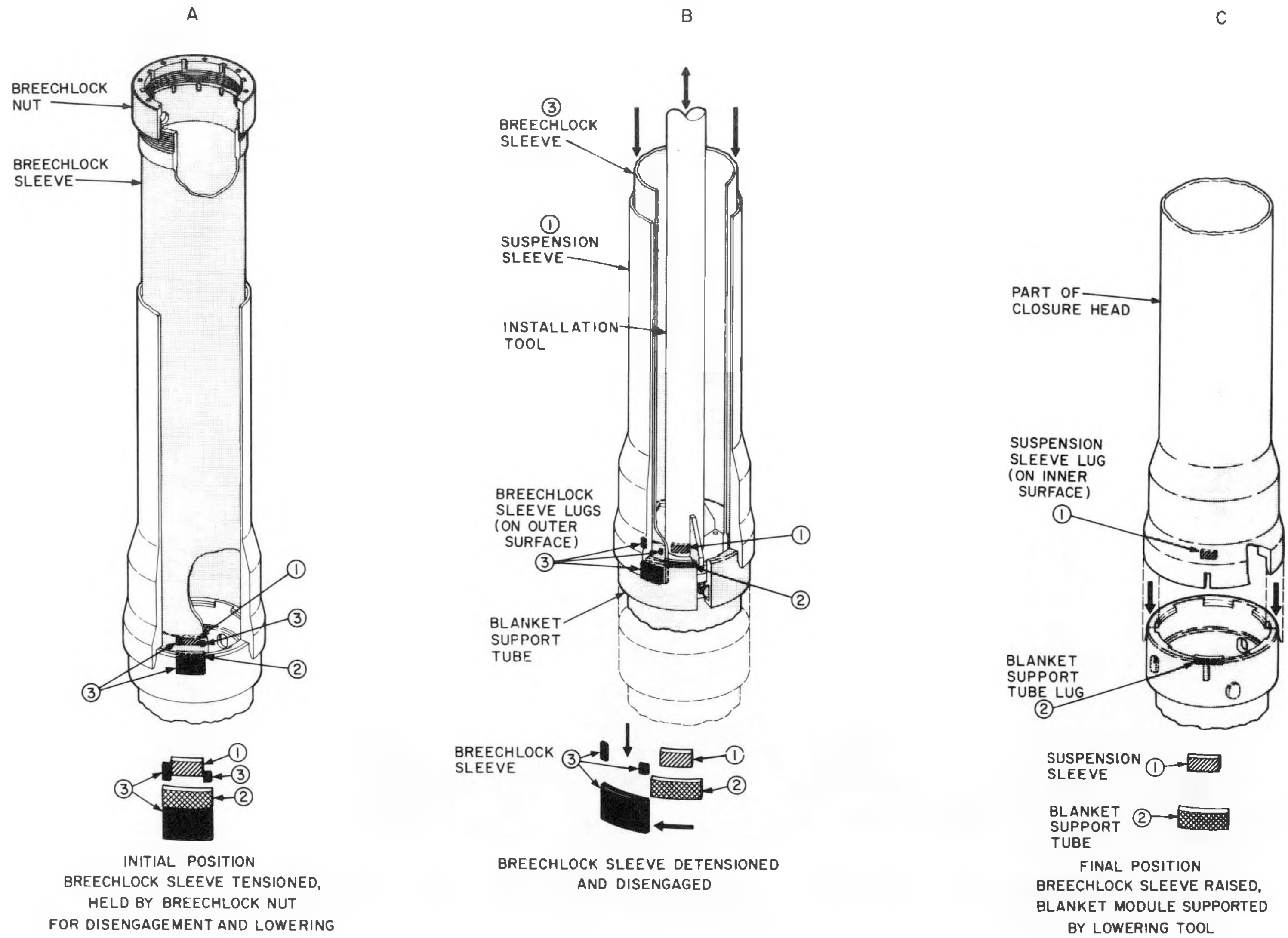


Figure 26. Blanket Module Suspension System Showing Lug Positions for Disassembly

and clearances existed between the fuel assemblies. However, analyses of end of core lifetime radiation-induced module bow indicated potential interferences between adjacent fuel assemblies. Therefore, a single increment (3-inch) seating operation was not possible at the end of core life because of the chance that grids on adjacent modules (Figure 4) could hang up on each other, preventing module seating and possibly damaging the module. To prevent this from occurring, no single module could be lowered more than the width of the grid in one lowering increment. The width of blanket module grids was 1.64 inches, but radiation-induced module growth and assembly tolerances combined to produce a potential end-of-life grid misalignment of 0.26 inch. Therefore, lowering of the fuel assemblies was restricted to increments of less than 1.38 inches.

An additional requirement was imposed on the first increment of lowering. Three centering pins were located at the top of each blanket support tube. These pins centered the blanket support tube within a counterbore in the base of the suspension sleeve. The nominal vertical travel required to disengage these pins from the counterbore in the suspension sleeve was 0.2 inch. Consequently, the first lowering increment for the fuel assemblies was limited to a nominal value of 0.2 inch.

The sequence in which the fuel assemblies were lowered was also determined by potential intermodule interferences. Differential, radiation-induced growth of the fuel modules reduced the clearances for all modules. Type I modules in the central region of the core were expected to have the least bow; hence, the largest intermodular clearance. In addition, the core bottom plate deflects elastically under the weight of the fuel assemblies, producing a small but measurable tilt of the modules toward the center line of the reactor vessel. Because of this, if the Type I modules were seated first, clearances for Type II and III modules for the final increment of lowering would be improved. Therefore, Type I modules were lowered first in each lowering increment to take advantage of the largest possible clearance. Sequencing of Type II and III modules was arbitrary, so Type II modules were lowered before Type III mainly to maintain 120-degree symmetry.

The breechlock sleeve detensioning and module lowering operations were accomplished with two defueling tools, which are described in detail in Appendix A8. The breechlock sleeve tensioner was used to remove the residual preload in the breechlock sleeve, but did not disengage the breechlock sleeve from the suspension sleeve and blanket support tube. The breechlock sleeve disassembly tool, which was actually an assembly of three separate tools, was used both to disengage the breechlock sleeve and to lower the fuel assemblies to the core bottom plate.

3.10.2 - Preload Removal Operations

The breechlock sleeve tensioner, shown in Figure 27 and detailed in Appendix A8, was used for the detensioning operation. The grappling assembly contained retractable lifting lugs which seated on the underside of an internal ledge within the breechlock sleeve. An axial load was applied to the breechlock sleeve with the grappling assembly by actuating a hydraulic piston. A force was applied to the breechlock sleeve which was sufficient to ensure that the breechlock nut unseated from the instrumentation spacer. The breechlock nut was then backed off with the nut driver. Finally, the preload, caused by the 0.067-inch mean final elongation at installation, was released by releasing the load on the tensioning tool.

As for other unthreading operations, consideration had been given to the possibility that a breechlock nut might not unthread due to galling. A contingency tool was designed, and was available during defueling, to cut the breechlock sleeve to permit module disengagement from the support sleeve. All 12 breechlock nuts were backed off easily, and contingency plans did not have to be invoked for this operation.

3.10.3 - Module Lowering Operations

The breechlock sleeve disassembly tool, shown in Figure 28 and detailed in Appendix A8, was a three-part tool consisting of a jack assembly, a module support tool, and a breechlock nut tool. Twelve assemblies consisting of a module support tool and a breechlock nut tool were installed, one on each of the 12 fuel assemblies, so that the fuel assemblies could be lowered from the head to seat on the core barrel bottom plate incrementally in a predetermined

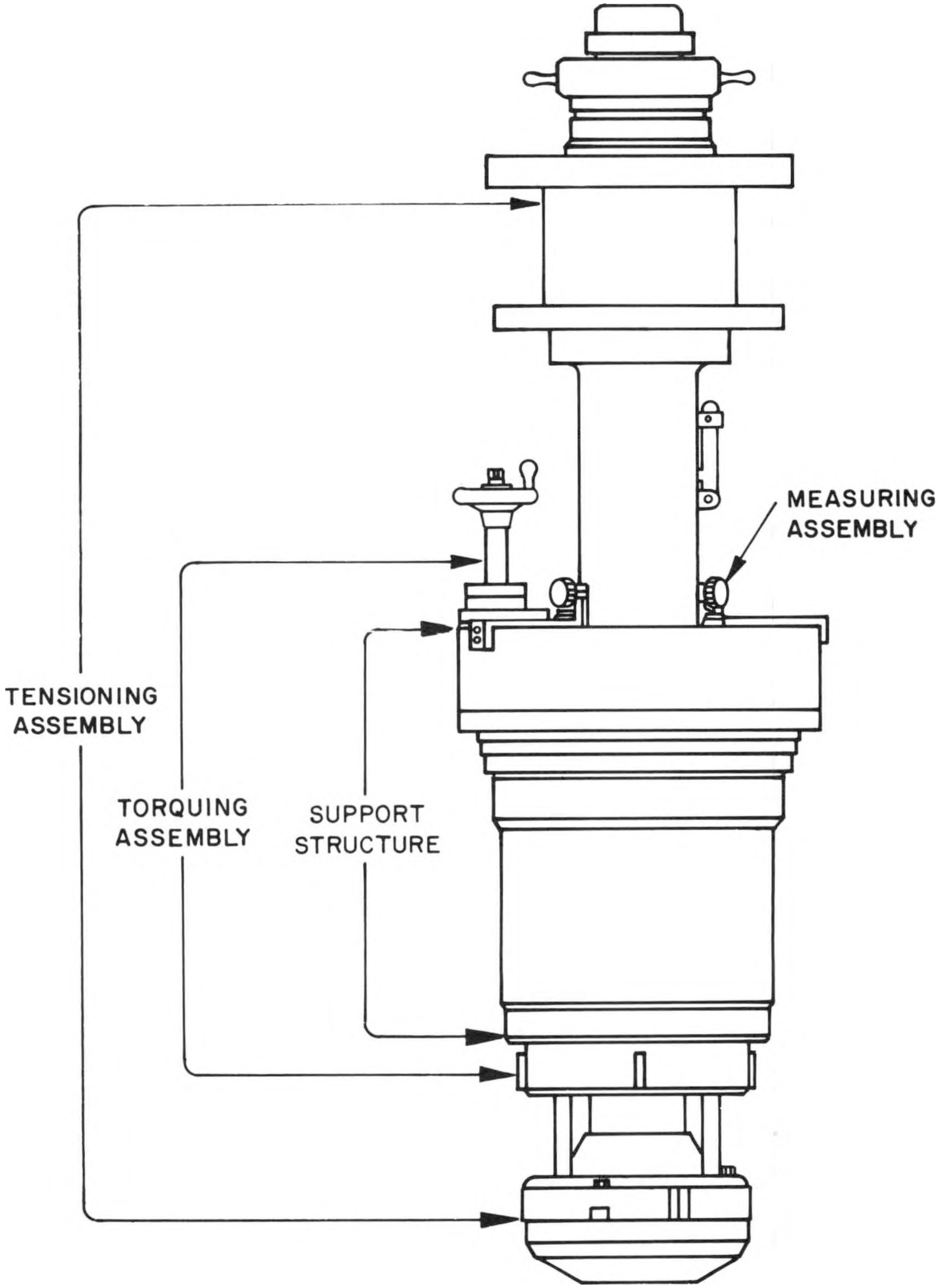


Figure 27. Breechlock Sleeve Tensioner

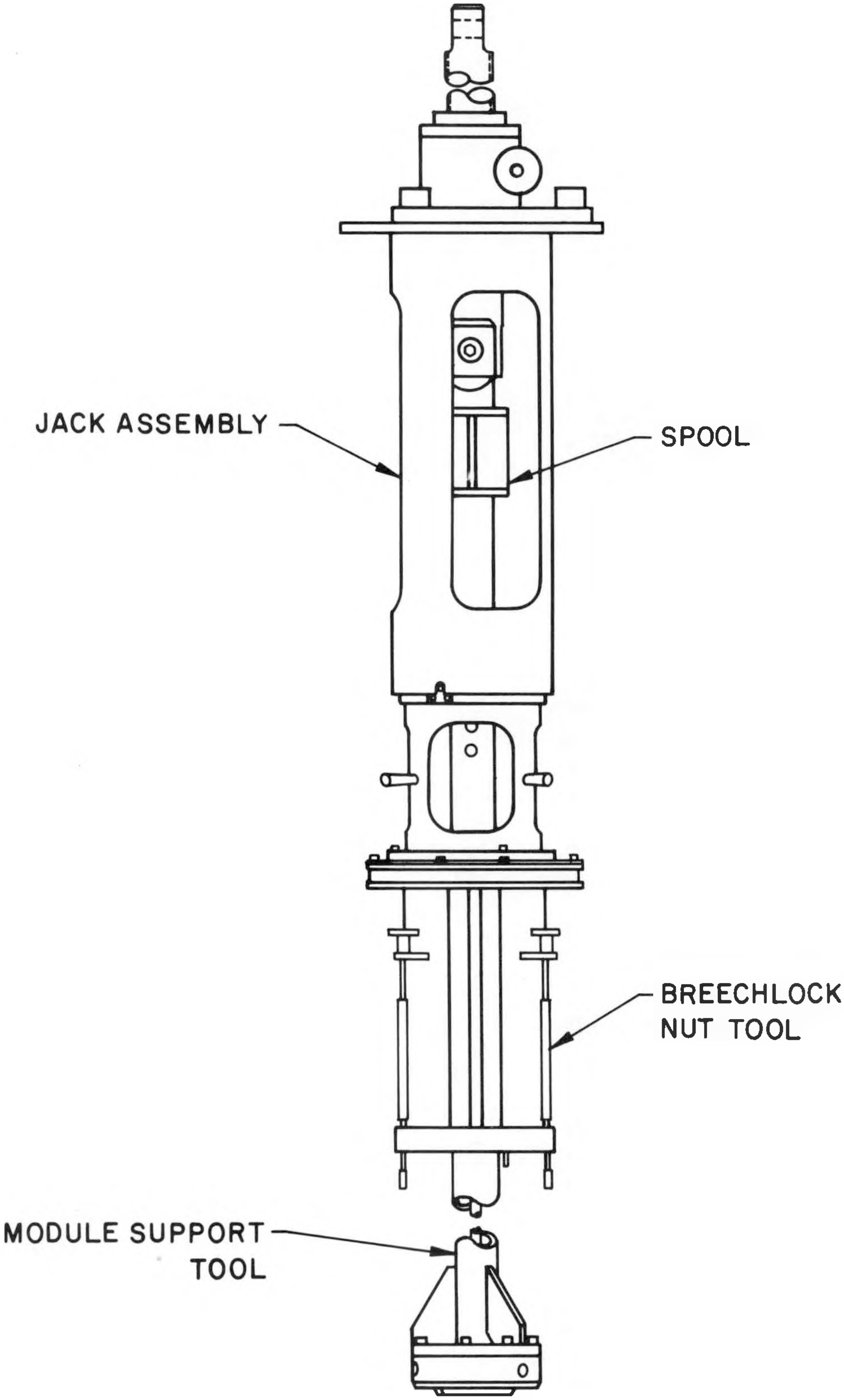


Figure 28. Breechlock Sleeve Disassembly Tool

sequence. One jack assembly was used with all 12 module support-breechlock nut tool assemblies to perform disengagement of the fuel assembly from the breechlock sleeve.

The breechlock sleeve disassembly tool was lowered into the CDM housing until the breechlock nut tool seated on the breechlock nut as shown in Figure 29 (position 1). The breechlock nut tool was secured to the nut, and lowering of the breechlock sleeve disassembly tool continued until the module support tool seated on the balance piston as shown in Figure 29 (position 2). The blanket support tube was grappled and a lift force, sufficient to remove the weight of the fuel assembly from the breechlock sleeve, was applied with the module support tool. The jack assembly was lowered and attached to the breechlock nut tool. The breechlock nut was backed off by rotating the breechlock nut tool counterclockwise. This action lowered the breechlock sleeve, disengaging the locking keys from the key on the suspension sleeve (Figure 26). The breechlock sleeve was then engaged by the breechlock nut tool and was rotated 30 degrees clockwise, thus disengaging the blanket support tube from the breechlock sleeve. The jack was then actuated to lift the breechlock sleeve until the bottom of the breechlock nut cleared the top of the CDM housing as shown in Figure 29 (position 3). A spacer was snapped onto the breechlock sleeve below the nut, and the breechlock sleeve was lowered with the jack until the snap-on spacer seated on the instrumentation spacer. The snap-on spacer ensured that the lugs of the breechlock sleeve and blanket support tube could not reengage.

The next operation was the first incremental lowering of the fuel assembly. The jack assembly housing was unbolted from the breechlock nut tool and was raised to mid-height on the jack screw. The spool was then lowered along the shaft of the module support tool to seat on the top surface of the breechlock nut tool. A rod was inserted through a hole in the module support tool just above the spool, and the fuel assembly was lowered until the rod was captured between the module support tool and the spool which was seated on the breechlock nut tool as shown in Figure 29 (position 4). The nominal lowering increment was the 0.2-inch distance required to free the blanket support tube centering pins from the suspension sleeve. Once the module support tool was

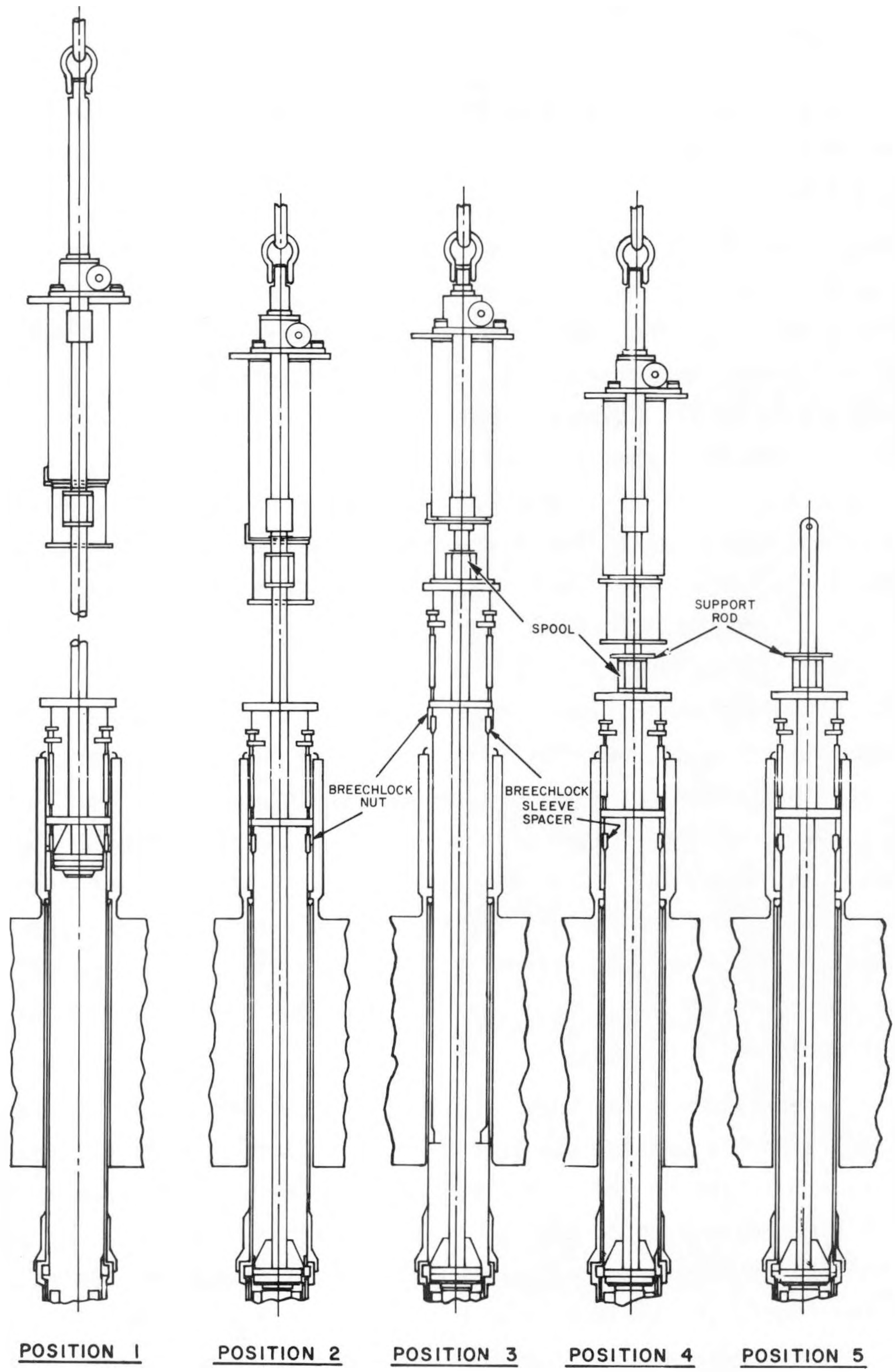


Figure 29. Operating Sequence for Breechlock Sleeve Disassembly and Module Lowering

seated on the rod, the jack assembly was removed from the module support tool as shown in Figure 29 (position 5). This sequence of operations was repeated for the remaining 11 fuel assemblies before continuing to the next increment of lowering.

A contingency operation for a stuck module was incorporated into the module lowering procedure for the first lowering increment only. If the module support tool did not seat on its support before a maximum weight dropoff of 250 pounds was attained, the spool was to be raised to contact the rod, and the gap between the spool and the top of the breechlock nut tool would be filled with shims. An attempt would then be made to lower all other fuel assemblies through the first 0.2-inch increment. Once all fuel assemblies were at least partially lowered through the first increment, a 0.1-inch maximum test lift was performed on all fuel assemblies (adjacent to the stuck fuel assembly) that were lowered prior to the fuel assembly becoming stuck. If the adjacent modules were successfully test-lifted without binding on the stuck module, the hangup was caused by the blanket support tube centering pins not clearing the suspension sleeve. Consequently, another attempt would be made to lower the stuck module using the full weight of the fuel assembly. Only one fuel assembly did not lower properly during the first lowering increment. However, it was not hung up on adjacent modules and was successfully lowered using the contingency procedure.

During the second and third lowering increments, the crane was rigged directly to the clevis of the module support tool. The weight of the fuel assembly and module support tool was supported by the crane, while the support rod was removed and reinserted into another hole located 1.00 inch higher on the module support tool. The fuel assembly was then lowered to seat on the support spool. The crane was derigged and moved to the next location. If a maximum weight dropoff were attained before seating on the spool, shims were to be installed between the spool and the breechlock nut tool as before. However, no contingency operations were incorporated into the module lowering procedure because a stuck fuel assembly at this point would indicate a probable grid hang-up and would be addressed on a case basis. No fuel assembly hangup occurred on the second through fourth lowering increments.

The fourth lowering increment procedure was identical to the second and third lowering increments except that the rod was removed from the module support tool and discarded. The fourth lowering increment was also smaller than increments two and three (approximately 0.5 inch). After all 12 fuel assemblies were lowered, the module support tools were removed from the reactor and prepared for scrapping. A measuring rod was then inserted into the housings to measure the height of each blanket module and to ensure that each was seated on the bottom plate. All 12 fuel assemblies were successfully disengaged from the closure head and seated on the bottom plate without any significant problems. All operations were performed in containment as detailed in Appendix A2. Maximum radiation level for these operations was 30 mR/hr above the CDM housings.

3.11 - CLOSURE HEAD STUD DETENSIONING AND CLOSURE HEAD REMOVAL

The LWBR closure head was held in place with 42 closure head studs, evenly spaced circumferentially through flanges on the closure head and reactor vessel. Each stud was 6.0 inches in diameter by 108.5 inches long.

The closure head was a steel (A-508, Class 4) disc 154 inches in diameter and up to 50 inches thick. There were 12 penetrations through the head for the blanket module suspension system and CDMs and six smaller penetrations for access to the BIF pipe supports (Figure 30).

At installation, closure head studs were preloaded with a hydraulic tensioner; the elongation in each stud was about 0.50 inch. To remove the studs, three stud tensioners, 120 degrees apart, were used to relieve the load on the top nut, which was then turned sufficiently to relieve approximately 0.25 inch of extension in the stud. The hydraulic pressure was then released in the tensioners, which relaxed the studs and reseated the stud nuts on the flange. Strain in all 42 studs was relieved in this manner on the first pass. A second pass of stud tensioning, nut rotation, and release was performed to complete the detensioning process; then the lower stud nuts and spherical washers were manually removed from the studs, permitting complete removal of the studs from the head.

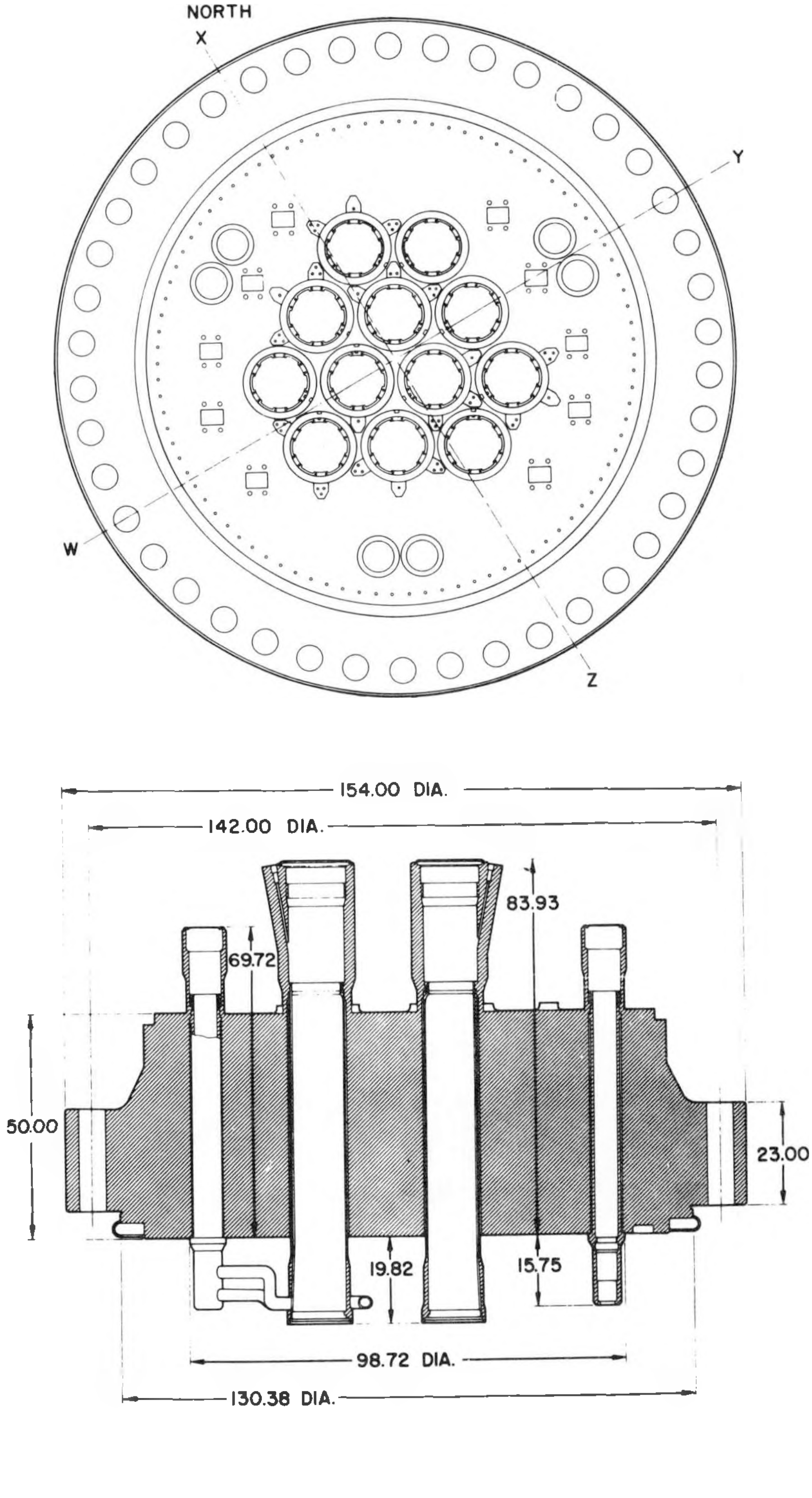


Figure 30. Closure Head (with Dimensions)

Removal of the closure head studs permitted access to the main closure seal, which was then cut (Section 3.4.6). After completing head area disassembly and blanket module lowering, the closure head was removed.

To prepare for closure head removal, a large containment bag (Appendix A2) was fastened between the closure head flange and the core support flange (Figure 31). The containment bag provided protection against spread of radioactive contamination when the reactor was opened and was a means of wrapping the closure head for transport from the reactor pit to storage in the head storage pit. After the containment bag was attached, the closure head was raised until the bag was almost fully extended. The bag was closed at the center by means of ropes encircling the bag, then the bag was taped and cut at the center. The closure head and the attached containment were then transported to the head storage pit (Figure 1A) and seated on wood cribbing in a reinforced plastic bag, which was closed and sealed.

The lower half of the containment bag featured 20 gloved sleeves and 20 transfer sleeves at the base of the bag, arranged around the circumference of the core support flange. Cleaning materials, including rags, scrubbing pads, wetting agent, clean and borated water, and lint-free paper towels, were passed into the bag and used to decontaminate the exposed surfaces of the flange so that installation of the defueling seal could be performed as a clean operation.

One minor problem occurred after 39 studs were partially detensioned. The tension loading of the closure head studs produced compression loading of other reactor vessel components (such as the closure head and core support flange). Although total compressive deformations were relatively small compared to the 0.50 inch elongation of the studs, as more of the studs were partially relaxed, more of the compression load was carried by fewer studs. As a result, it became increasingly difficult to turn the top nut until, after partially detensioning 13 sets of studs (39 studs), the last three nuts could not be turned when the tensioner was pressurized as specified.

It was noted that tensioner pressurization was based on stud extension required to just exceed that used for stud installation, not on manufacturer's

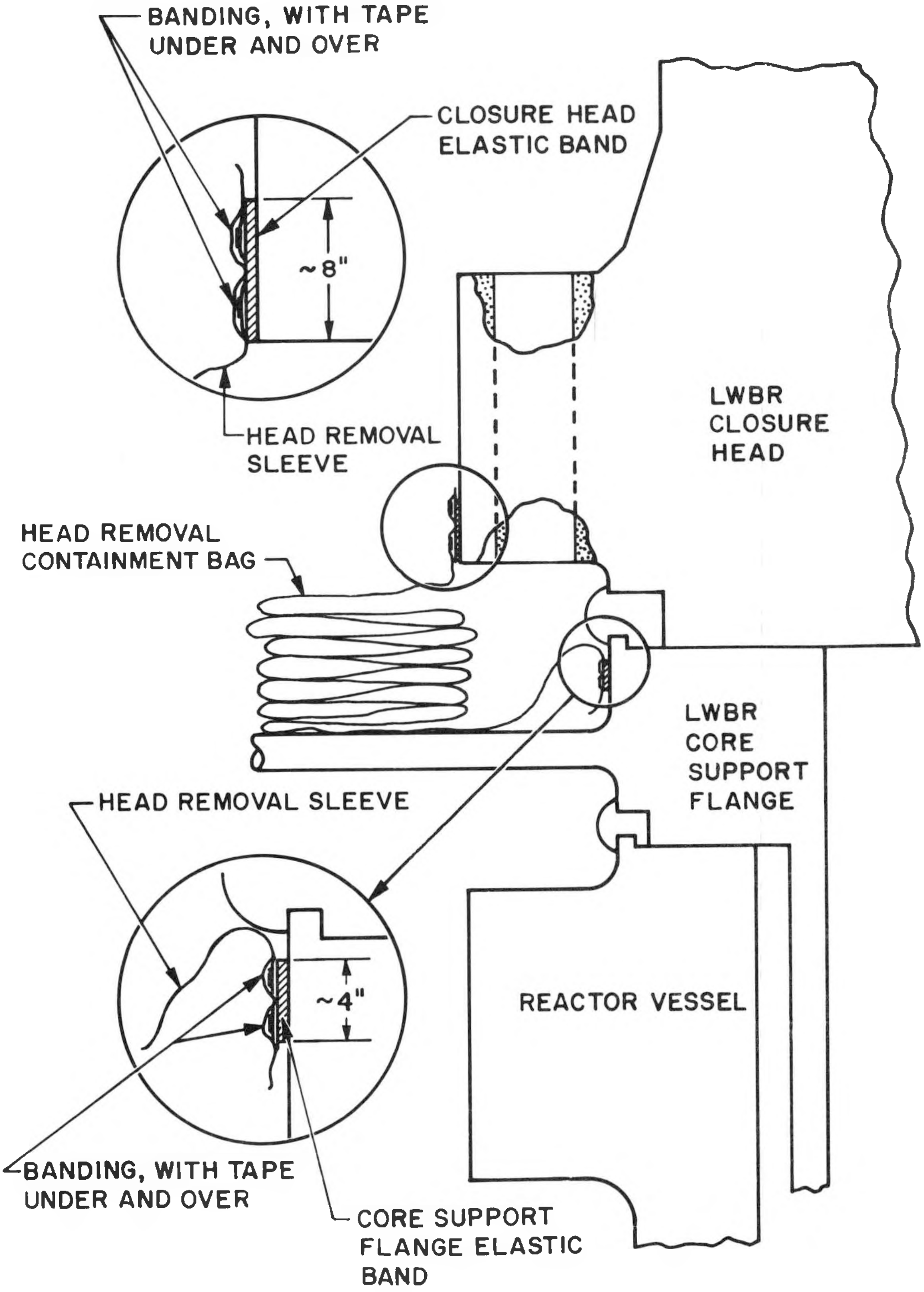


Figure 31. Attachment of Containment Between Closure Head and Core Support Flange

limitations on the tensioning equipment. A change to the procedure was processed, permitting incremental increase in tensioner pressurization to the point where the nuts could be moved. Pressurization was increased from 5700 to 5900 psi in one increment, and this was sufficient to break the nuts loose.

Another problem during head removal involved handling the very large containment bag. The problem is detailed in Appendix A9.

3.12 - INSTALLING THE REFUELING SEAL AND FLOODING THE REACTOR PIT

After closure head removal, the remaining defueling operations were performed with the reactor pit filled with water to provide the necessary radiation shielding. To provide a barrier that would confine water to the reactor vessel and reactor pit, a refueling seal was installed. The refueling seal was a two-part steel structure consisting of a cylindrical adapter which extended from the top of the reactor core support flange to the reactor pit floor level and a flat disc which closed the area between the dome bolting flange and the adapter (Figure 32). Closure head stud holes in the reactor vessel flange were utilized to provide holddown for the adapter.

Details of the sealing methods at the reactor pit to refueling seal joint are shown in Figure 33, View A; at the refueling seal to adapter joint in Figure 33, View B; and at the adapter to core support flange joint in Figure 33, View C. Redundant seals were provided at joints B and C in an attempt to avoid a leaking refueling seal. Test points for checking seal effectiveness were built into the adapter for joints B and C. Air pressure up to 15 psig was used to test the seals. The reactor vessel to adapter joint passed the test successfully, but the adapter to refueling seal joint did not, and an extended delay in defueling operations occurred while attempts were made to repair the seal. It was determined that leakage was occurring only in the secondary (silicone rubber) seal, in the groove between the seal and the adapter. The loss of redundancy was accepted at this joint because the gasket cover plate would prevent any serious damage to the primary seal for the duration of defueling, and the backup seal would still limit leakage if the primary seal developed a leak. This problem is discussed in detail in Appendix A9.

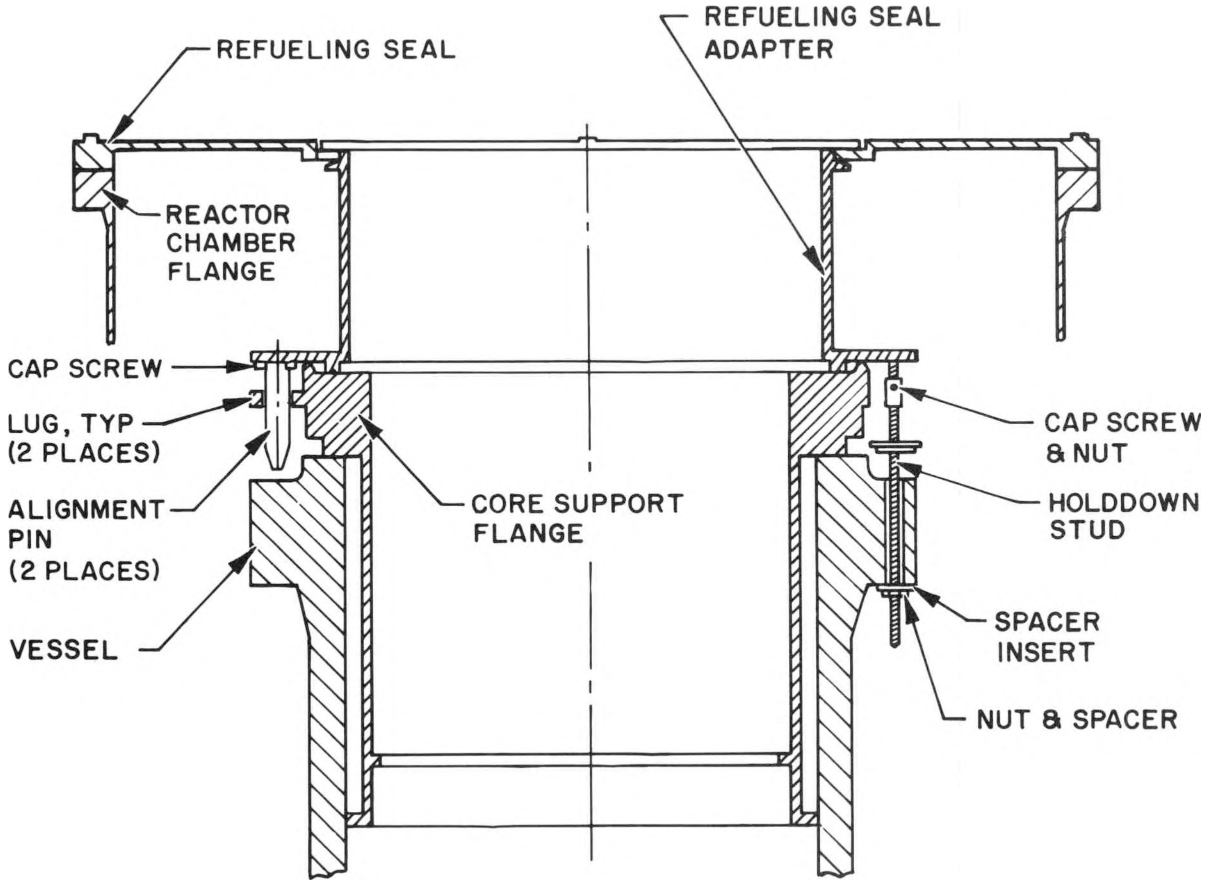
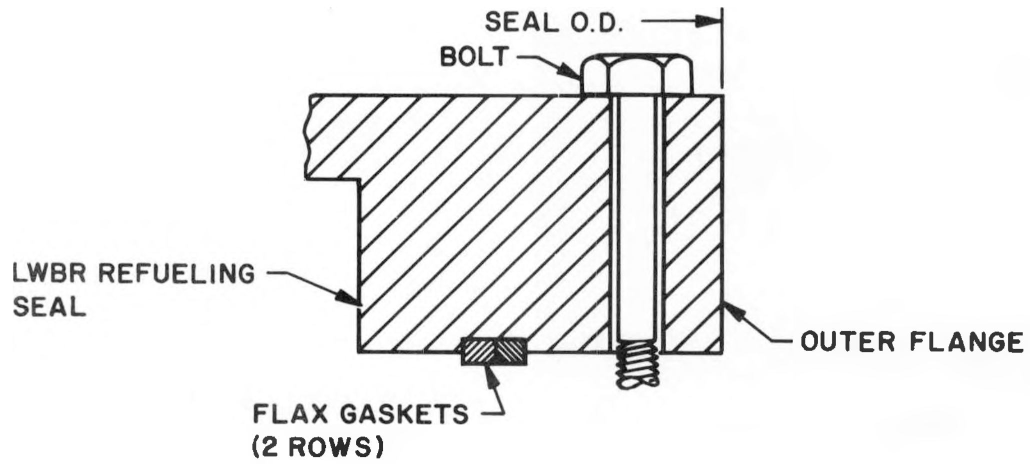
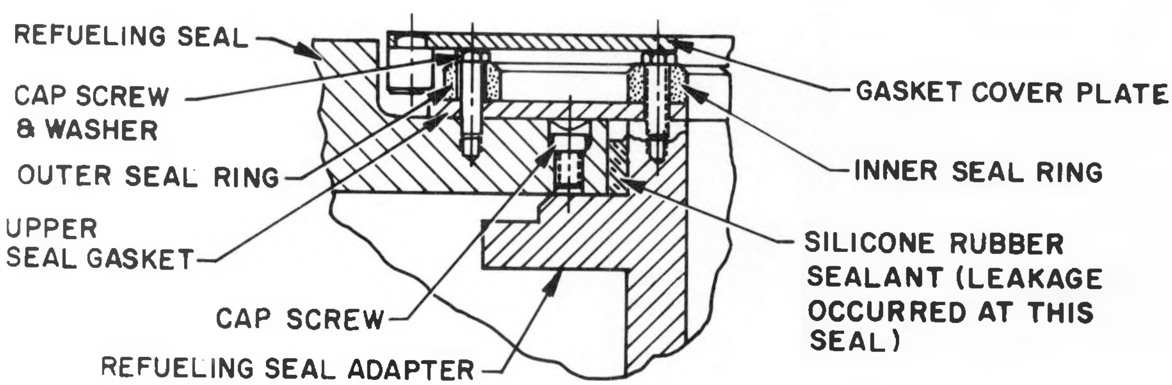


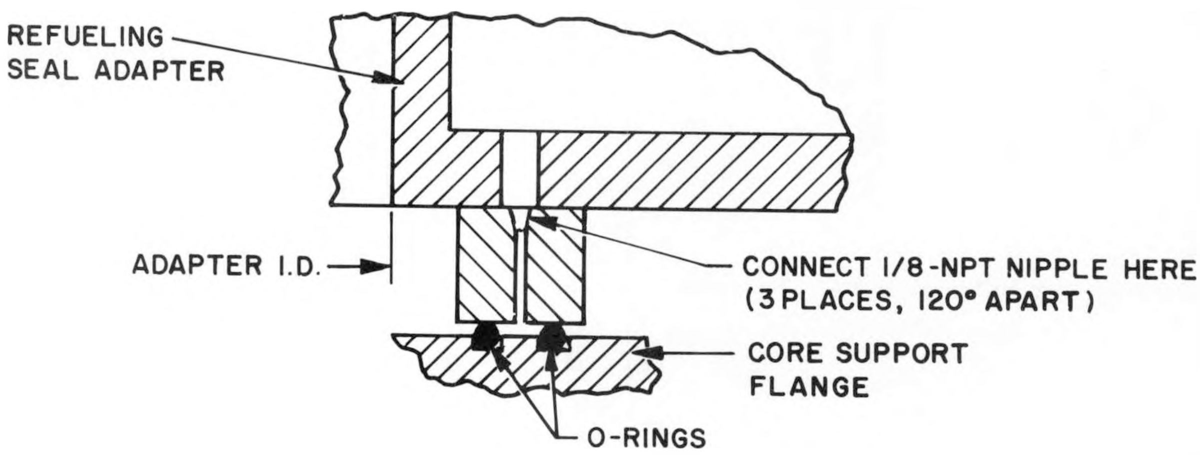
Figure 32. Refueling Seal and Adapter Installed on Reactor



A. Defueling Seal to Reactor Pit Floor Joint



B. Defueling Seal to Adapter Joint



C. Adapter to Core Support Flange Joint

Figure 33. Refueling Seal Details Illustrating Leakage Problem

After installing the refueling seal, operations were initiated to remove the holddown barrel (Section 3.13) by installing the core grappling rig (Figure 34) into the reactor vessel and onto the holddown barrel. At this point, the reactor pit was prepared for flooding. Flooding was performed in four increments, with visual checks performed at the refueling seal joints after reaching each incremental level. A small leak was found in the joint shown in Figure 33 (View A), which sealed itself in a short time. Subsequent to filling the pit, a daily visual check of these joints was performed for the duration of defueling; no further leakage was observed.

3.13 - HOLDDOWN BARREL REMOVAL AND SHIPPING

The holddown barrel (Figure 35) was a large (95 inches in diameter by 77.5 inches long) barrel-like structure that was seated on top of the reflector modules and contacted the closure head through six compression discs on its upper flange. Its purpose was to restrain the reflector modules in their positions against upward-flow forces of reactor coolant. It was necessary to remove the holddown barrel to gain access to the reflector modules.

The objectives of this evolution were to remove the holddown barrel, place it in a shipping container, close and seal the container, remove it from the reactor pit, and ship it by truck to a disposal site. The steel shipping container (Figure 36) was a cylinder 114.7 inches in diameter by 99.75 inches high, weighing 35,700 pounds and containing concrete as shielding.

To prepare for this evolution, the shipping container was wrapped in an anticontamination enclosure bag (Appendix A2) and placed in the reactor pit prior to flooding (Section 3.12). The shipping container cover was then removed and stored.

The tool used to remove the holddown barrel was the core grapple (Figure 34), which was used in almost all previous large-cylinder lifts at Shippingport. It was attached to the Fuel Handling Building 125-ton overhead crane hook, adjusted for attachment to the holddown barrel, then inserted into and grappled onto the holddown barrel at the four lifting holes shown in Figure 35. At this point, reactor pit flooding and anticontamination enclosure fill

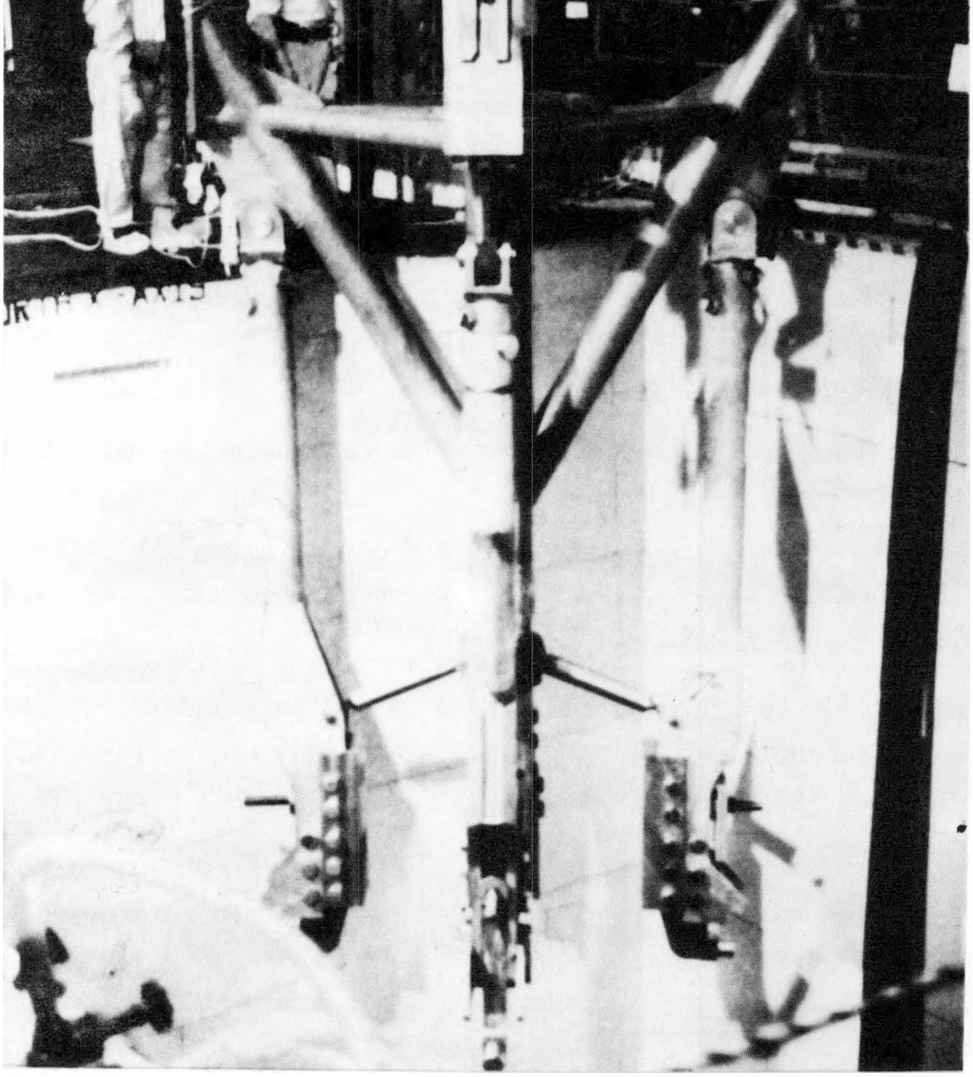


Figure 34. Core Grapple - A Four-Point Lifting Device for Removing the Holddown Barrel

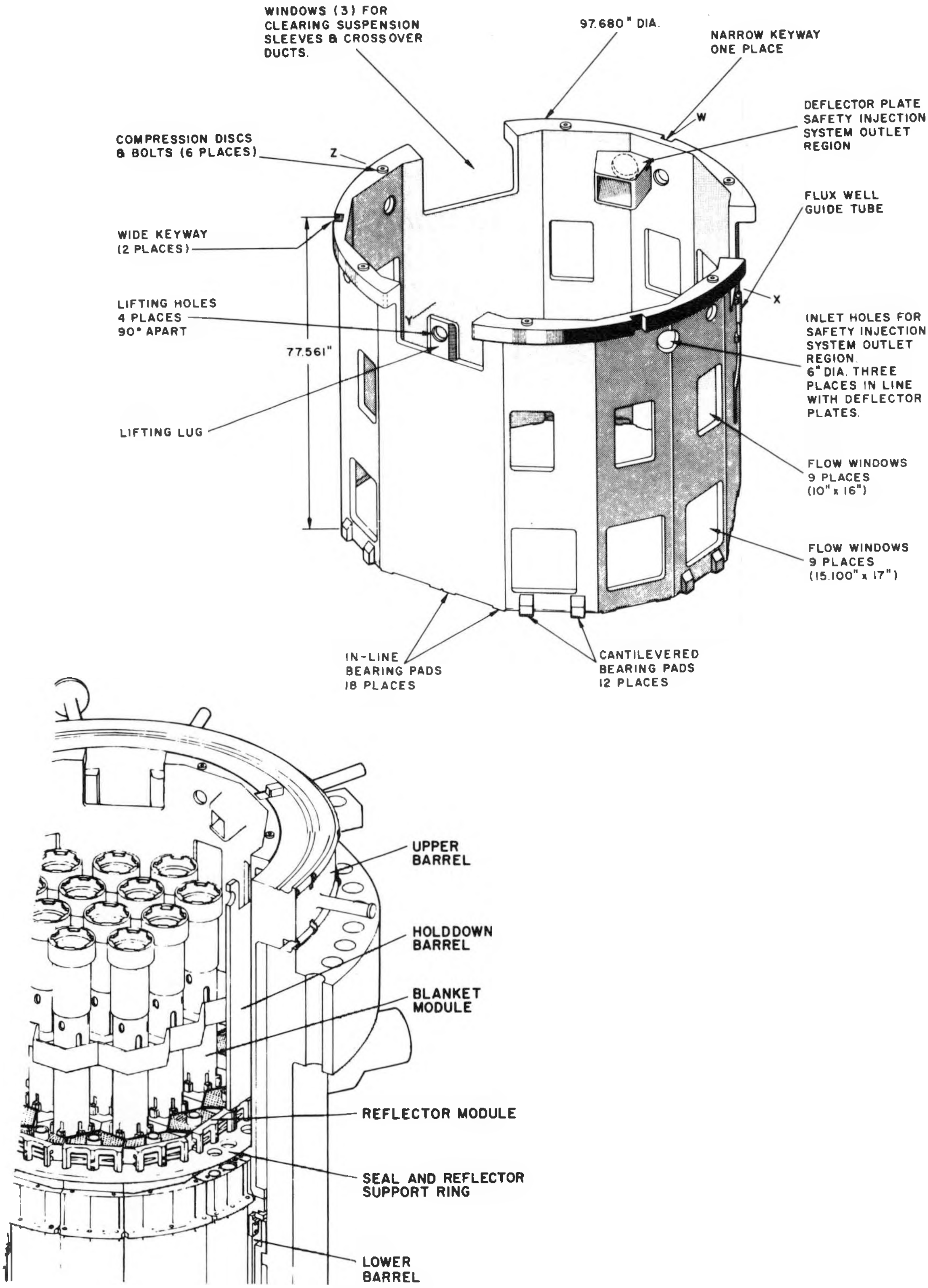


Figure 35. Holddown Barrel and Its Location in Core

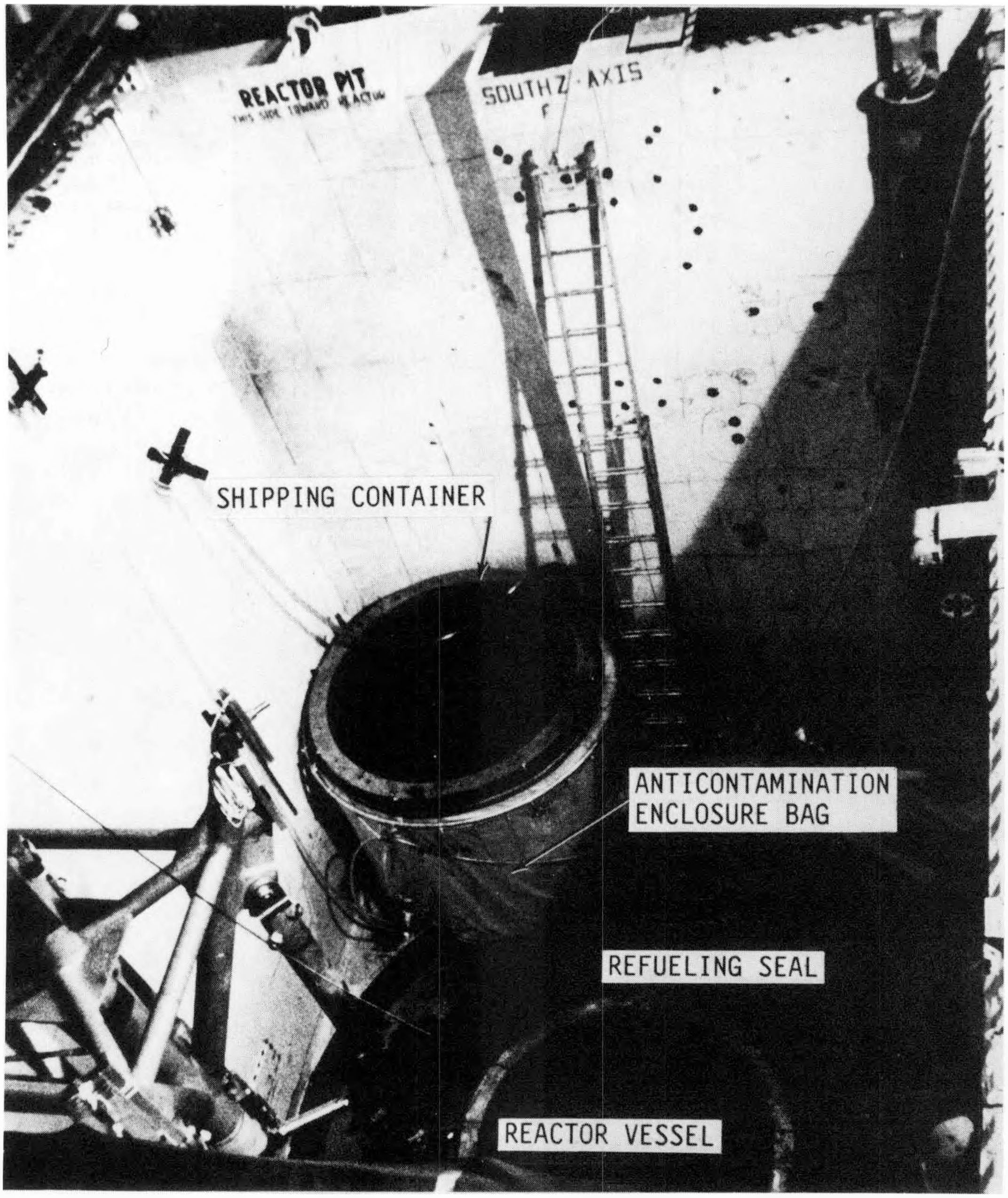


Figure 36. Holddown Barrel Shipping Container in Anticontamination Enclosure Bag

operations began (Appendix A2). Flooding of the reactor pit provided shielding water for holddown barrel removal.

After the reactor pit was filled with borated water, the holddown barrel was removed from the reactor vessel and placed in the shipping container. The shipping container cover was then replaced, using remote handling tools to install and tighten the 18 bolts holding the cover in place. The shipping container was removed from the reactor pit, cleaned (decontaminated), placed on a low-bed truck, and transported to a radiological waste disposal site for burial.

3.14 - FUEL MODULE REMOVAL

3.14.1 - General Discussion

Fuel module removal from the reactor vessel was complicated by the fact that the LWBR fuel module dimensions had changed due to bowing of the modules during operation in the reactor core. The primary cause of this module bowing was differential, radiation-induced Zircaloy growth which increased during the core operating life. An analysis predicted that bowing would vary across the core, that blanket modules located near the center of the reactor would have the least bow, and that reflector modules would have the greatest bow. This analysis also showed that bowing normally would be inboard (i.e., the module would be bent so that the center of its length was closer to the core center line than would the top and bottom of the module).

A bowed module requires a slightly larger clearance envelope than a straight module. Also, bowing of modules is cumulative and reduces the across-the-core clearance such that all clearance is taken up at the beginning of module removal; therefore, an adjacent blanket module could contact and exert a force on the reflector module being removed. Reflector modules were not considered to be subject to damage during their removal under these interference conditions because they had smooth outer shells. Blanket modules, because of exposed grid structures, were subject to damage under severe interference conditions between two blanket modules (when grids could hang up on each other during module removal). Removal of a reflector module adjacent to a blanket module could not result in a hangup on the blanket grids; therefore, no damage would occur. To prevent damage to blanket modules, the removal sequence required the adjacent reflector modules to be removed first. Removal of adjacent reflector modules further reduced potential for damage to blanket modules by permitting slightly off-center lifts of blanket modules, which pulled the module being removed away from adjacent modules and which maximized clearances with respect to any remaining modules.

At the beginning of reflector module removal, interference of up to 0.120 inch could exist between the reflector and the adjacent blanket module at the blanket seal block elevation. Additional close clearance locations were passed as the reflector module was lifted through the upper core barrel as shown in Figures 37 and 38. These close clearances of up to 0.020 inch were such that the fuel handling equipment did not have the capability of positioning the lift point accurately enough to ensure reflector removal without contacting structures, even with no bowing of the modules. Also, the bow tended to direct the top of the reflector module toward the barrel wall and the potential interference points as the module was lifted from the core. Contact of upper barrel components with the heavy seal block or the smooth shell of the reflector module was judged not to cause damage to the reflector assembly. Any catching of the seal block under an edge of any barrel part or blanket module has the potential for causing a removal problem.

In considering the close clearance points (Figure 37), it appeared that any hangup during reflector removal would most likely occur at the BIF vibration dampers or at the flow instrumentation riser cover. These two points have ledges which could cause a hangup with the reflector seal block. The BIF bracket clearance condition affected six reflector modules, IV-4 through IV-9 (Figure 38). The flow instrumentation riser cover affected only two reflector modules, IV-7 and IV-9.

Another close clearance was caused by the inlet plenum safety injection system duct. This close clearance affected reflector modules IV-4, IV-5, and IV-6. It was not considered likely to catch the reflector seal block because it did not have a step or edge, and the reflector could slide along this duct without catching.

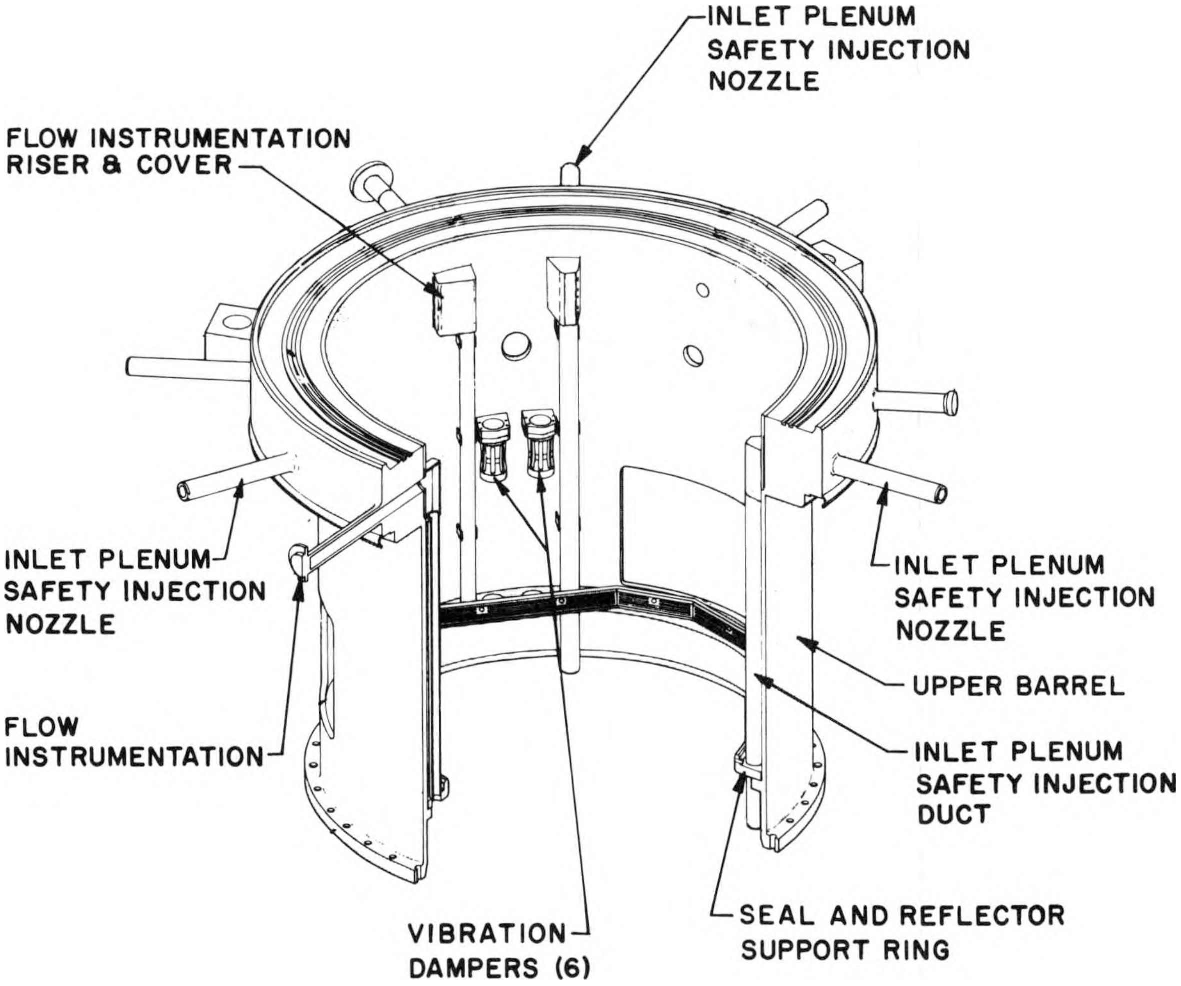


Figure 37. Support Structure Upper Barrel Assembly Showing Potential Interference Points for Reflector Module Removal

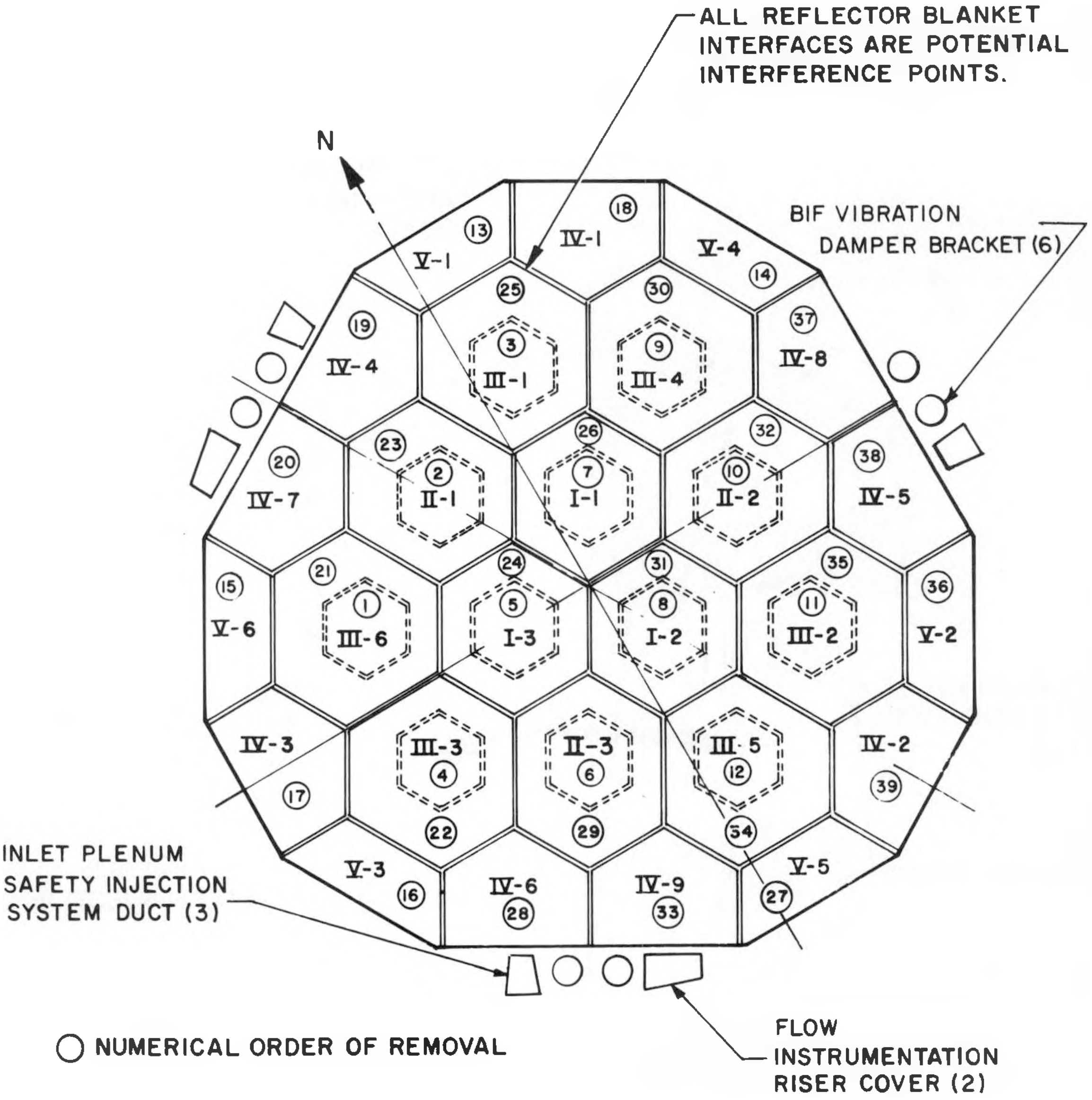


Figure 38. Module Removal Sequence Showing Potential Interference Points

The remaining close clearance was the adjacent blanket splash plate (Figure 4), which affected each of the 15 reflector modules. This was not considered likely to catch the reflector seal block because the outward bowing of the reflector tended to increase the clearance. Also, any contact between the blanket seal block and reflector would tend to hold the reflector away from the splash plate.

The removal procedures included controls limiting the removal force and specifying the sequence of removal which prevented damage from contact with the aforementioned upper core barrel components. Also, the module spreader and reflector positioning tool (described in Appendix A3, Section A3.2.1) was used during removal of the first two side-by-side Type IV reflector modules (IV-4 and IV-7) to maximize the space envelope bounded by the adjacent modules and to enable defueling personnel to push the reflector module being removed away from expected interferences at the BIF bracket and at the flow instrumentation riser. The module spreader was used to apply up to 1500 pounds force to move the adjacent blanket modules away from the reflector being removed. The reflector positioning function of the tool was used to apply a 200-pound radial force (inboard) and a 30-pound tangential force to the reflector module shell.

3.14.2 - Controls On Fuel Module Removal Sequence

The defueling program design included several features to facilitate removal of fuel modules from the reactor vessel. These features involve removal sequence, special procedure actions, and special equipment.

The seed modules were removed from the reactor vessel first because of the special criticality-related controls during their removal (Section 3.18). The reflector and blanket module removal sequence was controlled to provide adequate removal clearance, to be consistent with the desired disassembly and shipping sequence, and as limited by the fuel storage rack storage capacity. Table 1 and Figure 38 show the final removal sequence.

Prior to removing a Type IV reflector module, the adjacent Type V modules were removed. This control was imposed because the design of reflector seal blocks was such that removal of a Type V module first provided more removal

Table 1 - Module Removal Sequence

Sequence Number	Module Type	Core Location
1	Seed	III-6
2	Seed	II-1
3	Seed	III-1
4	Seed	III-3
5	Seed	I-3
6	Seed	II-3
7	Seed	I-1
8	Seed	I-2
9	Seed	III-4
10	Seed	II-2
11	Seed	III-2
12	Seed	III-5
13	Reflector	V-1
14	Reflector	V-4
15	Reflector	V-6
16	Reflector	V-3
17	Reflector	IV-3
18	Reflector	IV-1
19	Reflector	IV-4
20	Reflector	IV-7
21	Blanket	III-6
22	Blanket	III-3
23	Blanket	II-1
24	Blanket	I-3
25	Blanket	III-1
26	Blanket	I-1
27	Reflector	V-5
28	Reflector	IV-6
29	Blanket	II-3
30	Blanket	III-4
31	Blanket	I-2
32	Blanket	II-2
33	Reflector	IV-9
34	Blanket	III-5
35	Blanket	III-2
36	Reflector	V-2
37	Reflector	IV-8
38	Reflector	IV-5
39	Reflector	IV-2

clearance than would have been available if a Type IV module had been removed first. For the first of the three cases where two Type IV reflector modules were side-by-side (i.e., there was no adjacent Type V module on one side), it was judged to be necessary to provide additional clearance by using the module spreader and reflector positioning tool (Appendix A3, Section A3.2.1). The three reflector modules on each side of locations IV-4 and IV-7 had to be removed first to provide clearance for installation of the module spreader. The module spreader was used only once, for removal of the first adjacent pair of Type IV reflector modules. For the other two pairs, a sufficient number of modules were removed so that the module positioning tool (Appendix A3, Section A3.2.2) provided adequate additional clearance to permit safe removal of these modules.

Blanket module removal clearances were improved by offsetting the crane hook center line 2.38 inches from the module center line, in the direction away from adjacent modules. This required that fuel modules adjacent to three adjoining sides of the blanket module to be removed had to be removed first. For this reason, and because of the controls placed on reflector module removal noted above, eight reflector modules were removed before removing the first blanket module.

3.14.3 - Fuel Removal Handling Tools and Rigging

Three handling tools were used for all fuel movements, one each for seed, blanket, and reflector modules. Fuel removal rigging used to connect handling tools to the Fuel Handling Building 25-ton crane included a chain hoist, a remote reading load cell, and a flexible link (spring). The chain hoist permitted a controlled, slow hoisting rate. The load cell provided a convenient and sensitive readout to detect load changes. The flexible link provided a spring in the rigging. (The technical aspects of the flexible link are detailed in Appendix A6.) These components worked together to permit the force to change gradually during vertical fuel movements so that a hangup could be detected and hoisting stopped before a fuel module could be damaged or rigging components overloaded.

Criteria established in the approved Defueling Safety Assessment which affected designs of the three fuel handling tools are:

1. Each tool had to provide positive indication that grappling or ungrappling actions were completed properly.

2. The grapples had to be locked in the grapple position by a mechanism actuated in an operation independent of the grappling action, and which would operate only if the grapple was in the proper position.

The design of the tools met a third criterion that was important for radiological safety: handling tool lengths were designed to ensure that fuel modules remained under water to provide adequate shielding during all fuel handling operations. An adjunct to this criterion was that all fuel module lifts were made with single rigging (i.e., tool lengths and rigging lengths were set so that, regardless of the location of the fuel modules, all movements were accomplished without detaching the rigging to insert or remove additional rigging).

Grappling of blanket and seed modules was accomplished by rotating a central shaft in each tool 90 degrees. For both tools, this was done by moving a handle across a guide slot in the outer body of the tool. This turned a cam plate at the bottom of the tool, extending three heavy steel pins that engaged mating holes in the buffer cylinder of seed modules or in the support tube of blanket modules. The handle was locked at either end of the slot by a spring-loaded pin, which captured the handle between two lugs. Assurance of grappling was obtained by two actions. First, the handle had to move freely from side-to-side with the tool seated on the module. This verified that the pins were aligned with the mating holes. After extending the pins, the tool was raised enough to obtain a loading equal to about 10 percent of the module weight. An attempt was then made to move the handle to the ungrappled position. Proper grappling was confirmed if the handle did not move when a light force was applied to it.

Reflector module grappling differed significantly from seed and blanket module grappling. Spacers, which were remotely adjustable to make the tool fit either a Type IV or Type V reflector module, contacted a vertical side of the seal block to provide a reference location for aligning the grapple head with the lifting port. The lifting port, a 4.31-inch outside diameter, 3.0-inch internal diameter cylinder which was an integral part of the top orifice plate, had J-slots (Figure 39) machined in the internal diameter (as opposed to mating holes as in the other modules). The reflector handling tool grapple head had three machined lugs which entered the long legs of the J-slots. The grapple head was turned in the J-slot by a handle at the top of the tool that attached to the load-carrying central shaft. The free end of the handle ran in a J-slot in the latching mechanism analogous to the one in the lifting port. The central shaft terminated at the top of the tool in a threaded length and was supported by a mating nut that rested on a thrust bearing. After inserting the tool into the lifting port on a module, the nut was turned to lower the central shaft, which lowered the lifting lugs into the long leg of the J-slot in the lifting port and lowered the handle in the latching mechanism's analog plate in which the handle ran. Rotating the handle in the latching mechanism rotated the lugs at the bottom of the handling tool, thus engaging the short leg of the J-slot in the lifting port. Grappling was confirmed by noting that the handle moved freely. The lugs were then moved up into the short leg of the J-slot by turning the support nut again. Finally, a spring-loaded pin was inserted in the latching mechanism to capture the handle and lock the grappling system.

The tools were designed so that they could be conveniently grappled to the fuel modules in the deepest location in the reactor vessel (Figure 40), then drawn up to the 25-ton crane upper height limit without raising any part of the fuel module above the water surface. For further safety, extension links of specific, predetermined lengths were added to the rigging to ensure a minimum depth of water coverage for the fuel modules, even at maximum attainable crane hook elevation.

3.15 - FUEL MODULE REMOVAL OPERATIONS

Operations related to each type of fuel module and the problems unique to each type are discussed in this section. As noted in Table 1 and Figure 38,

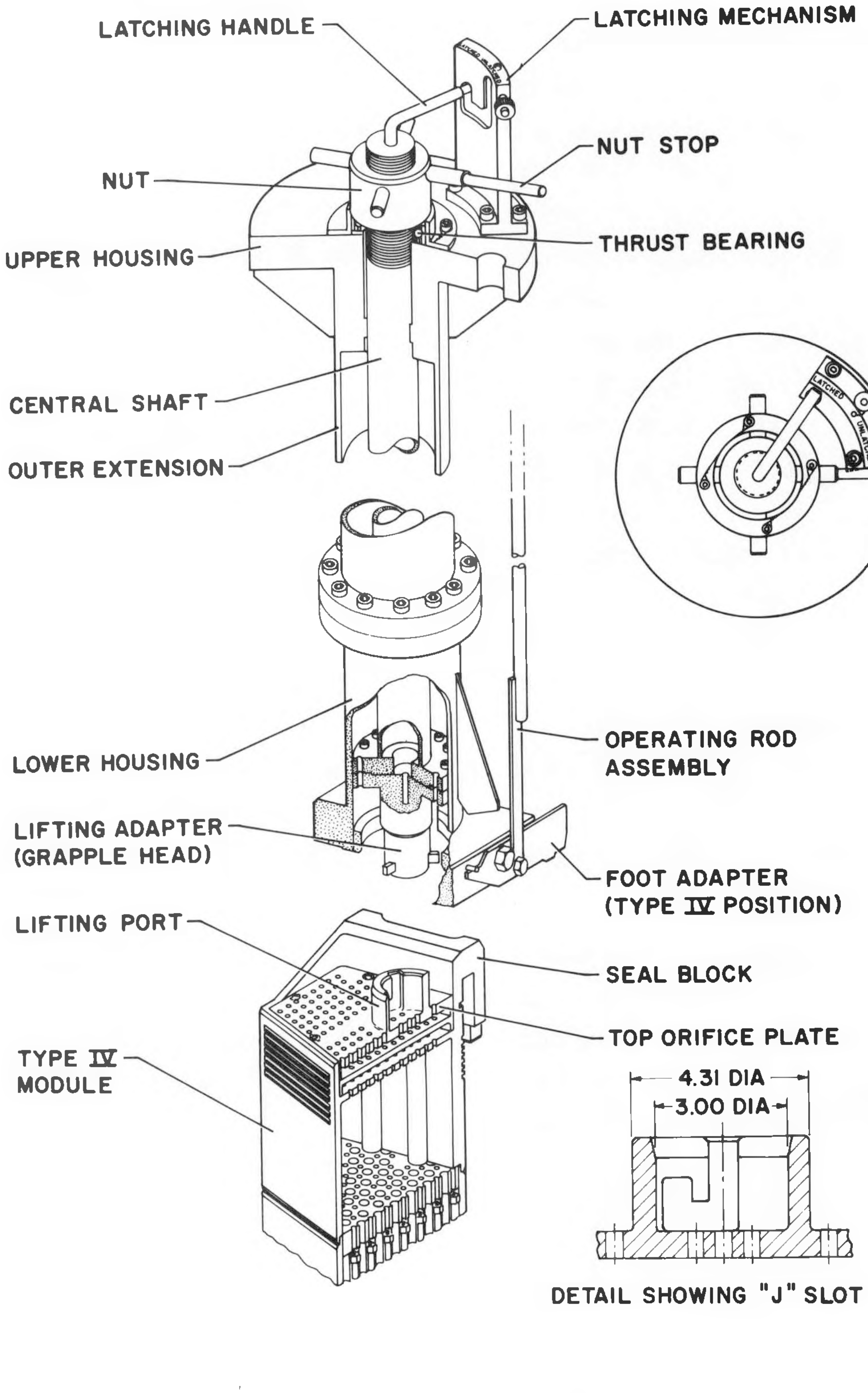


Figure 39. Reflector Module Lifting Port and Handling Tool Showing J-Slot Characteristics

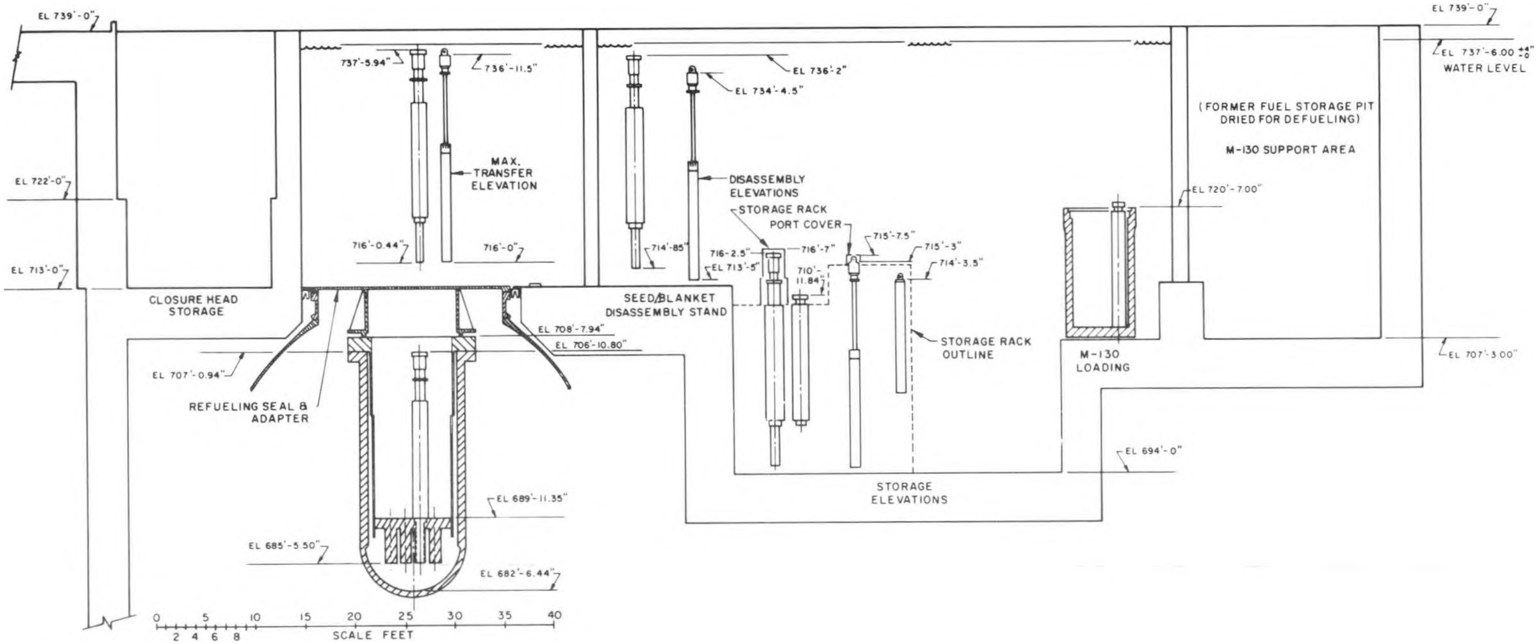


Figure 40. Canal Elevations for Defueling

all seed modules were removed from the reactor first, but reflector and blanket module removal was alternated as required by shipping schedules and storage space availability. Each module removed from the reactor was immediately inspected using the module visual inspection station (Appendix A5), which provided a close-up video record of the sides of each module. These inspections confirmed that there was no damage to any of the fuel modules as a result of removing them from the reactor and that they were in excellent condition following extended LWBR operations. After removal of the first module of a type, operations were repetitive. Therefore, the following discussion is generalized; specific modules are highlighted only as they affected overall operations.

3.15.1 - Seed Module Removal

Because lifting a seed module out of its mating blanket module would result in the nearest approach to criticality encountered during defueling, special controls were imposed during this operation. Just prior to the start of lifting each seed module, the procedure required checking and verifying that canal water level was normal, that the boron concentration monitors were operating, and that boron concentration was normal as determined by chemical titration performed within 2 hours before starting the lift. The procedure also required plotting the trend of boron concentration change as determined from five readings taken at 8-hour intervals just before seed module removal. This plot was made to ensure that boron concentration would not decrease below the specified minimum limit during the seed module removal operation. The actions to be taken in case a low boron concentration alarm occurred (and low boron concentration was confirmed) included immediately lowering the seed module to seat in the vessel if it was below the most reactive elevation (Section 3.18). If withdrawal had reached or passed the nearest approach to criticality point, seed module removal was to continue without delay.

During the initial lift (0.20 inch) of each seed module, the procedure limited the removal force to 500 pounds greater than the weight of the module and its handling tool (1100 pounds in water) and required measurement of the actual load. Above this initial lift, the removal force was limited to the initial lift load plus 200 pounds. These limits were imposed to prevent damage to either the seed module being removed or the mating blanket module.

The seed modules were removed successfully with no damage to the modules or to the equipment. There were no low-boron concentration alarms; therefore, no seed modules were lowered to seat in the vessel once the removal sequence was started. There were no significant problems with either the procedure or the equipment during this operation.

3.15.2 - Reflector Module Removal

The reflector handling tool used three turnbuckles, which were adjusted so that the handling tool and a grappled module were vertical when freely suspended in the canal water. Since the lifting adapters on all reflector modules were on the vertical centers of gravity of the modules, one setting of the turnbuckles satisfied all reflector handling conditions. This setting was established, and the turnbuckles were locked, prior to using the reflector handling tool for module removal.

There were two types of reflector modules (Types IV and V) having physically different seal block shapes. Because the handling tool was guided by a vertical surface on the seal block, two different grapple head configurations were required. The two configurations were obtained by remotely adjustable spacers on the grapple head. The procedure included steps to check and establish the correct spacer position for the type of reflector module to be grappled.

The procedure limited the removal force to 600 pounds greater than the weight of the module and its handling tool during removal from the reactor vessel. (Type IV reflector modules weighed about 5700 pounds and Type V reflector modules weighed about 5200 pounds in water.) This limit was specified to prevent damage to either the module being removed or the adjacent reflector and blanket modules. There were several close clearance points to upper core barrel features during module removal. The procedure identified the elevations of these potential hangup points for each module and specified caution during lifting of the module through the upper core barrel.

The reflector modules were removed from the reactor vessel successfully with no damage to the modules or to equipment. There were no significant problems with either the procedure or the equipment during the operation.

3.15.3 - Blanket Module Removal

There were three types of blanket modules, Types I, II, and III, each with slightly different vertical centers of gravity. The center of gravity coincided with the module center line only for the Type I modules. The vertical center line of the blanket handling tool coincided with the vertical center line of the support tube when the handling tool was grappled to a blanket module. To have the blanket module hang plumb when lifting it from the reactor vessel, the handling tool had to compensate for this center of gravity displacement. This was accomplished by an adjustable slide and rotatable plate on the handling tool, which permitted adjusting the lift point of the tool off its center line. Prior to grappling each blanket module for removal from the reactor vessel, the specific predetermined lift point offset and orientation for that module were set on the handling tool.

When lifting blanket modules out of the reactor vessel, the overhead crane was positioned to lift at a small angle from vertical to pull the module away from adjacent fuel modules. This feature permitted the blanket module to move into the space made available by the previously removed reflector and blanket modules, thereby providing additional clearance and precluding grid hangups.

In addition to crane offset, a second module positioning system was used to enhance clearances for removal of the first four blanket modules and for reflector modules IV-6 and IV-9. This equipment, discussed in detail in Appendix A3, Section A3.2.2 consisted of two identical units, each having two hydraulically operated cable tensioning systems that operated on caps inserted into blanket support tubes. Up to three blanket modules surrounding the module to be removed were pulled to increase clearances.

The procedure required the first blanket module of each Type (I, II, and III) removed from the reactor vessel to be checked for verticality (plumb) to verify the handling tool offset calculations. The modules had to be plumb to ensure that they could be safely transported and accurately inserted into storage racks and M-130 liners because they had minimal clearances. The check consisted of measuring from reference seal block surfaces at the top and bottom ends of the blanket module to a plumb wire. The operation was performed under water using a measuring scale with a long handle and an underwater TV camera. The measurements were made in only one plane. The procedure also provided the steps necessary to correct module verticality if necessary. This consisted of determining the amount of correction needed and its direction, based on the measurements. The module was then rested on the reactor pit floor and the slide adjusted to the new offset dimension. Following adjustment, the verticality was rechecked. The first blanket module removed (from core location III-6) did not meet the verticality criterion, even though the blanket handling tool had been adjusted before grappling. Using the underwater viewing system, it was found that one of the three grapple pins in the lifting tool had partially disengaged from the lifting hole in the blanket support tube. Although the module had been grappled correctly and verified as grappled, forces on the module during removal from the reactor had caused a slight shifting of the handling tool such that a safety lip on one of the grappling pins was inside the lifting hole, thus raising one side of the module slightly higher than the other side. There was no possibility for the pin to become completely disengaged. To do so would have required a horizontal motion of the grappling head relative to the blanket support tube of 0.60 inch, the length of pin engagement. Clearance between the grappling head and the blanket support tube was only 0.12 inch. The verticality was adjusted to reduce the out-of-plumb condition, and the blanket module was transported to the disassembly stand. This was the only instance of a nonvertical module and the only use of the verticality correction procedure during LWBR defueling.

During the initial lift (0.20 inch) of each blanket module, the procedure limited the removal force to 500 pounds greater than the weight of the module and its handling tool (in water) and required measurement of the actual load. (Type I blanket modules weighed approximately 7800 pounds; Types II and III blanket modules weighed in the range of 8600 to 9300 pounds in water.)

Above the initial lift, the removal force was limited to the initial lift load plus 100 pounds. These limits were imposed to prevent damage to the module being removed as well as to the adjacent blanket modules.

The blanket modules were removed successfully with no damage to modules or to equipment. The only unexpected condition occurred during removal of the blanket module from core location III-6 when it became necessary to adjust the blanket handling tool to correct a nonvertical condition. There were no significant problems with the procedure or the equipment during blanket module removal.

SECTION 4 - DEFUELING SUPPORT

Defueling of LWBR was not merely a natural extension of reactor operations, but required extensive planning and organization that began even before LWBR went critical. The Engineering department designed and procured defueling tools, conducted checkouts of the tools, then wrote procedures for using them. Allowing sufficient time before reactor shutdown, a Defueling Operations group was formed and trained, first at Bettis Laboratory, then at Shippingport. Defueling operations were performed by Bettis Laboratory and Duquesne Light Company, under the technical direction of the Department of Energy. Responsibilities of the defueling organizations were formalized so that communications among the three organizations was maintained. Support for defueling operations was provided by Engineering, Quality Assurance, Planning and Procurement, and Radiological Controls groups.

Many changes to the physical plant at Shippingport were required to prepare for defueling. Both floor space and canal area space were at a premium due to the number of tools and equipment used and the number of components to be removed and dispositioned. The overall defueling program was carefully coordinated and conducted in phases to ensure optimum use of available facilities.

4.1 - DEFUELING ORGANIZATIONS

Defueling of LWBR was performed by two commercial organizations: Bettis Atomic Power Laboratory (division of Westinghouse Electric Corporation), and Duquesne Light Company, a public utility company operating in the metropolitan Pittsburgh, Pennsylvania area. Operations were under the technical direction of the Office of the Deputy Assistant Secretary for Naval Reactors of the Department of Energy through their Shippingport Branch Office.

The responsibilities of each organization were outlined in a master administrative document, the Refueling Administrative Manual, which was developed in a joint effort among the three organizations. The manual presented information (in the form of directions and requirements) for the administration and control of defueling, and for handling, storing, disassembling, and shipping spent fuel. The manual also outlined requirements for personnel training, cleanliness controls for defueling operations, control and use of detailed procedures, defueling equipment control, and disposal of reactor components. The purpose of the manual was to establish criteria for conducting safe and timely defueling operations. Additionally, detailed administrative documents established procedures guiding all aspects of the defueling effort within the bounds of the criteria established by the manual.

An important aspect of the defueling operation was the interaction among the three responsible organizations. Figures 41 and 42 present the organization charts for defueling operations as performed either by Bettis (LWBR Defueling and Shipping) or Duquesne Light Company. LWBR Defueling and Shipping was responsible for the overall administration and technical direction of the performance of all phases of the defueling. This responsibility included the advanced planning prior to plant shutdown and the detailed planning for defueling and for personnel training. It further included providing the personnel and services necessary to prepare and issue defueling documents.

Communication among the responsible organizations was maintained through daily and weekly planning meetings. Overall direction of defueling activities was focused through the Joint Defueling Group, which was responsible for overseeing the safe performance of defueling work. It was established to facilitate local approvals of the documents for administration of the defueling and for communications among the responsible organizations. Representatives of each of the three responsible organizations comprised the Joint Defueling Group.

The defueling procedures and any applicable procedures in component or equipment technical manuals contained the basic requirements for defueling. These procedures were prepared by Bettis, approved by Naval Reactors and the Joint Defueling Group, and issued by LWBR Defueling and Shipping. Strict compliance with approved defueling procedures was required. These procedures established the requirements and constraints necessary to ensure reactor safety and proper disassembly of reactor components. Operations covered by these procedures were properly sequenced during all phases of defueling, including reactor preparation prior to fuel transfer, to ensure that these

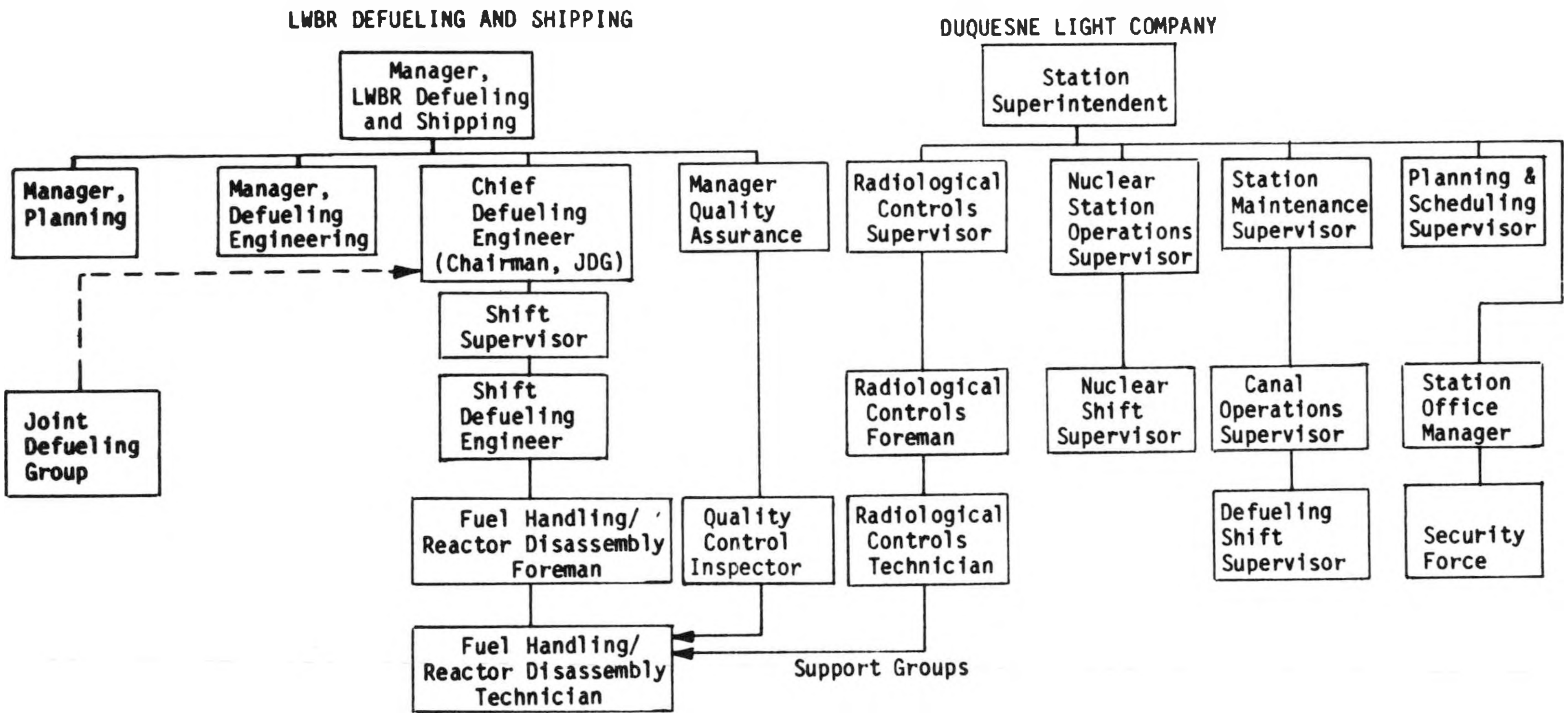


Figure 41. LWBR Defueling Organization Chart (Bettis-Performed Defueling Operations)

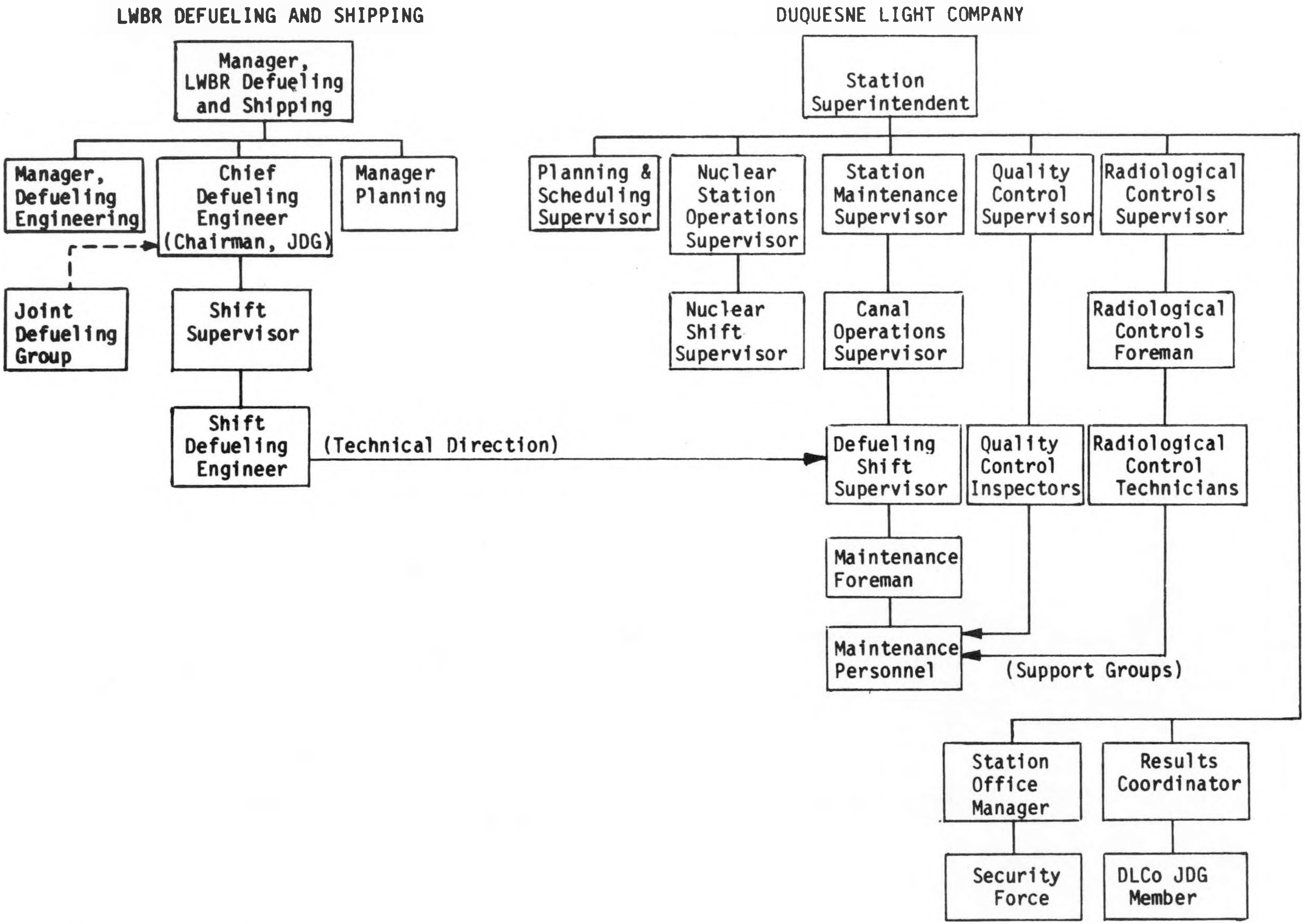


Figure 42. LWBR Defueling Organization Chart (Duquesne Light Company-Performed Defueling Operations)

requirements and constraints were preserved. Defueling sequence charts were used to control defueling operations in an organized and safe manner. Detailed charts were developed and approved for use by the Joint Defueling Group. These charts defined, sequenced, and displayed not only the mainline defueling effort but also the parallel and support work items as well.

4.2 - DEFUELING SUPPORT GROUPS

As noted on the defueling organization charts (Figures 41 and 42), there were several personnel groups that supported the mainline defueling efforts: Planning, Defueling Engineering, and Quality Assurance under LWBR Defueling and Shipping, and Radiological Controls under Duquesne Light Company. The interaction of these groups with mainline defueling operations personnel resulted in a successful and on-schedule defueling.

4.2.1 - Defueling Engineering

Engineering of defueling tools began with mechanical design of the reactor itself. Defueling Engineering was responsible for designing, procuring, and checking performance of tools and equipment to be used in defueling operations. Personnel performing checkout operations on tools and radiological containments formed the core group for Defueling Operations. After tools were successfully checked out, Engineering personnel wrote procedures for using them. When defueling operations began at Shippingport, the Engineering group was divided into two subgroups. One group remained at Bettis to complete procurement of tools and equipment that would be required for later operations while the second group was stationed at Shippingport to be immediately available for consultation on problems with tools and procedures.

4.2.2 - Defueling Planning

Responsibilities of the Defueling Planning group were twofold: scheduling defueling operations to optimize personnel and equipment availability, and administering procurement and preparation of tools and equipment. The scheduling functions are detailed in Section 4.3. The procurement function involved everything from office supplies to large shipping crates for contaminated tools and components. Because of space limitations, careful planning was required to ensure that equipment required at various stages of defueling was available and that equipment no longer needed was quickly disposed.

Defueling Planning personnel worked with Quality Assurance inspectors to ensure that all equipment met requirements and specifications. They advised Engineering personnel of deviations so that actions could be taken to correct problems on a timely basis.

4.2.3 - Quality Assurance and Quality Control

Both LWBR Defueling and Shipping and the Duquesne Light Company maintained quality assurance groups that were given autonomy for overseeing defueling operations to ensure that they were conducted in strict accordance with written procedures. The Quality Assurance activity was structured in compliance with applicable portions of the Code of Federal Regulations, 10CFR50, Appendix B. The primary objective of the surveillance function was to prevent damage to fuel assemblies, especially damage which was indeterminate in origin.

To meet this objective, Quality Control inspectors were trained and certified as the on-the-job representatives of Quality Assurance for overseeing defueling activities. They were responsible for inspecting and accepting work areas to prevent entry of foreign materials into spaces where fuel modules would be worked on or stored. They performed procedurally specified dimensional measurements and verification checks of critical operations. They also interacted with Defueling Planning to conduct receipt inspections and shipping inspections.

Quality Engineers reviewed all procedures for compliance with Federal regulations on nuclear fuel handling, resolved any problems with Defueling Engineering, and performed periodic audits of defueling work to ensure that performance met standards and regulations.

4.2.4 - Radiological Controls Group

Duquesne Light Company maintained the Radiological Controls group with a Bettis manager as the supervisor of radiological controls. The function of this group was to ensure that all activities were conducted in accordance with good radiological practices and to define the radiological condition of the entire plant to the Department of Energy dismantling agency at the time of plant turnover.

Radiological Controls reviewed all procedures to ensure that the radiological controls content met all standards and regulations. It was this group's responsibility to continually monitor the plant and surrounding environment to identify and control potential spread of contamination and radiation, and to maintain an up-to-date radiological status of the plant and all equipment.

4.3 - DEFUELING PLANNING

Planning for the LWBR defueling was initiated before the completion of the LWBR installation. From a technical standpoint, the scope of the defueling was developed, refined, and packaged as the LWBR Defueling Technical Plan. This plan included all known design, procurement, and software items needed to accomplish the LWBR defueling. Regular updates were provided as new and additional information was made available. The first planning document from a schedular standpoint was the LWBR Mobilization Plan issued in December 1981. Once the LWBR shutdown date was decided, planning for a timely completion of the facility preparations, personnel training, transfer of personnel and equipment to Shippingport, and the issuance of required software was essential. The Mobilization Plan provided these plans up to the LWBR shutdown date of October 1, 1982.

The LWBR Defueling and Shipping Operational Plan was the first document to detail the actual LWBR defueling work from reactor chamber dome removal through shipment of the tenth M-130 container to the Expended Core Facility in Idaho. This plan, developed in early 1982, projected September 11, 1984 as the completion date for the LWBR defueling. Later in 1982, the first official

Defueling and Shipping Operational Plan was issued for use. Refinements to the original plan and revised time estimates, particularly in the area of fuel module transfers, reduced the overall time required and projected a defueling completion date of June 4, 1984.

The Defueling and Shipping Operational Plan was the basis for the development of the defueling portion of the Duquesne Light Company Master Activity Schedule. The schedule, issued in October 1982, was a bar-chart schedule with a month-by-month display of all known defueling work to be performed and the required crafts personnel. It contained both the controlling (main) and non-controlling work and was used to balance the manpower availability for the defueling effort. No revisions to the Master Activity Schedule were issued during defueling. Normally, revisions are issued after a major change affects the end date. Although small slippages in the completion date occurred almost from the start of the defueling, a major change did not occur until installation of the refueling seal. By this time, only a few work items remained until the repetitive operations of fuel module handling and disassembly and M-130 operations were to occur. A revision to the Master Activity Schedule was not required to list these relatively few line items.

A similar type of Master Activity Schedule was used by Duquesne Light Company for LWBR defueling preparations. This schedule was issued in April 1982, and it depicted all of the facility preparations, equipment, checkouts, personnel training, and manpower required to prepare for the start of LWBR defueling and all subsequent defueling operations. The schedule was successfully met for completing all of the required preparations for the start of defueling. Numerous work items supporting later defueling operations, however, were deferred in order to support an early defueling start date. The deferred work was incorporated into the Duquesne Light Company Defueling Master Activity Schedule.

The Duquesne Light Company Plan of the Week listed the line items of the Master Activity Schedule, but in more detail. This plan was based on the latest known information, including problems with material, equipment, or procedures. The plan was short range (2 weeks), with the first week being as firm as possible. This document was the basis for Duquesne Light's Plan of the Day meeting, which coordinated the defueling effort for close control between the various work crafts and site groups. Bettis and Duquesne Light interfacing was a key to the successful and timely completion of the defueling. Issues such as main crane use and access to key areas of the Fuel Handling Building (deep pit, north end, etc.) arose routinely because of continuous planning. Open items were discussed and issues resolved to permit operations to continue.

Following shipment of the second M-130 container to the Expended Core Facility, a revised LWBR Defueling Operations schedule was developed because the defueling end date had slipped approximately 3 months during the first year, and Duquesne Light's Master Activity Schedule was outdated and no longer achievable. In addition, the majority of the first-time operations had been performed. Only seed module loading and the PWR-2 lower core barrel disposal work had not been performed at least once. The updated schedule, issued in December 1983, identified September 12, 1984 as the new defueling completion date. Several months later, numerous changes in the work schedule resulted in the need for another revision. Because of weekend work, changes in the fuel module shipping sequence, and improved work efficiency, defueling operations were approximately 1 week ahead of schedule. In addition, the division of work between Bettis and Duquesne Light had been revised and other current information was available. A second updated Defueling Operations schedule was issued in May 1984 which indicated that the final M-130 container would be available for shipment on August 30, 1984.

A graphic view of the actual completion of the LWBR defueling, including major training evolutions, is shown in Figure 43. A detailed breakdown of the Bettis fuel module handling operations (Item X on Figure 43) is presented in Figure 44. Major delays which did impact the schedule were decontamination of the core support flange after removal of the LWBR closure head and installation of the LWBR refueling seal. Other sizable delays in the schedule were for the performance of facility preparations that had been deferred to support an early defueling start date. The major delays and other problems that directly affected the targeted completion dates are discussed in Appendix A9.

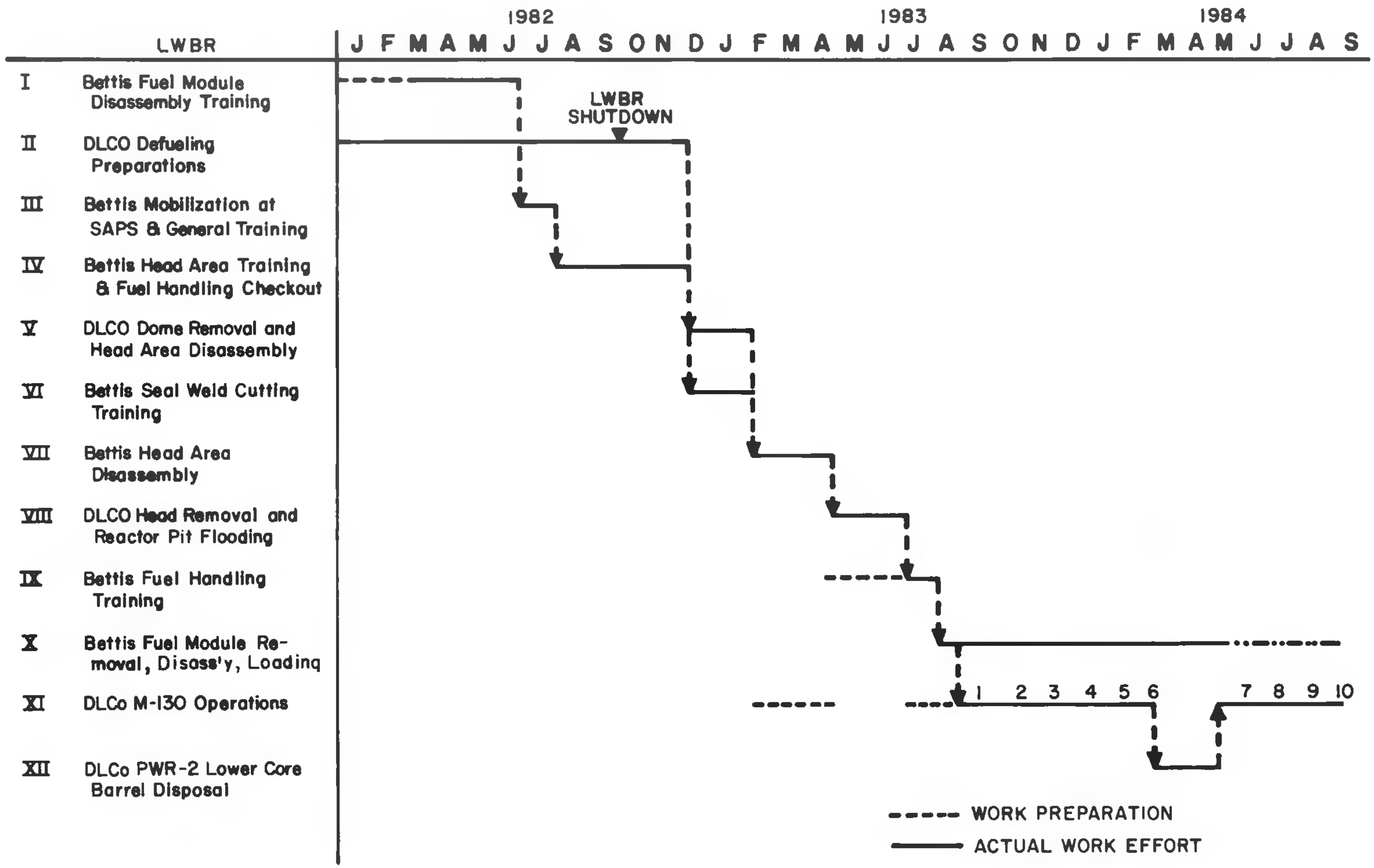


Figure 43. Chronology of Defueling Operations

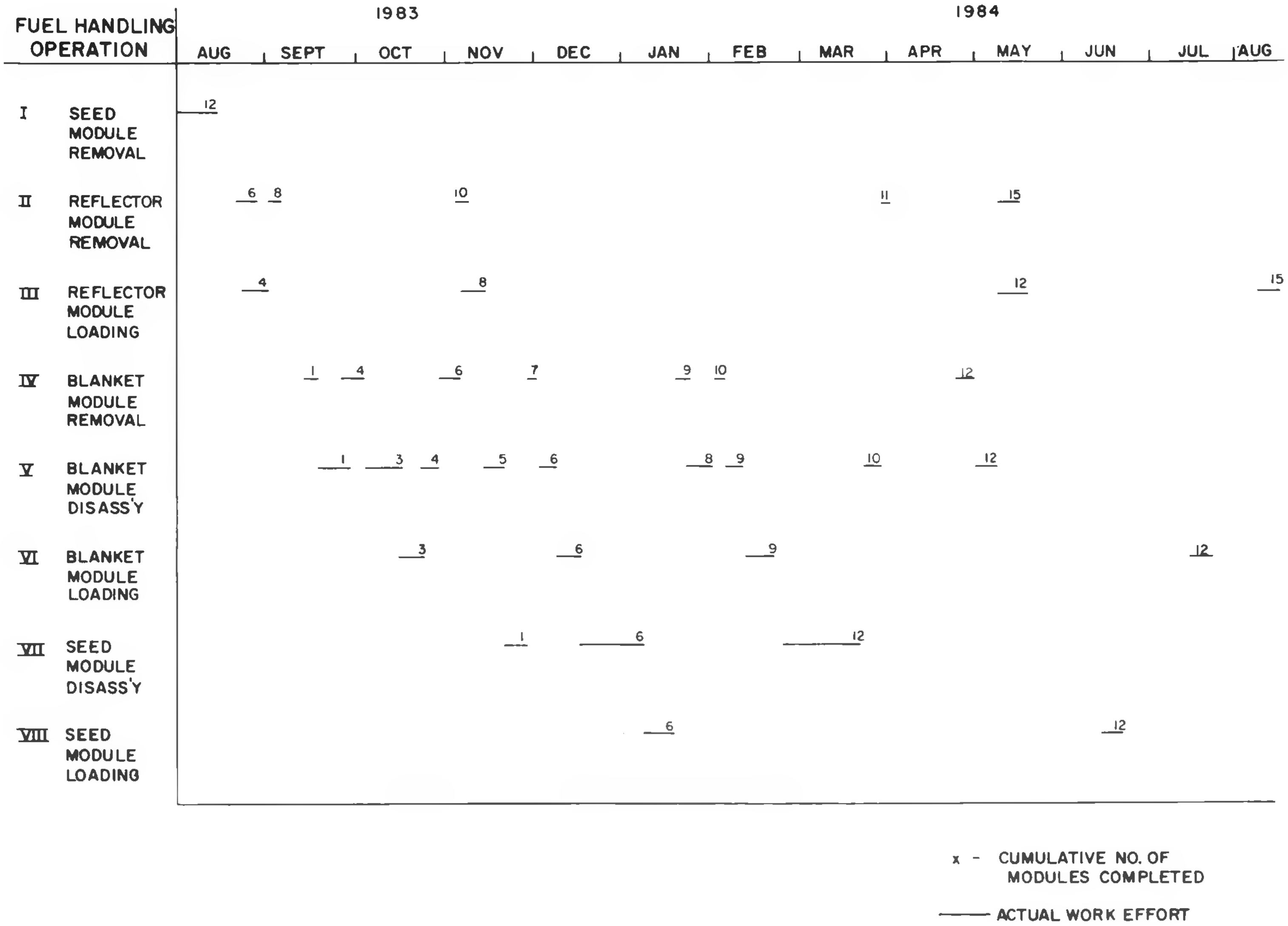


Figure 44. Fuel Module Removal, Disassembly and Shipping Chronology

4.4 - TRAINING PROGRAM AT BETTIS AND SHIPPINGPORT

The defueling training program was designed to prepare and qualify supervisory and nonsupervisory personnel for performing the operations required in defueling. The overall responsibility for the content and conduct of the training program was assigned to LWBR Defueling and Shipping. This responsibility included providing all training of Bettis defueling personnel assigned to Shippingport and training of Duquesne Light Company defueling personnel.

To qualify personnel for defueling, the training program was structured with three goals in mind. One goal of the program was to give trainees an understanding of what was to be accomplished in defueling. Another aim consisted of teaching personnel the manner and techniques in which components, tools, and devices were to be handled and operated. Finally, the program was designed to enable trainees to understand the necessity for strict adherence to specific controls and procedures used in defueling. These goals were achieved through the use of numerous training methods such as lectures, briefings, self-study, visual aids and mock-ups, demonstrations of equipment and procedures, and participation in operations closely simulating actual defueling conditions.

Training was administered and tailored in a manner that considered each worker's previous refueling experience and requirements of the trainee's job classification. Supervisory personnel, such as Shift Defueling Engineers and Defueling Shift Supervisors, were required to pass written and oral examinations (in addition to practical training on operations to be performed) prior to assuming their respective responsibilities in defueling. Defueling technicians, on the other hand, were required to participate in a minimum of two cycles of selected training operations involving the use of actual or simulated defueling equipment and procedures. Trainees were considered qualified by demonstrating their ability to perform assigned operations safely and effectively in reasonable time and by coping with extraordinary and emergency conditions that might arise during defueling through satisfactory participation in emergency drills.

The training program also presented an opportunity for additional checks on the adequacy of defueling procedures, tools, equipment, and safety provisions which were used during practical training sessions. During fuel handling training for blanket modules, for example, difficulty was encountered while attempting to grapple the blanket training fixture. The cause of the problem was traced to the blanket module handling tool internal bearings, which were subsequently replaced. Discovery and correction of this and other problems during training avoided mainline schedular delays and problems during handling of components.

Several minor written procedure problems were identified and corrected during training operations. On the average, seven changes were made, correcting one or more problems, for each head area disassembly and fuel handling procedure. After training was completed for each procedure, corrections made to the training instructions were incorporated into the defueling procedure.

By familiarizing defueling personnel with equipment and procedures, coupled with identification and correction of hardware and software deficiencies prior to performance of the actual operation, the amount of radiation exposure to workers was minimized. Simulation of radiological conditions during training helped improve personnel proficiency in control and handling of radioactive materials, thereby minimizing the time spent in radiation fields, spread of radioactive contamination, and generation of radioactive wastes.

Head area disassembly operations were simulated for Bettis personnel in the Fuel Handling Building dry pit (Figure 46), adjacent to the reactor pit, using an LWBR test (REM-3) closure head and head components, and for Duquesne Light personnel in an auxilliary equipment room. Because training was performed in parallel with other defueling preparations involving the main crane, jib cranes with reduced mobility and capacity were substituted in the dry pit. Head area space limitations were duplicated using mock-ups of head area components. Scaffolding problems in the dry pit, which limited access to rigging and tools in some cases, were not present in the reactor pit during actual head area operations. Due to the elevation of the REM-3 head, the bypass inlet flow supply tube and the blanket support tubes were mocked-up using components of shorter length and differing weight. These differences between the simulated and actual conditions had little effect on the quality or efficiency of training of personnel for head area disassembly.

Fuel handling training was conducted in the deep pit (Figure 46) for Bettis personnel using actual fuel handling tools and facilities with training fixtures for blanket and reflector modules and a seed module mock-up. Training was conducted for module grappling, removal from the reactor vessel, installation and removal from the disassembly stand, and installation and removal from the fuel storage rack. Minor differences between simulated and actual conditions included such things as different grappling elevations and weight indications, and an inability to simulate the close module clearances that existed in the reactor vessel. These differences did not significantly affect training of personnel for handling nuclear fuel. Final training was conducted prior to removal of the first seed module from the reactor vessel by performing a dry run of seed module handling.

Success of the training program depended on each individual worker's attention to detail and ability to demonstrate proficiency at his assigned tasks during training. The defueling training program thus contributed towards successful completion of the LWBR defueling at Shippingport in the required time, safety, and quality constraints.

4.5 - FACILITY PREPARATIONS FOR DEFUELING

Facility preparations at the Shippingport Atomic Power Station Fuel Handling Building are illustrated in Figures 45 through 47. Looking at Figure 45 and starting at the north end of the Fuel Handling Building, a fenced-in area was used to store and stage equipment and was the main storage area for small hand tools. The guide tube extension bolt cutting machine air compressor was located on the west balcony of the building. This location was chosen because: (1) it did not use valuable floor space, (2) it was in reasonable proximity to the module disassembly stand where cutting operations were to be conducted, but remote enough so that the noise would not disturb operations, (3) an electrical power supply was in proximity, and (4) the equipment

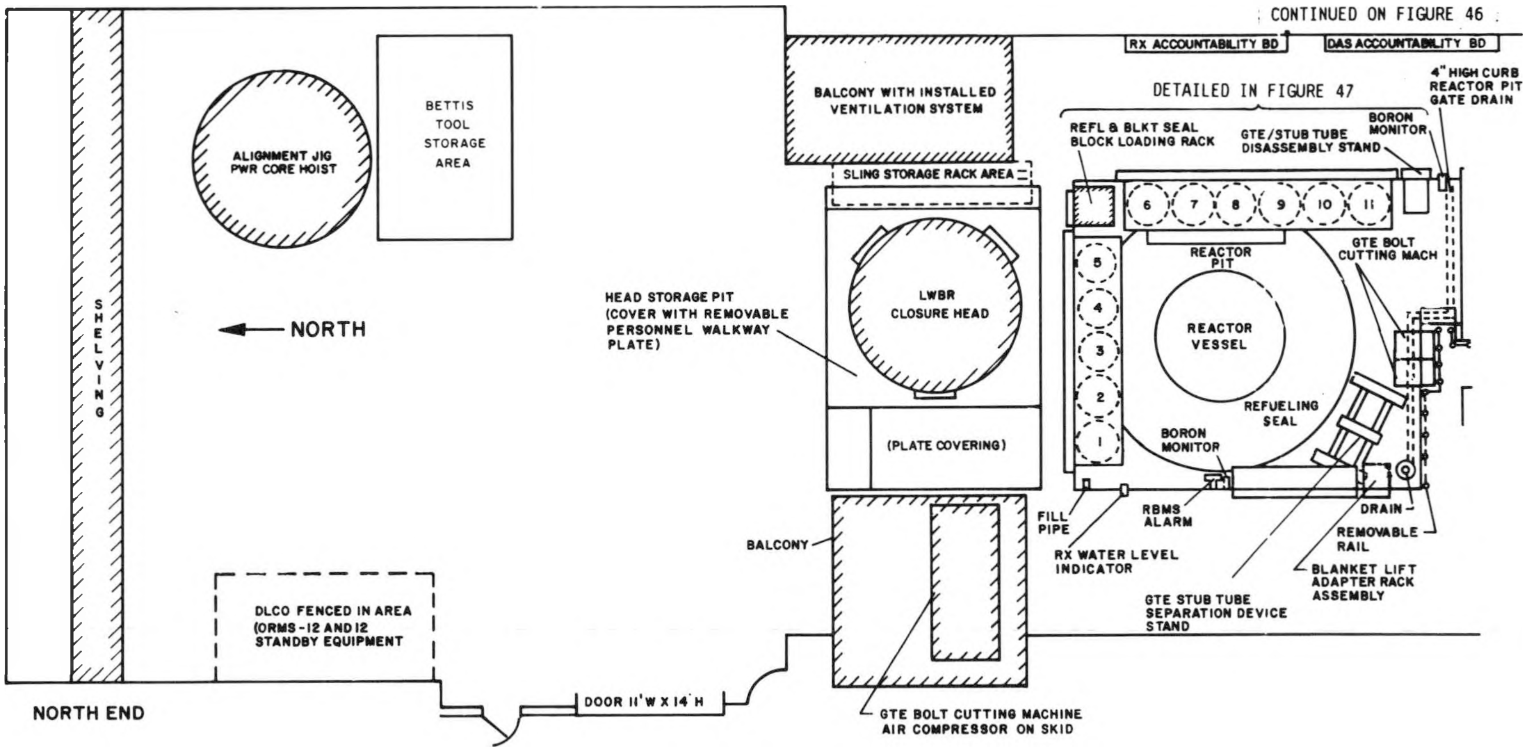


Figure 45. Fuel Handling Building Facility Preprations (North End)

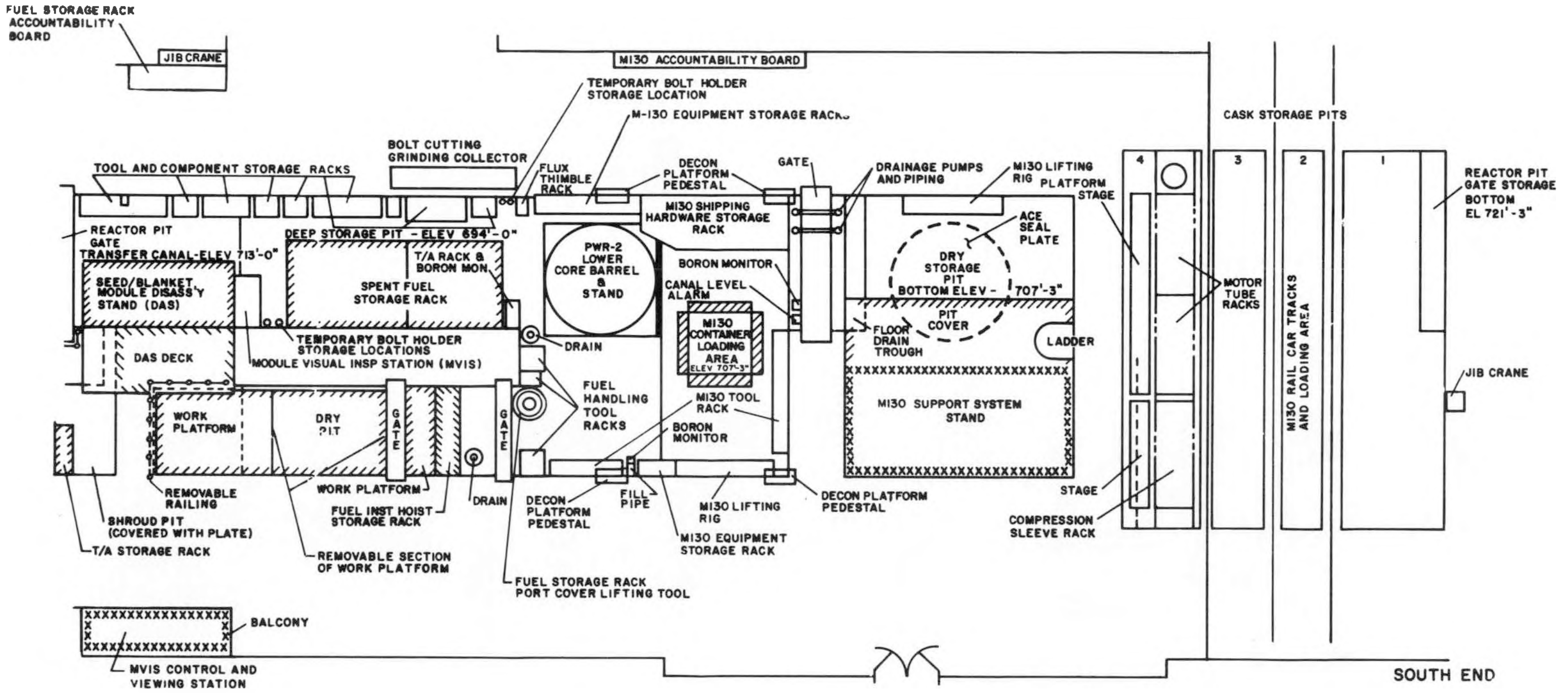


Figure 46. Fuel Handling Building Facility Preparations (South End)

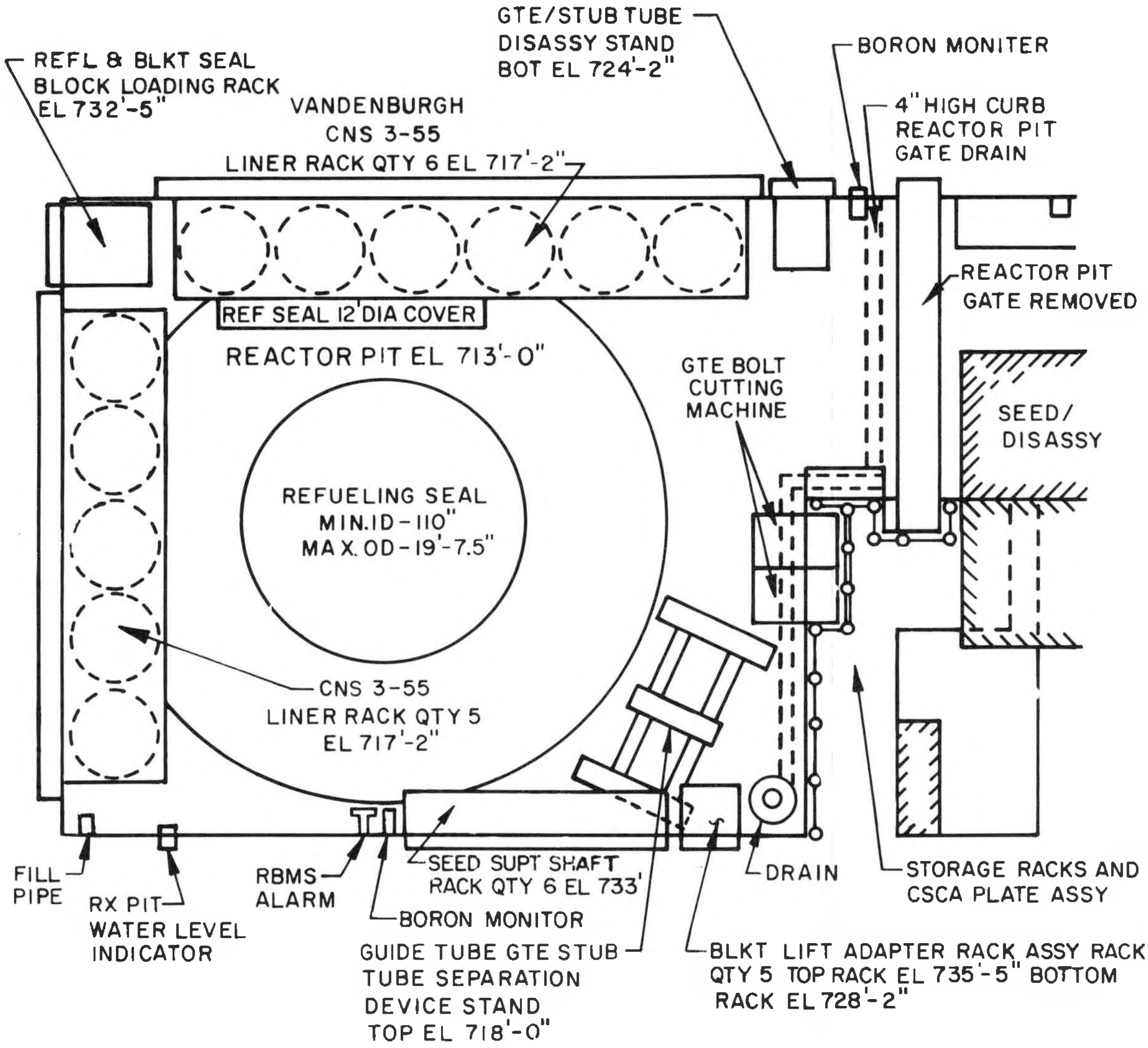


Figure 47. Facility Preparation for Defueling
(Reactor Pit Area Details)

formerly located on the balcony was not being used and could be scrapped. The head storage pit was modified by removing the cover support cross beams to prepare for installation of the LWBR closure head in the pit. After the closure head was installed in the pit, pit covers were reinstalled and the cover area was utilized for light equipment storage and a personnel work area. The lifting sling rack was relocated from the dry pit section of the building to the east balcony. The large LWBR closure head slings were stored on this sling rack.

The various racks and equipment installed in the reactor pit are shown in Figure 47. Most of the racks were fastened to the top surface of the canal concrete curb with expansion bolts. They were installed after holddown barrel removal but before starting fuel removal to support fuel disassembly operations. The racks and stand were located in the reactor pit because they would be close to the disassembly operations in the module disassembly stand, thereby saving critical path time, and space was available and optimally utilized. The largest amount of space in the reactor pit was taken by two racks that supported up to seven* large disposal drums (actually liners for the standardized CNS 3-55 "Vandenburgh" disposal casks). The Vandenburgh liner racks were the underwater platforms which supported and secured the Vandenburgh liners. These liners were loaded with the disassembled structural components of the blanket and reflector modules (Reference 2). Various core structural component or defueling equipment storage racks or stands also were installed to support defueling and disassembly operations.

Facility preparations conducted south of the reactor pit are shown in Figure 46. Irradiated core component racks were located in the shroud pit, along the east wall of the deep storage pit, and south of the fuel storage racks for underwater temporary storage. Module disassembly and fuel handling tool racks were installed along the east wall of the transfer canal and deep

*Figures 45 and 47 show spaces for 11 liners, but several spaces were unused at any given time to provide clearance for component movement and extra work space for certain other operations.

storage pit, and south of the spent fuel storage racks. M-130 shipping container tools and equipment were stored in three racks located in proximity to the M-130 loading area. Four boron concentration monitor brackets were installed in the transfer canal and deep pit areas. A major preparation effort was the draining and cleaning of the fuel storage pit at the extreme south end of the canal. After cleaning, a plastic sheet liner was installed to cover all wall and floor surfaces. Platforms were installed for the M-130 support system (Reference 2) and to provide a work area. As modified, the fuel storage pit supported several defueling and shipping operations. Personnel work platforms and component storage racks were installed in cask storage pit No. 4. To save main crane usage and, in turn, critical path time, a jib crane was installed on the south support beams of the building to support M-130 shipping container operations. Also, a jib crane previously installed at the north end was moved to a more useful location near the module disassembly stand. Work platforms were installed in the dry pit section, west of the disassembly stand, to provide storage for hand tools and rigging and a personnel work area for guide tube extension bolt cutting machine operations using the control console. This dry pit area was also readied as a training area to prepare personnel for reactor head area disassembly operations. The reactor pit gate storage pit was prepared for gate storage for the duration of defueling operations.

The facility preparations in the Fuel Handling Building successfully supported the defueling operations conducted in the building.

4.6 - DEFUELING REACTIVITY CONTROL

The primary nuclear safeguard invoked during defueling was the large shutdown method (i.e., the addition of a nuclear poison to ensure at least a 10-percent shutdown margin at all times during normal defueling operations, and maintenance of subcritical conditions at any fuel handling location in the event of any credible accident scenario). This was accomplished at Shippingport by ensuring that both the reactor vessel and canal water were borated with potassium tetraborate to a minimum concentration of 4200 parts per million (ppm) by weight of natural boron. An analysis performed prior to defueling using a qualified model (Reference 7) conservatively demonstrated that no credible fuel handling scenario could be postulated that would insert sufficient positive reactivity to cause criticality. The amount of boron dissolved in the reactor vessel and canal water ensured that the core remained shut down by at least 10 percent in the most reactive defueling configuration. This occurred during removal of the first seed module when the module reached a height of 105 inches above the other 11 seed modules, which were bottomed in the reactor vessel. As modules were removed from the core, the shutdown margin of the remaining array continually increased. Although analysis showed that a boron concentration of 3800 ppm was the minimum required to obtain a 10-percent shutdown margin, defueling administrative requirements called for a concentration of 4400 ±200 ppm to allow for slight fluctuations in overall boron concentration due to evaporation and makeup, and to cover inaccuracies in sampling equipment and instrumentation. Boron concentration monitoring and administrative controls to ensure safe concentration levels are discussed in Appendix A4. Problems related to boron and its monitoring system are presented in Appendix A9.

Boration of reactor vessel and canal water was the key safety feature for criticality control. However, strict procedural and physical controls were also invoked to prevent accidental reactivity increases.

4.6.1 - Reactivity Control Prior to Fuel Transfer

Prior to fuel transfer from the reactor vessel, fuel module support components were disconnected from the closure head, the fuel modules were lowered to the reactor bottom plate, and the closure head was removed.

Verification that the seed assemblies were on the bottom at the end of testing was made in the Control Room by observing that all seed bottom lights were on. Positive verifications that the seeds remained bottomed were made during head area disassembly operations by direct measurement and weight control.

Prior to head removal, verification was provided that plant fluid systems were aligned to limit flow of water into the reactor vessel. Double valve isolation of connected flow paths was implemented to prevent introduction of fresh water into the canal and the consequent dilution of boron. Boron concentration within the vessel was verified by conductivity cell readings (Appendix A4), as well as by chemical titration of samples obtained through the flow instrumentation.

Strict load limits were imposed to ensure that each component which could contact the upper end of the seed support shaft was removed without causing accidental lifting of the seed.

Prior to head removal, all blanket assemblies were verified to be free of the head by a direct measurment to ensure that no fuel component was lifted with the head.

4.6.2 - Reactivity Control During Fuel Transfer

Due to the large shutdown margin, no unacceptable reactivity increases could occur during fuel transfers. Defueling sequence controls limited fuel movement to one module at a time, both procedurally and as a consequence of having only one crane capable of lifting a fuel module in the Fuel Handling Building. All 12 seed modules were removed from the core prior to removing any blanket or reflector modules. They were stored in the fuel storage rack, which was designed to ensure nuclear decoupling between adjacent modules. Although reactivity increased during removal of each seed module, the high boron concentration ensured that the shutdown margin never decreased below 10 percent. After removal of all seed modules, the shutdown margin was increased to over 20 percent, and no possible configuration of remaining blanket and reflector modules could provide such a large increase in reactivity.

Reactivity was controlled during additional fuel movement into and out of the fuel storage racks and the disassembly stand and into the M-130 shipping container by the high boron concentration and by maintaining nuclear decoupling through facility design and procedural controls of fuel movement.

4.6.3 - Reactivity Changes During M-130 Support Operations

To minimize the effects on canal water chemistry at the Expended Core Facility that would result from introducing into the canal fuel modules exposed to heavily borated water, it was necessary to remove residual boron from the M-130 interior prior to shipment from Shippingport. This was accomplished by draining the sealed M-130 of borated water, filling and flushing with grade B fresh water, then draining the flushing water (Reference 2).

The action of backfilling with fresh, nonborated water resulted in an increase of reactivity. The worst-case condition was that of a fully loaded seed module shipment. Fully moderated during flushing, the shutdown margin was calculated to be about 15 percent. In this case, reactivity was controlled by proper design of the M-130 internals, which maintained nuclear decoupling by physical separation of adjacent fuel modules.

4.7 - RADIATION AND CONTAMINATION CONTROL

LWBR defueling operations overall objectives were to minimize personnel radiation exposure and to control contamination. A defueling radiation control plan was established with the following elements: personnel radiation exposure estimates, man-rem budget and reduction program, radiological containment, shielding, equipment design, procedure design, radiological control supplements, operations planning, training, and emergency plans.

As a first action in controlling radiation exposure, personnel radiation exposure (man-rem estimates), man-rem budgets, and radiation levels were estimated. These estimates provided data to plan defueling operations and identified which operations involved the most radiation exposure. From this starting point, a Man-Rem Budget and Reduction Program was instituted which provided for establishing man-rem goals and tracking individual exposure on a daily basis. This action provided assurance that radiation exposure was maintained as low as practicable and well within prescribed limits. The exposure reduction program also included a checklist as a guide for procedure writers to use for ensuring that operations were performed with minimum personnel and in minimum time. The use of shielding and containment was incorporated into the procedures, and specific radiological control requirements for each defueling operation were spelled out in a separate radiological control supplement. A sequence chart was used for scheduling and controlling defueling operations. One of the considerations in preparing the sequence chart was the sequencing of operations to minimize radiation exposure.

Carefully designed and effective local containments were used for reactor disassembly operations performed after the primary system was opened and after the reactor pit was drained (Appendix A2). These operations included the various seal cutting and disassembly operations, the cutting of the upper main closure seal, and closure head removal. Local containments prevented the spread of contamination to personnel and uncontaminated locations. For those operations for which containment was not practical, a high-efficiency particulate air (HEPA) filtered exhaust system and HEPA-filtered respirators were used.

Reactor head area disassembly was performed using temporary shielding such as lead-filled blankets and portable lead sheets, as well as specially designed shielding when practical to minimize radiation levels.

Equipment design was carefully evaluated on the basis of minimizing personnel radiation exposure as well as on other requirements, including cost and reliability. Equipment design included evaluation of LWBR installation equipment for defueling, evaluation of equipment modifications, and design of new equipment. Equipment design documentation addressed the radiation control features of the design. The equipment was designed to be compatible with containment and shielding. When practical, integral shielding was incorporated into the equipment. Equipment developed for LWBR defueling, including containment, was checked out with nonfueled LWBR test equipment at Bettis and at Shippingport to the maximum practical extent.

Training on mock-ups simulating actual surroundings was conducted both at Shippingport and Bettis. Training operations gave the personnel a feeling for how the equipment operated, checked out the equipment for proper operation, and gave personnel experience for greater efficiency to minimize radiation exposure time. The training for LWBR defueling contributed significantly to the efficiency of the actual defueling and to minimizing radiation exposure.

A defueling procedure was prepared which specified actions to be taken in the event of an emergency during defueling operations. Regular periodic review of emergency procedures was conducted as a part of workplace briefings prior to performing any defueling operations. Drills covering emergency procedures that may be required for upcoming work were conducted as a part of preparations for major defueling evolutions.

As a result of careful control of radiation exposure, defueling was completed with a total personnel dose of 76.2 man-rem, and no individual received more than 10 percent of the 5 Rem annual limit.

SECTION 5 - SUMMARY AND CONCLUSIONS

Removal of nuclear fuel from the LWBR core, along with many nonfuel components, was the first stage of total decommissioning of the Shippingport Atomic Power Station. The objective was to remove the 39 fuel modules comprising the LWBR core and ship them to the Naval Reactors Expended Core Facility in Idaho for component examination and evaluation of the breeding concept in a thorium-based fuel cycle.

Defueling operations began in December 1982 with draining of the reactor pit and removal of the reactor dome. Before fuel could be removed, all of the hardware, instrumentation, and piping used to control reactor operation had to be removed from the closure head area.

After removal of instrumentation and piping from the top of the closure head, the reactor primary system was breached by cutting a weld and removing a vent plug at the top of two motor tubes. Other primary system seals were cut at the base of the motor tubes, at the closure housing of the bypass inlet flow (BIF) pressure equalization system, at instrumentation penetrations surrounding the motor tubes, and at the base of the closure head; then the motor tubes and translating assemblies were removed, as well as the BIF piping, and flux wire thimbles, thermocouples, and pressure taps comprising core internal components of the instrumentation system.

To gain access to the blanket module support system, a guide tube for seed module translation was removed from each fuel assembly port in the closure head. This was followed by a series of operations to detach the blanket modules from the closure head and lower them, along with the mating seed modules, about 3.0 inches to seat on the core barrel bottom plate. Module lowering was performed incrementally on each of the 12 fuel assemblies in 1.0-inch intervals because dimensional changes occurring within the blanket modules as a result of radiation-induced growth presented a very high potential for module-to-module interference and hangup. The operations were accomplished successfully.

After removal of all items connected to the closure head, the head was removed and placed in storage.

The preceding operations were performed in the drained and covered reactor pit using local containments to guard against spread of radiological contamination. Heavily borated water filled the reactor vessel to provide both radiation shielding and criticality control. After the head was removed, the reactor pit was flooded to provide shielding for the highly radioactive materials which were to be removed from the reactor vessel. After flooding the reactor pit, the first component removed was the reflector module holddown barrel, which was installed into a shielded shipping container and shipped to a disposal site. At this point, all of the fuel modules were accessible for removal.

The first fuel modules removed were the seed modules. All 12 modules were removed and placed in storage for later disassembly. The sequence for removal of blanket and reflector modules from the reactor was dependent on both available storage space and M-130 fuel container shipping schedules as well as on requirements that certain modules had to be removed before others to avoid interferences. Thus, after seed modules were removed, eight reflector modules were removed, of which four were stored in the fuel storage racks and four were loaded into an M-130 fuel shipping container, disassembled, and shipped to the Expended Core Facility. A blanket shipment was prepared by removing three modules from the reactor and storing two of them, disassembled, in the fuel storage rack and storing the third in the disassembly stand. After the second reflector shipment, blanket modules were removed and stored either assembled or disassembled as scheduling permitted, whereas reflector modules were loaded into the M-130 container directly from the reactor.

The prime consideration throughout defueling was personnel safety, including freedom from personal injury, and control of radioactive contamination and radiation exposure. An intensive training program familiarized defueling personnel with operations and equipment through use of actual tools and accurate mock-ups of equipment and components. The training program contributed significantly to reduced radiation exposure as well as to checking out procedures and equipment prior to defueling operations. A man-rem reduction program tracked individual radiation exposure and influenced defueling procedures and planning to minimize total radiation doses received by defueling personnel.

Defueling was completed with no personal injuries and with total radiation exposure by defueling personnel of 76.2 man-rem, with no individual receiving more than 10 percent of the 5 Rem annual limit.

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APPENDIX A1 - MAIN CLOSURE SEAL AND OMEGA SEAL WELD CUTTING EQUIPMENT

A1.1 - MAIN CLOSURE SEAL GRINDING MACHINE

Several methods of performing main closure seal parting were evaluated, including the milling cutter used on previous Shippingport PWR cores, prior to selecting grinding as the most effective method for LWBR defueling. The grinding method was estimated to save up to 72 percent in time and man-rem exposure over the PWR cutting machine method.

The machinery developed for the closure head seal parting operation is shown attached to the closure head mock-up in Figure A1-1. The tool consisted of a grinding wheel driven by a hydraulic motor mounted on a framework, which also contained an air-powered motor used to drive the entire assembly around the closure head. The grinding wheel and its hydraulic drive motor were contained in the lower frame. The resinoid-bonded aluminum oxide grinding wheel was 1/4 inch thick and 10 inches in diameter. The motor and wheel were connected to a sliding frame which was manually operated to provide the greatest degree of operator control. Because the internal surface of the main closure seal was radiologically contaminated, a double chamber containment was constructed to ensure that radioactive debris created by the cutting operation would not become airborne. Debris collected in the chambers was evacuated into a pair of wet/dry vacuum cleaners equipped with high-efficiency particulate air filters. Rubber wipers and spatter shields prevented the escape of grindings from the area of the closure head.

The lower frame was bolted to an upper frame assembly which supported the drive mechanism and the reservoir for cooling water. Cooling water was sprayed on the top and bottom of the grinding wheel. The drive mechanism consisted of an air motor and gear box, which was connected through a cog wheel to a chain encircling the closure head. An idler wheel on the upper frame was adjustable and provided tensioning necessary to hold the assembly radially stable. Vertical stability was provided by two rollers riding on the top of the head bolting flange and one wheel riding on the bottom of the flange.

The air motor drive system was under operator control and was reversible. A single air hose connection provided air for both the drive system and

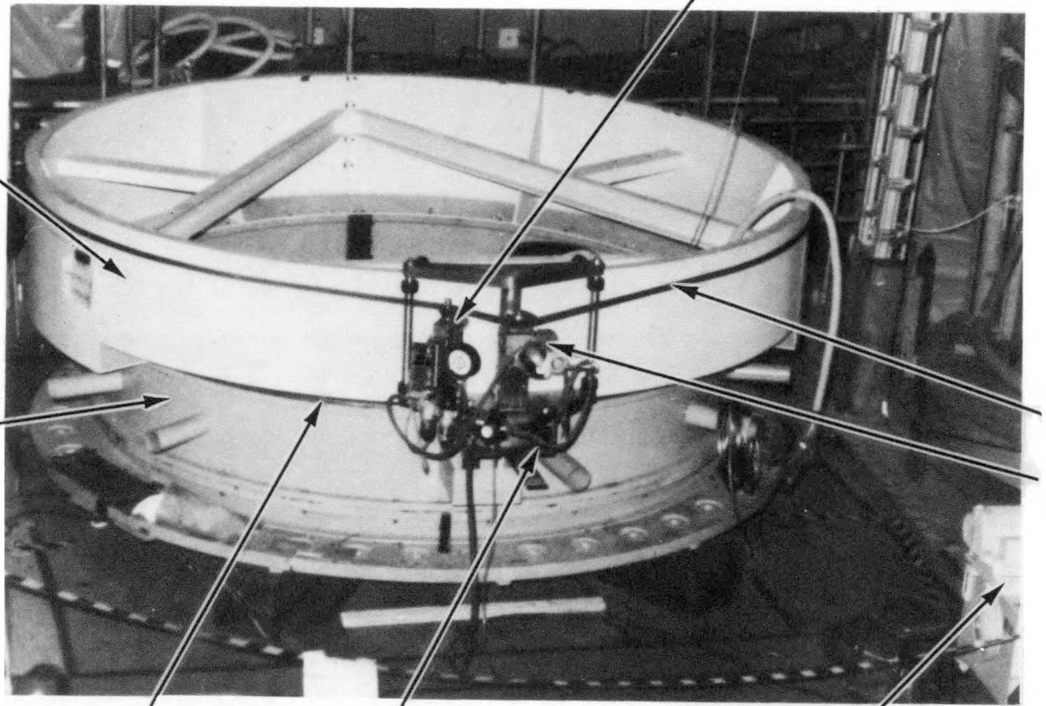


Figure A1-1. Closure Head Grinding Machine Attached to Mock-up During Checkout the coolant sprayer. The system travel rate was adjustable between 5 and 12 inches per minute around the closure seal.

As previously noted, alternative systems were considered for closure seal parting operations. The PWR closure head seal cutting machine was an existing system using milling cutters driven by an electric motor. It ran on a rigid track which was cumbersome and difficult to erect, especially in the limited space around the head. Based on experience with this machine in cutting previous closure seals, it was known that setup would take nearly 5 days and cutting time would take an additional 2 days.

Previous uses of the milling system took into consideration the fact that the seal was to be rewelded for PWR-2 and LWBR cores. For this final seal parting, reuse was not a consideration. For this reason, grinding and using a chipping hammer were viable alternatives. Chipping hammers are used commercially in applications that are similar to cutting the LWBR seal. In those cases, the chipping hammer is used as a hand tool, similar to an air-powered drill. It is guided manually and requires no setup time. A chipping hammer was tested under conditions that would exist for cutting the LWBR seal, and several drawbacks were found. Because of the thickness of the LWBR seal, a tool large enough to cut at a satisfactory rate was too large to manually handle conveniently in the cramped space under the closure head. It would have been necessary to develop a tool holder and drive system for either a grinding machine or a chipping hammer. Tests showed that a grinder was considerably faster and easier to control in this application. The grinder was selected for these reasons.

A1.2 - OMEGA SEAL CUTTING EQUIPMENT

Omega seals, so called because of their cross-sectional shape, provided pressure boundary seals between the 12 control drive mechanism (CDM) housings and their installed motor drives and between the six bypass inlet flow (BIF) housings and their installed plugs (Sections 3.4.3 and 3.4.4). The cutting equipment used to sever these seal welds is shown in Figures A1-2 and A1-3. The operating characteristics of both machines were similar, and the same cutting tools were used for both CDM and BIF seals.

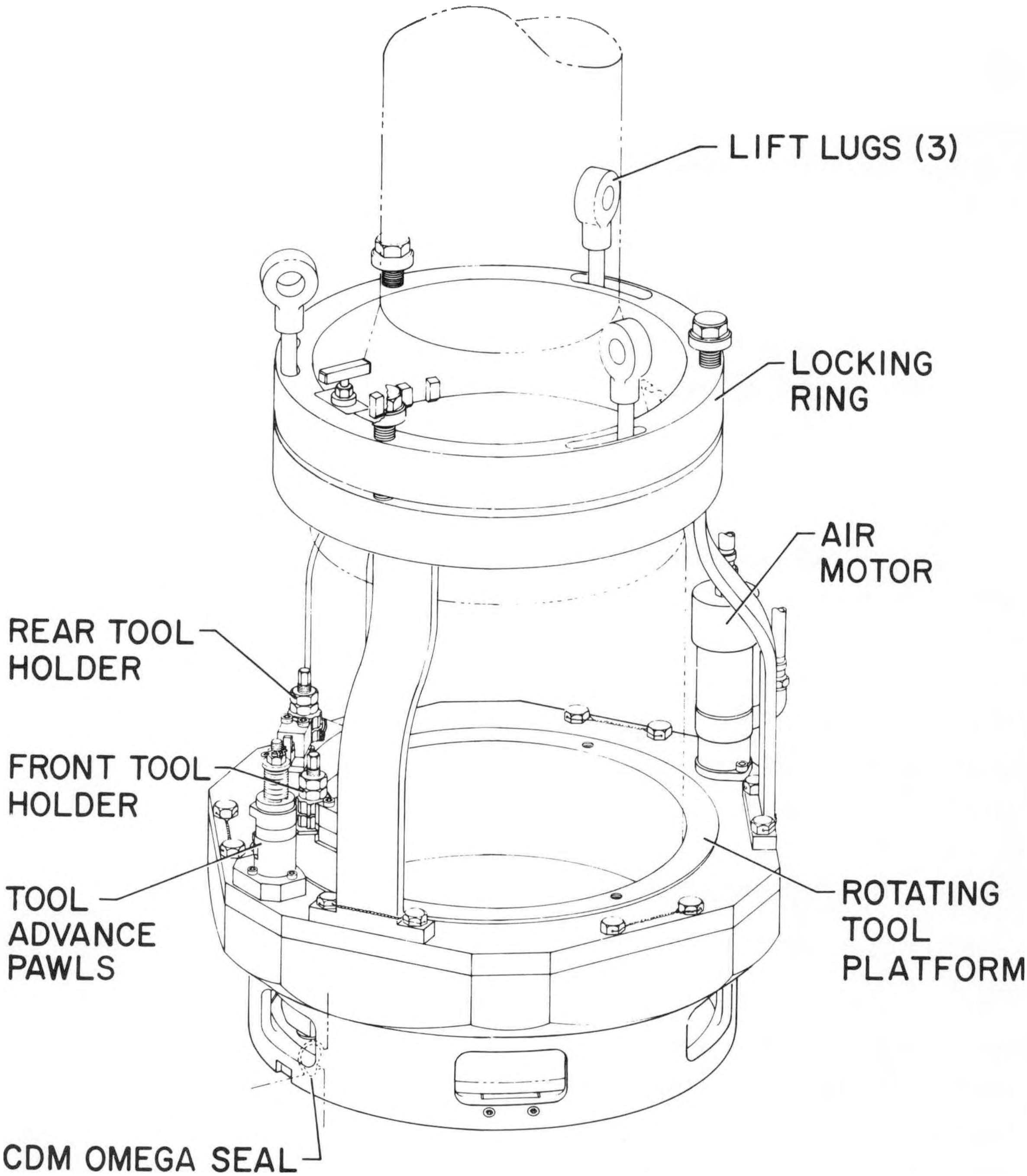


Figure A1-2. CDM Omega Seal Cutting Machine

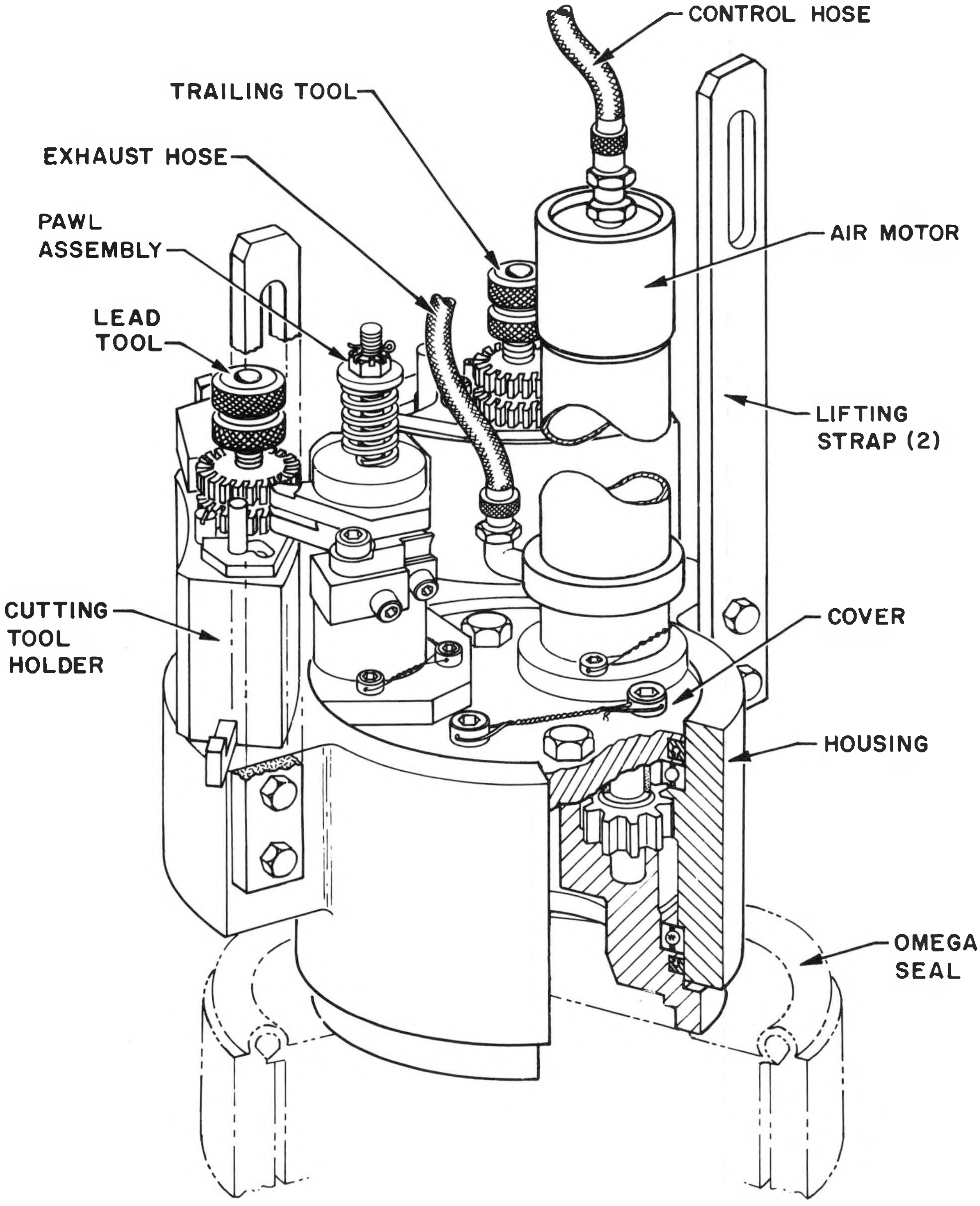


Figure A1-3. BIF Omega Seal Cutting Machine

The basic components of both machines were an air motor and two tool holders. These components ran in a framework designed to keep the cutting tools in contact with the top of the omega seal. The air motors were geared to drive the tools at about 40 feet per minute. The speed was operator controlled and could be varied as required.

Operations using the machines were relatively straightforward and trouble-free. A machine was installed on the component to be cut and locked into place. A broad facing tool was installed into one of the two tool ports, and a facing cut was made to remove high points and rough surfaces from the welded area of the seal. The facing cut was made to a depth of 0.024 inch below the lowest measured surface point in the welded area. The tool was fed into the cut automatically by a ratchet and pawl mechanism that advanced the tool 0.0014 inch per revolution.

After facing the cutting area, two grooving tools were used in tandem to complete the cut. The final grooving tool was made as narrow as physically possible to reduce radiologically contaminated waste to a minimum. The wider tool was only 0.010 inch wider than the narrow cutter. The wider tool was set to cut 0.015 inch shallower than the narrow tool to clean out the channel cut by the narrow tool and thus reduce chances of tool breakage.

The cutting machines operated trouble-free for all cuts. Because of welding distortion in the seal, a few cutting tools were broken near the end of cuts as the seal halves relaxed and pinched the cutting tool.

No alternatives to this system of omega seal cutting were considered. The two machines used for LWBR defueling were developed for contingency operations during core installation in case problems developed after the BIF and CDM omega seals were welded; hence, they were already available for defueling. Referring to Figure 13, it is seen that access around the motor tubes was restricted by the close packing of the assemblies; hence, hand-operated grinders or chippers were impractical. Grinding with other devices similar to that used for main closure seal grinding would have required a long development program. For this reason, the cutting equipment described herein was considered optimum for LWBR defueling.

APPENDIX A2 - CONTAINMENT BAGS FOR DEFUELING OPERATIONS

A2.1 - INTRODUCTION

The first of two basic methods for radiological containment is "area containment", whereby the entire work area is enclosed in a containment building or tent, and where personnel in air suits work within the containment. The second method is "local containment", whereby the equipment is kept in plastic bags, with personnel working through the bags. This method minimizes both cleanup requirements and the amount of restrictive anticontamination clothing that workers must wear. The Shippingport Fuel Handling Building was unacceptable as a containment building because the physical structure was not airtight, and the interior would have been difficult to decontaminate. The use of area containment over the top of the reactor pit was impractical because a crane could not be included within the containment without major plant modification. Therefore, local containment was selected for the LWBR operations.

The local containments were transparent, portable, flexible bags made of clear, polished, fire-retardant polyvinylchloride (PVC). They were designed for installation over the open primary system or a component rather than placing the system or component in a permanent enclosure.

Following breaching of the LWBR primary system by cutting the head area seal welds, radiological containments were required during the 13 reactor disassembly operations listed in Table A2-1. The work encompassed very simple operations such as bypass inlet flow (BIF) housing plug removal, which required only a small bag for containment, to complex operations such as breechlock sleeve disengagement and simultaneous module lowering, which required a sophisticated handling system using 12 module handling tools, all done in containment. Radiological containments were required for these operations because highly contaminated primary system internal surfaces were exposed. Radiological containments were also used on all shipping containers placed under water to simplify decontamination of these items when they were subsequently removed from the canal for shipment. Following closure head removal, operations involving highly contaminated or radioactive LWBR components were performed under water, which provided the required radiological containment.

Table A2-1 - Reactor Disassembly Operations Requiring Radiological Control Containments

No.	Operation	Figure Reference
1.	Cutting and Removal of Motor Tube Vent	A2-4, A2-5
2.	Cutting and Removal of BIF Pressure Tap to D/P Cell Piping	A2-6
3.	Removal of Thermocouples, Flux Thimbles, and Pressure Taps	A2-7, A2-8
4.	Removal of BIF Nozzle Closure Plugs	A2-9
5.	Removal of BIF Compression/Tension Tube Assemblies	A2-10
6.	Removal of BIF Supply Tubes	A-11,
7.	Removal of LWBR Motor Tubes	A2-12
8.	Removal of LWBR Translating Assemblies	A2-13, A2-14
9.	Removal of Compression Sleeves	A2-1, A2-15
10.	Removal of Preload from Breechlock Sleeves	A2-16, A2-17
11.	Disengagement of Breechlock Sleeves and Lowering of Blanket Modules	A2-18
12.	Removal of the LWBR Closure Head	31*, A2-19
13.	Removal of the LWBR Holddown Barrel	36*

An extensive development program involving full-size mock-ups was carried out for the radiological containments for LWBR head area disassembly. Numerous design modifications were tried to provide containments that were effective and practical. The transfer ring and cinch strap designs were innovative contributions to a practical containment system.

A2.2 - CONTAINMENT DESIGN CONSIDERATIONS

This section presents the various containment design features, including hardware and software items, considered for the LWBR head area disassembly

*Figures located in main text.

containments. Figures A2-1 through A2-3 illustrate the containment design features discussed below.

A2.2.1 - Size

The dimensions, both diameter and length, of containment bags are extremely important to the job operation. Containment bags which are too small can restrict the equipment operation or prevent proper cutting and J-sealing where bag-in/bag-out operations are required. Conversely, bags which are too large become unwieldy and can cause problems if the bag is to be bunched up or collapsed, such as when a tool is lowered into the reactor.

LWBR experience called for making the containment bigger than required if any uncertainty existed, leaving enough containment material for any cutting and sealing required. However, for containment bags attached to hardware (e.g., motor tube standpipes, transfer rings, glove attachment rings), the bag circumference was slightly smaller than the hardware item. This allowed the bag to be stretched over the hardware item, thus eliminating puckers or folds in the containment which, in turn, could result in contamination leaks.

A2.2.2 - Stiffening Rings

Use of stiffening rings is a method by which various degrees of radial rigidity can be manufactured into a containment bag. This rigidity may be required to maintain bag shape as it is bunched up or to keep the bag from collapsing onto the equipment during operation.

Soft plastic tubing is the primary material used for forming stiffening rings. This method imparts a "soft" rigidity to the containment and is usually sufficient for containment bags under 25 inches in diameter.

For containment bags greater than 25 inches in diameter, or anywhere additional bag rigidity is required, acrylic plastic rod or tubing can be used. These rigid plastic stiffening rings are generally useful at the top end of a long containment bag to hold the bag in a cylindrical shape and to impart structural support for tie-offs.

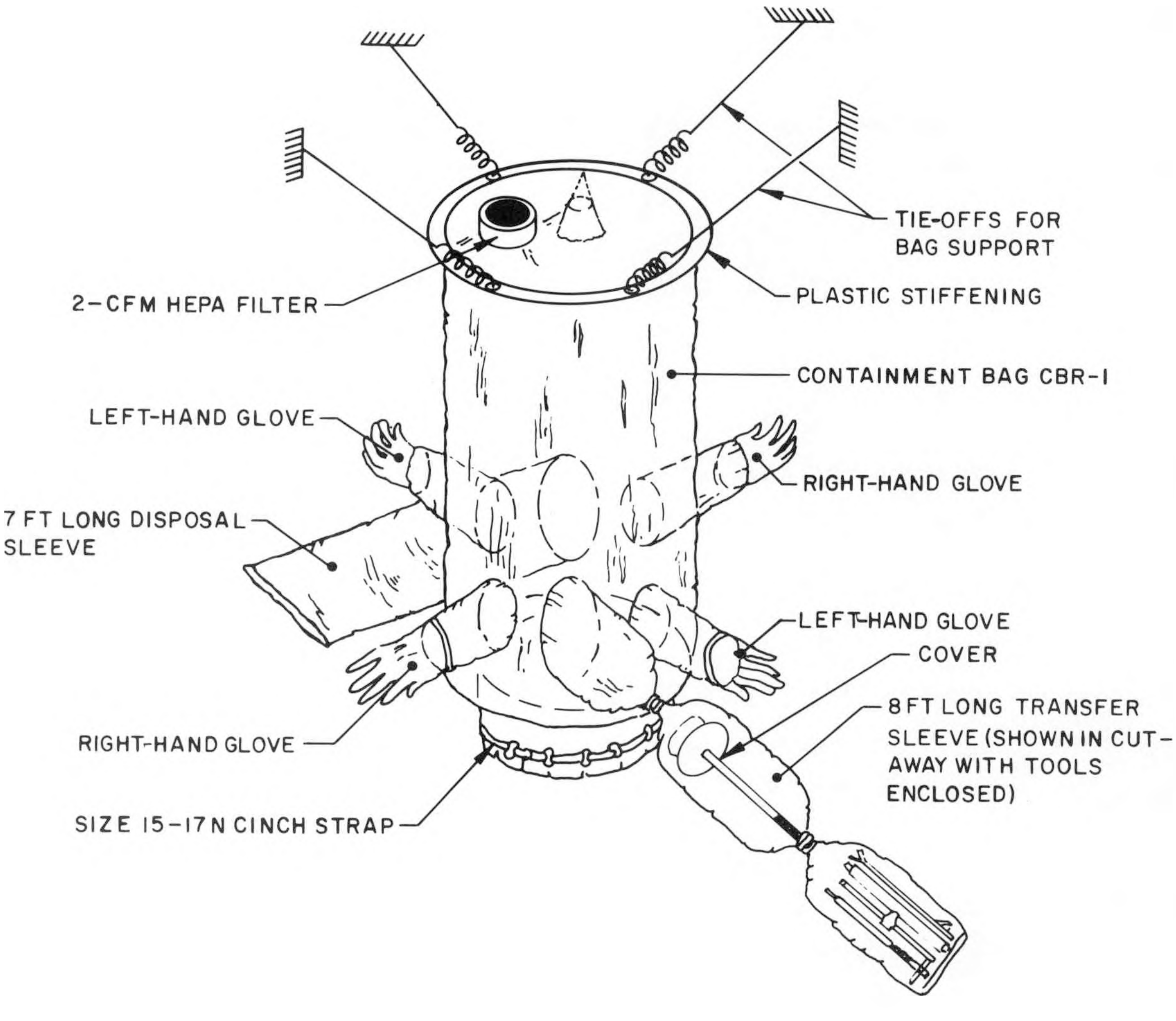


Figure A2-1. Containment Bag, Model CBR-1, Incorporating Desirable Features

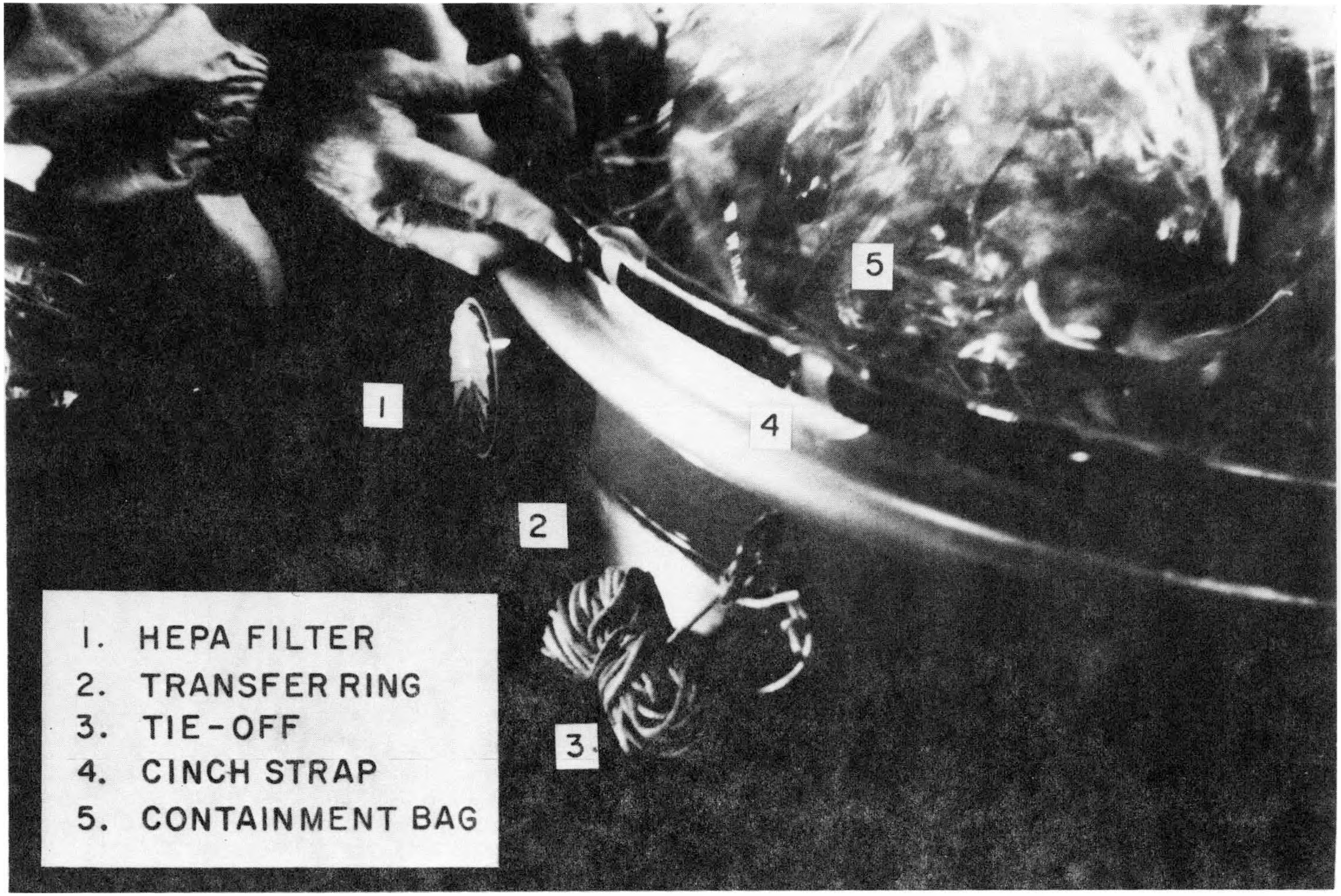


Figure A2-2. Transfer Ring Showing Bag Attachment, Tie-Offs, and HEPA Filters

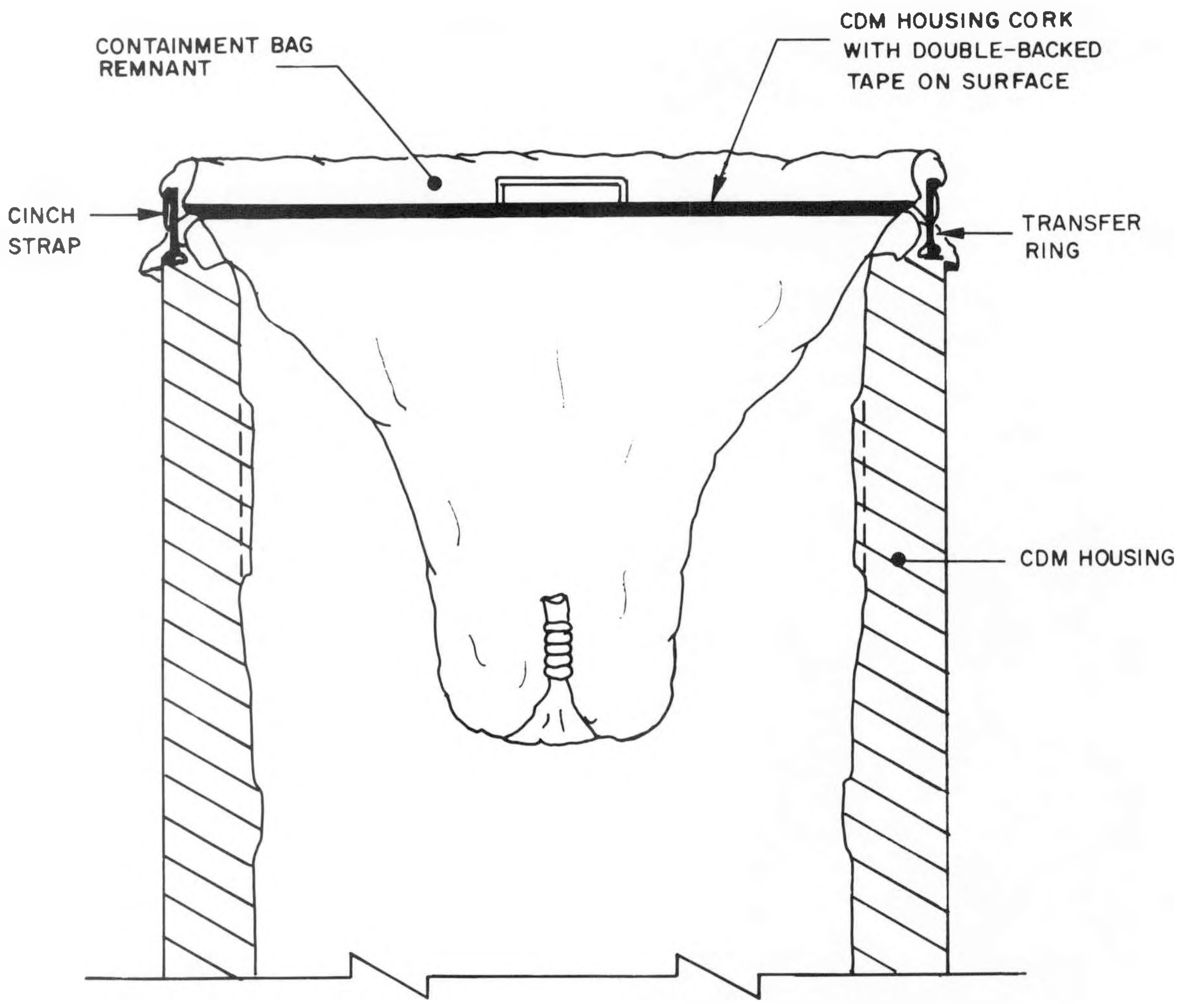


Figure A2-3. Transfer Ring on CDM Housing

Figure A2-1 illustrates the use of a stiffening ring on an LWBR containment bag, Model CBR-1. In this case, a soft ring was used with tie-offs to aid in maintaining bag shape.

A third form of stiffening ring for LWBR containment bags was also used. This form uses small-diameter (approximately 1/4 inch) steel rods as stiffening rings. This type of stiffening ring was used on the translating assembly removal containment bag where rigidity was required, but space was limited due to the proximity of adjacent motor tubes. These small-diameter stiffening rings also permitted better handling control over a containment bag by rigidly holding the bag in a circular configuration, while allowing it to bunch up tighter than a bag with plastic stiffening rings.

An alternate method for maintaining radial rigidity was the use of a series of tie-off points. These tie-off points were spaced circumferentially around the containment bag. The shape of the bag was maintained by tying off these points to adjacent structures. In general, this method was found to be undesirable for the defueling operation. Adequate structures for tying off were not always available, and the ropes tended to be in the way. Further, this method required considerable work be performed in a radiation field. Therefore, preplaced stiffening rings were used whenever possible.

A2.2.3 - Transfer Rings

Transfer rings provided the method for easily connecting two containment bags together. They are a portable adaptation of the rings on glove boxes used to attach rubber gloves and bag-in/bag-out sleeves. LWBR transfer rings were developed to separate the multiple-use equipment containment bag from the single-use component removal containment bag. Figure A2-2 illustrates the features of a transfer ring used to separate two containment bags. This method of bag construction was used when a tool was inserted into the primary system to perform an operation (such as loosening the nut on the BIF tension/compression assembly), but the tool was removed without removing a component. A second tool was subsequently inserted to perform removal operations. By using two bags separated by a transfer ring, containment was maintained on the torque tool, the removal tool, and the component being removed.

In another application, a permanent transfer ring was attached to the top of each control drive mechanism (CDM) housing for core disassembly. These transfer rings (as illustrated on Figure A2-3) provided the point for containment attachment for all head area disassembly operations through CDM housings.

Transfer ring diameters are dependent on containment bag diameters but should be slightly larger than the bag. Transfer ring widths are subject to the designer's needs. It was found, however, that a minimum of 3/4 inch greater than the width of the cinch-strap is required for attaching a containment bag to the transfer ring.

The most convenient method for providing containment support was found to be support at the transfer ring. Because the transfer rings are rigid, support was provided by simply tying off the transfer ring with three or four lanyards at the handles on the transfer ring (Figure A2-2).

A2.2.4 - Cinch Straps

Nylon straps utilizing a split metal O-ring and hook-and-loop locking material were developed for LWBR disassembly. These straps were used to cinch containment bags around the top end of the CDM housing and around transfer rings.

The cinch straps were used in lieu of rubber O-rings or other stretchable straps because they provided a better lock of the containment to the standpipe or transfer ring during tool operation. Cinch straps were made wide or narrow, depending upon the application. Figure A2-2 illustrates the use of cinch straps in attaching containment bags to a transfer ring.

Cinch straps were developed to replace taping of containments in limited access areas. Further, the elimination of taping greatly reduced both the stay time in a radiation field and the material control problem associated with numerous pieces of tape.

A2.2.5 - Tent Slides

Several operations required raising and lowering the containment system by adjusting the transfer ring support ropes. In the checkout program, this was accomplished initially by untying, adjusting, and retying the support rope. Normally, the repositioning of the ring would require several adjustments of the rope. This operation was time-consuming and cumbersome when performed while wearing rubber gloves. The incorporation of a simple tent slide, which was used the same way as when installed on a tent guy rope, permitted fast adjustment of the transfer ring elevation over the full length of the rope.

A2.2.6 - Containment Bag Changeover

It was necessary to change out containment bags over the CDM and BIF housings because more than one item was removed from each of these ports. Three methods of bag changeout were considered.

The first method provided total containment throughout the changeout procedure. A new bag was placed over the remnant of the old bag, and was attached to the transfer ring prior to removing the remnant from the ring. Completing removal of the remnant was then accomplished through glove ports in the new bag. This method was used for attaching a new containment to the bottom of a tool which had a permanent containment bag attached at the top and a transfer ring to which was connected a remnant of a previously used containment. Use of this method was not possible with CDM disassembly operations because the required type of transfer ring would have interfered with subsequent defueling operations.

The second method considered went to the opposite extreme, permitting temporary operation with no containment. The old containment remnant would simply be removed from the transfer ring, and a new containment bag quickly attached in its place. This method was considered viable as long as an air suction device and high-efficiency particulate air (HEPA) filter system were also used to provide a positive air flow. This method was rejected for radiological control considerations.

The method used for containment changeover at the CDM housing was as shown in Figure A2-3. A thin circular plug was used to hold the containment bag remnant and provide a barrier over the CDM or BIF housing. This concept was a compromise between 100 percent total containment and momentary opening of the CDM or BIF housing. The top surface of the plug was prepared with double-backed tape prior to use. Thus, when the containment remnant was loosened and removed from the housing, it was held (stuck) to the plug. The new containment bag was then attached to the housing, and the plug and containment remnant were bagged out through the new containment. In this fashion, only the top part of the housing and containment remnant were momentarily exposed. The potential spread of contamination was limited and controlled.

A2.2.7 - Tie-Offs

The design and application of tie-offs are shown in Figures A2-1 and A2-2. Tie-offs are a standard item on most containment bags. However, LWBR Defueling adapted tie-offs to be used as belt-loops for cinch-straps.

Tie-offs were made of PVC of greater thickness than the containment they were attached to (e.g., containment bags of 0.008-inch thickness had tie-offs made from 0.012-inch thick PVC). In addition, tie-offs were heat-sealed (rather than cemented) because heat-sealing provides a stronger joint.

Tie-offs attached to transfer rings (Figure A2-2) provided greater strength and rigidity than those attached to containment bags and were able to support greater weight with fewer tie-off locations.

A2.2.8 - High-Efficiency Particulate Air Filters

The standard application for HEPA filters was as shown in Figure A2-1. A correctly sized filter was provided for the containment bag if the bag was bunched up or extended as the encased tool or equipment was operated. A containment bag that collapses onto the tool or equipment or expands balloon-like due to inadequate HEPA filter air flow is both awkward and radiologically undesirable.

Filters were added to a containment bag as shown in Figure A2-1 or mounted on a transfer ring as shown in Figure A2-2. This latter option was desirable where collapsing or bunching the containment bag closed off the air passage to the HEPA filter.

A2.2.9 - Zippers

Fold-lock-type zippers (such as found on food freezer bags, but with a pull closure) were incorporated into several LWBR containment bags. Their use permitted easier insertion of certain tools into the bags with subsequent sealing of the bag around the tool. The fold-lock-type zipper did not produce a strong joint, and taping was required to ensure closure during operations.

A2.2.10 - Additional Considerations

1. Wherever possible, use of captivation lanyards on tools inside containments should be avoided. Attempting to use tools which are lanyarded in containment is awkward and time-consuming. A possible alternative to lanyards is to plug the hole the containment is over before using any tools in the area. Another alternative is to design tooling or modify existing tooling such that its size prevents entrance into the opening of concern.

2. Provide adequate visibility by using clear, polished PVC in the containment construction. Recognize, however, that clear polished PVC is stiffer than frosted PVC. Thus, the containment bag designer must reach an acceptable median between adequate visibility into the bag and proper flexibility of the containment.

3. Containment attachment facilities should be included into the equipment design from the beginning. Three of the LWBR defueling tools incorporated rotating transfer rings such that containment bags were easily attached or removed and the tool was operated within the containment. The defueling equipment containing this feature was simpler to operate inside containment, and the containment design was also simplified.

A2.3 - CONTAINMENTS USED FOR LWBR DEFUELING

The containments used for LWBR defueling operations listed in Table A2-1 will be discussed in this section with emphasis on the design considerations just presented.

A2.3.1 - Vent Valve Plug Cutting

The containment bag for this operation is shown in Figure A2-4. In addition to a sleeve which provided access for the cutting tool, the containment bag had inlet and exhaust sleeves for purging the bag to eliminate hydrogen. The purge and detector hoses were sealed to the purge bag sleeves with tape. Glove sleeves provided access for the operator to change the cutter tip without opening the bag. An access sleeve was also available as a port for a vacuum cleaner hose used to remove cutting chips. After completing cutting of the vent valve seal weld, the vent plug was removed and the top of the motor tube was covered with a small plastic bag to serve as a containment until a purge valve was installed (Figure A2-5).

A2.3.2 - Cutting Bypass Inlet Flow Pressure Tap to Differential Pressure Cell Piping

The containments (Figure A2-6) for cutting the BIF pressure tap instrumentation piping required special features because they had to fit around a continuous run of pipe. These bags were fabricated with a full-length zipper that was closed after the bag was wrapped around the pipe. Because there was contaminated water within the pipe that could flow out after cutting the pipe, the ends of the bags were sealed to the pipes inside the containment to ensure a waterproof seal. In spite of its small size, each bag had two sets of glove ports, one for the operator doing the cutting and one for an assistant. Also, there were two transfer sleeves, one to contain the hacksaw and other materials needed to cut and seal the pipe, and the other to bag out wet cloths and other scrap.

After sealing the cut pipe and cleaning up cutting chips and water, the bag was removed and scrapped.

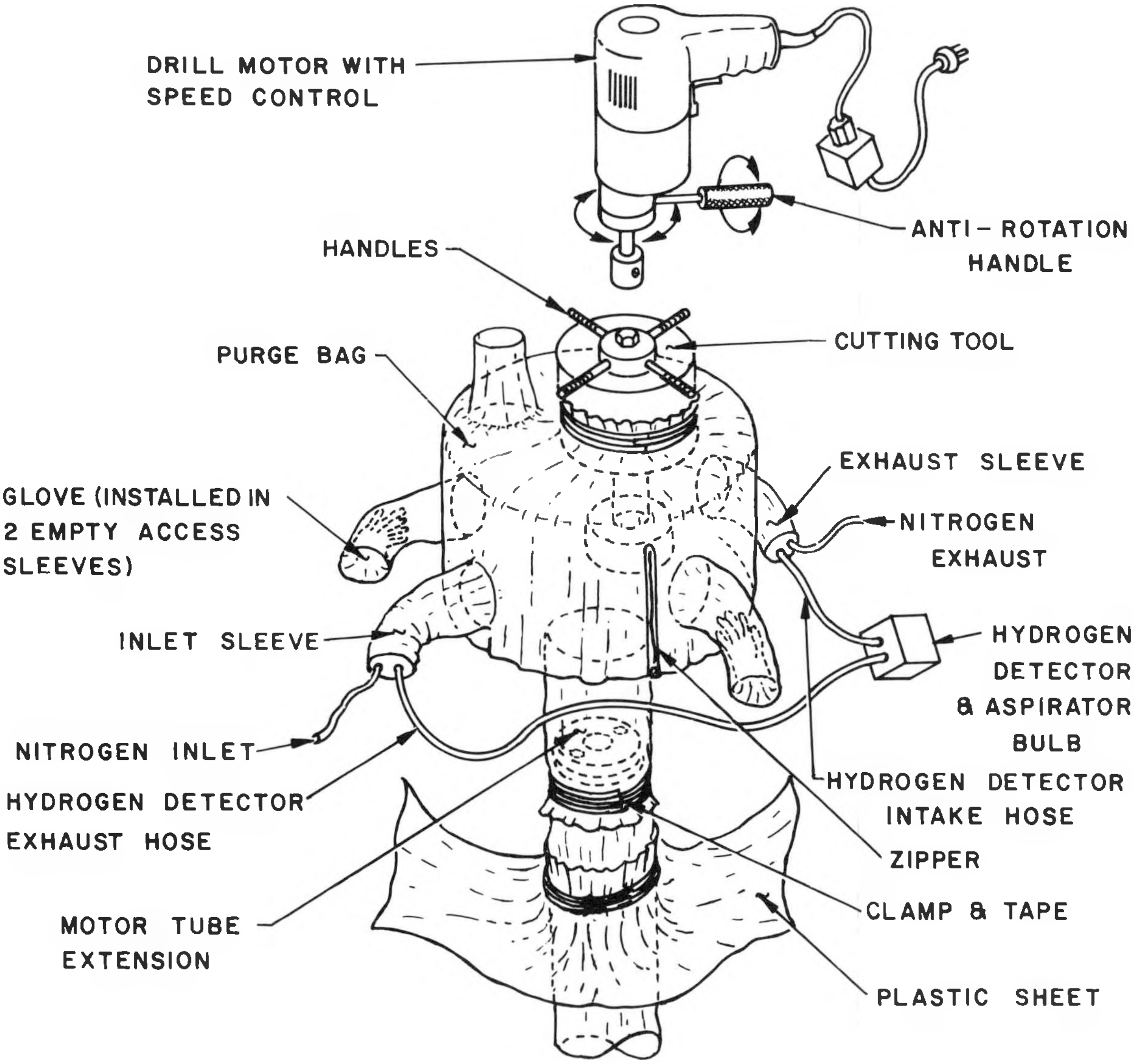


Figure A2-4. Containment for Motor Tube Vent Valve Plug Weld Cutting

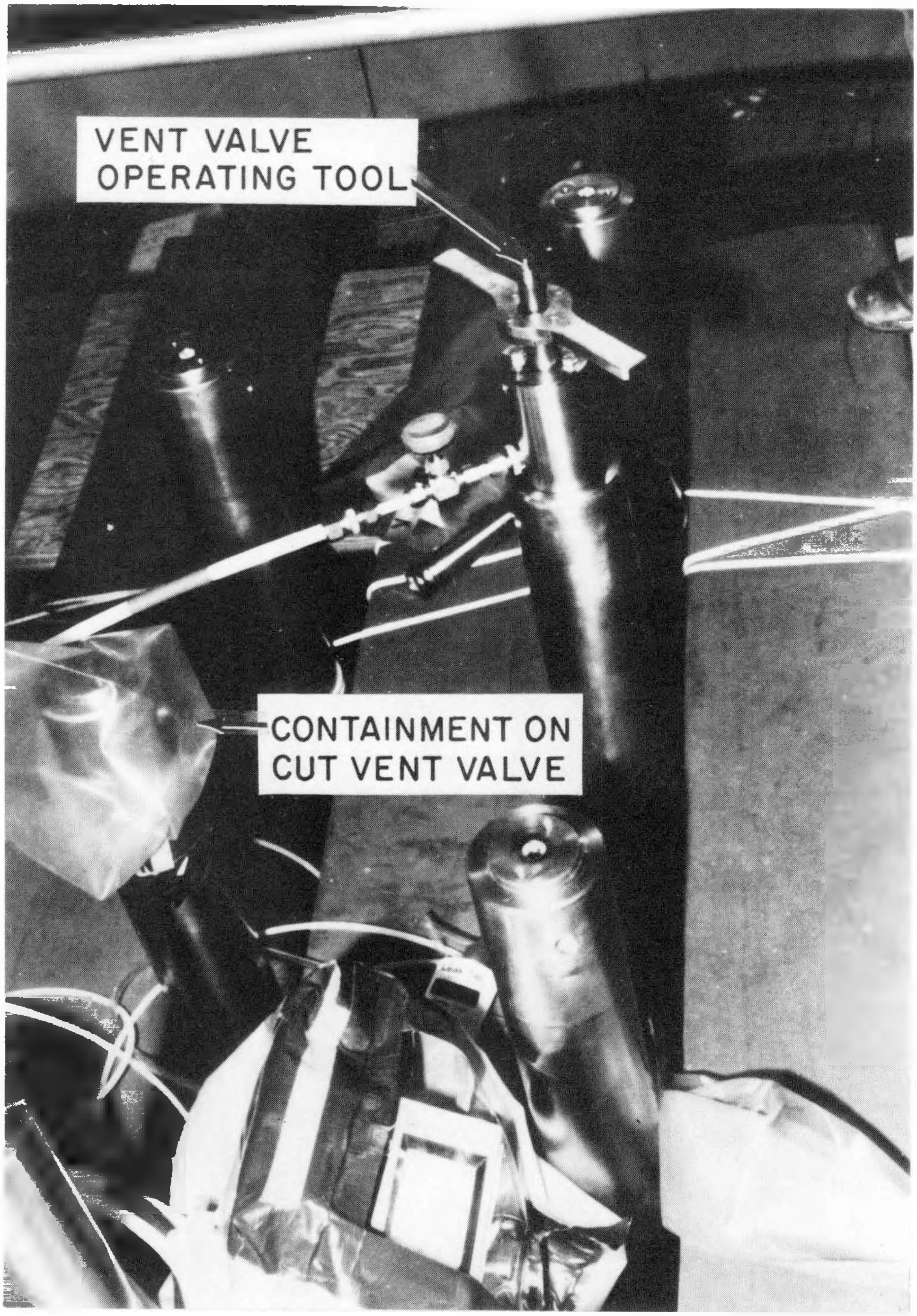


Figure A2-5. Motor Tube Vent Valves Opened for Attachment of Nitrogen Purge System

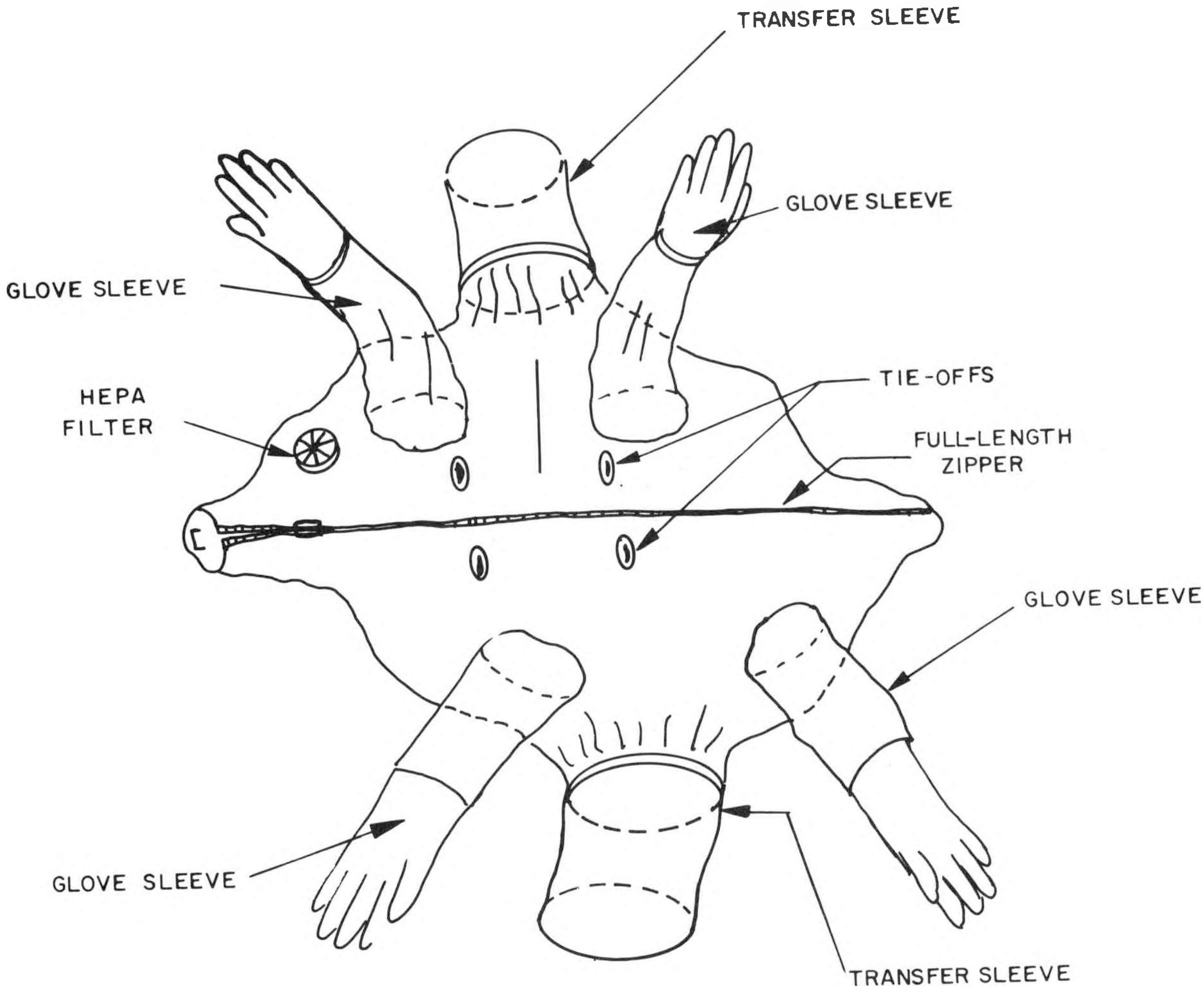


Figure A2-6. Containment for BIF Differential Pressure Cell Housing

A2.3.3 - Removal of Thermocouples, Flux Thimbles, and Pressure Taps

Containment bags for instrumentation removal (Figures A2-7 and A2-8) were fabricated simply from plastic sleeving with a HEPA filter attached. The top end of each containment was fastened with hose clamps and tape near the bottom end of the pull rope, but enough rope was allowed to extend through the bag (which was bunched up) to provide access to attach the rope to the instrumentation. The bottom end of the bag was attached to an adapter which facilitated attachment to bosses on the CDM housing or to the BIF housing. Removal consisted simply of manually pulling the previously loosened item(s) into the containment, sealing and cutting the containment, and transporting the items to disposal.

Because of the high level of radiation on flux thimbles (Section 3.8), the flux thimble and containment were pulled into a large shielding container. A weight was attached to the bottom of the containment after cutting and sealing, and the contained flux thimble was discharged into a water storage area to await disposal in a shielded container.

A2.3.4 - Bypass Inlet Flow System Disassembly

Three BIF system components were removed from each of the six BIF housings. The first component was the closure plug at the top of the housing. The containment bag for this operation is shown in Figure A2-9. The bag was fastened to the tool at a built-in attachment ring, which permitted the tool to be rotated while maintaining a leak-free seal. The bottom of this bag was taped to the top of the BIF housing. Transfer sleeves were provided so that supplies needed to aid plug removal (penetrating fluid, hammer, and cleaning equipment) and to protect the opening after plug removal were all readily available within the bag.

The second component was the tension/compression tube assembly that provided restraint for the main component, the BIF supply tube assembly. Because the disassembly and removal tool entered the primary system, it was necessary to provide continuous containment for the tool after removing the component. This was accomplished by using a two-part containment separated by a transfer

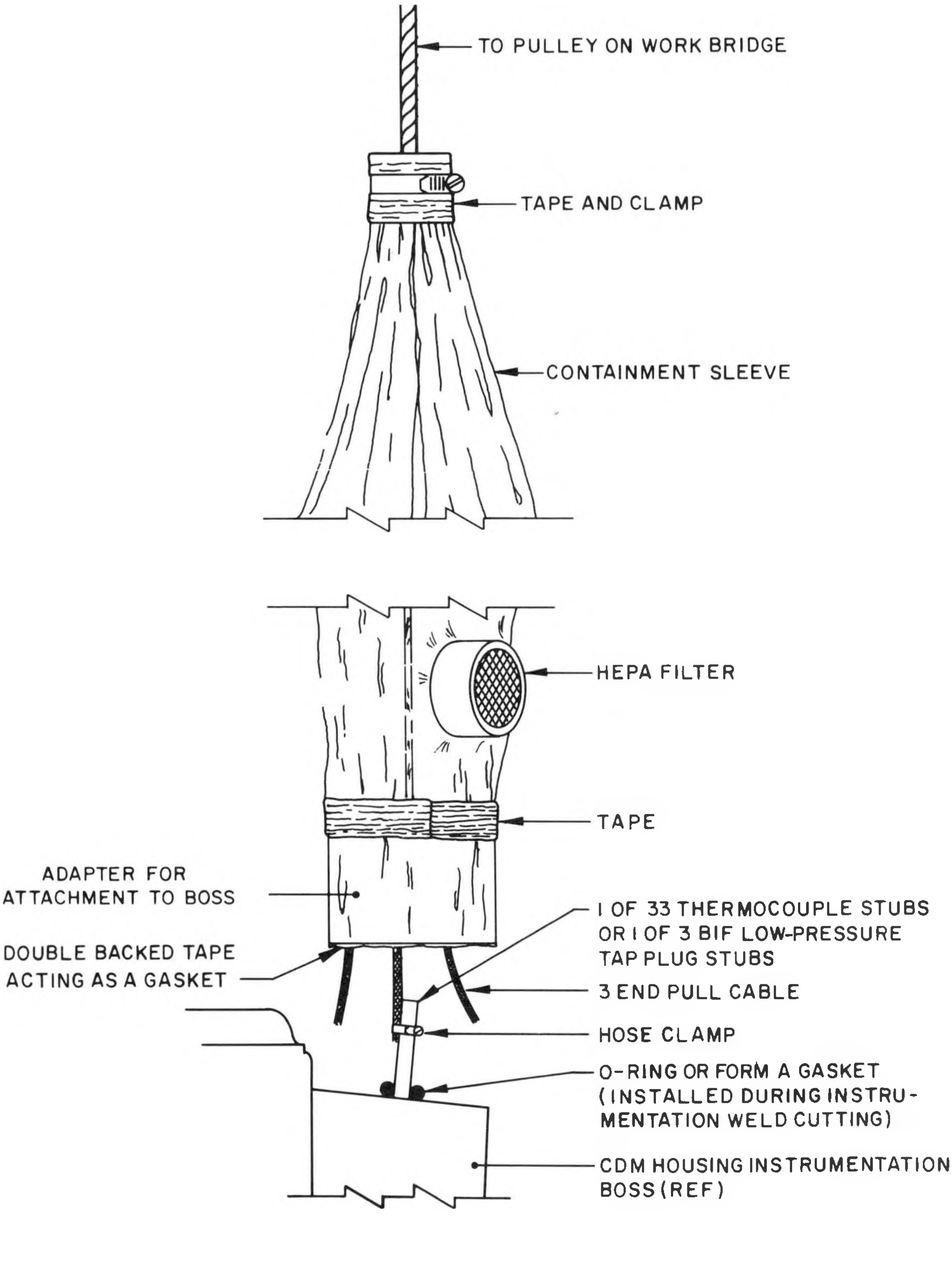


Figure A2-7. Containment Sleeve for Thermocouple and BIF Low-Pressure Tap Removal

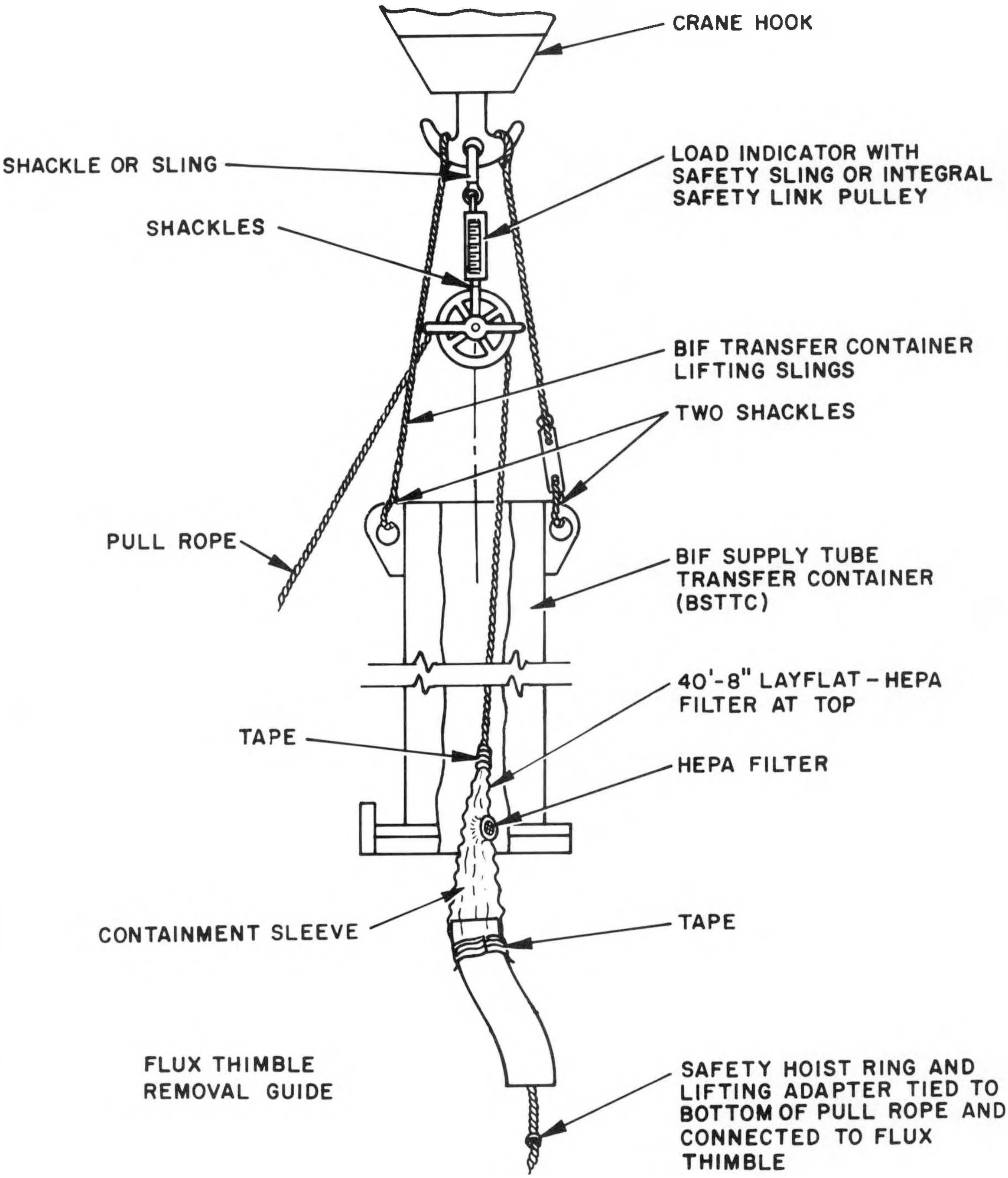


Figure A2-8. Containment Sleeve for Flux Thimble Removal

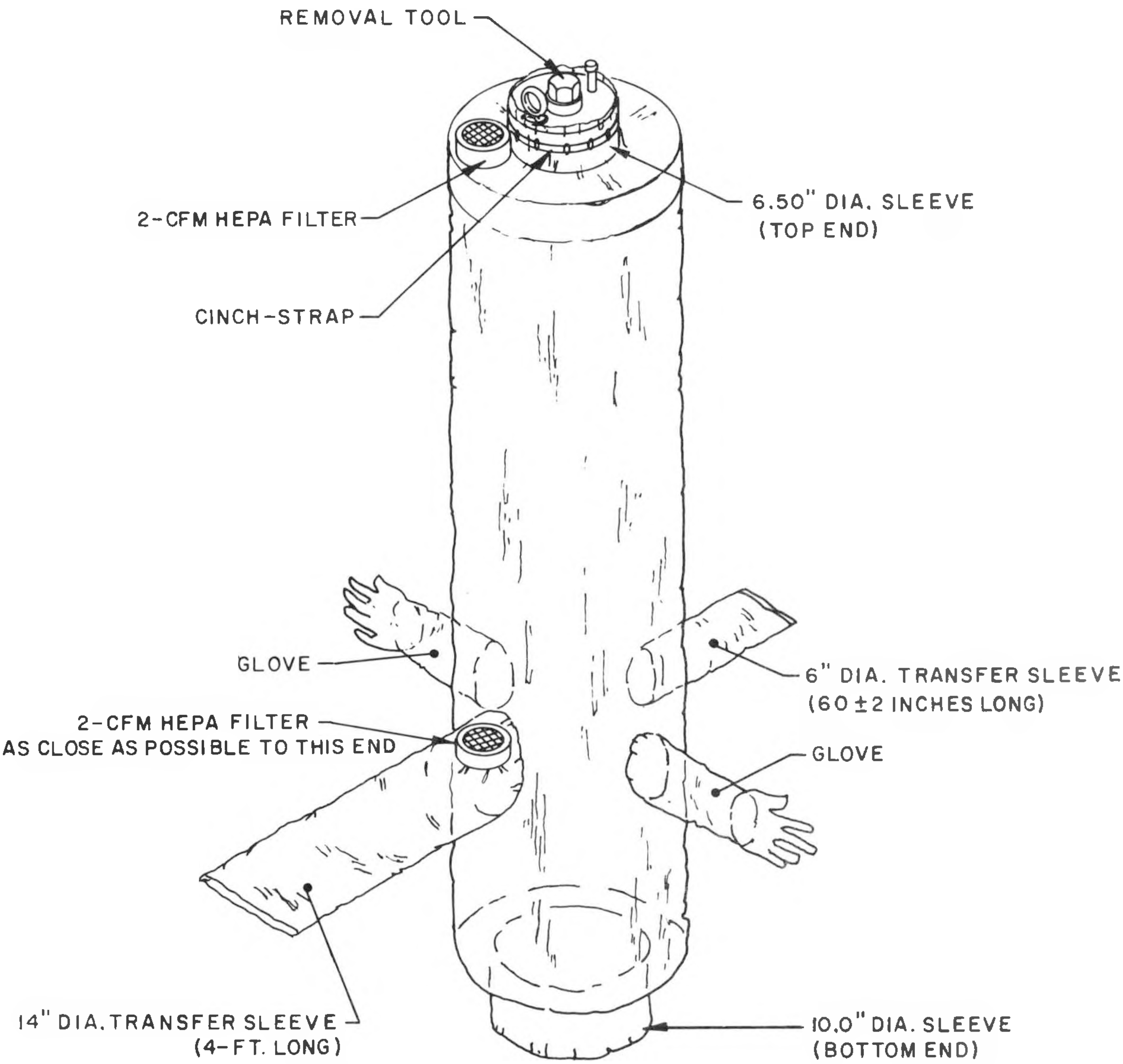


Figure A2-9. Containment for BIF Housing Plug Removal ring (Figure A2-10). The upper bag and transfer ring remained with the tool during removal of all six tension/compression tubes. The lower bag was fastened to the BIF housing, replacing the remnant of the previous bag. The tube assembly was removed from the reactor using the dual-purpose disassembly and removal tool, pulled up into the lower bag, and transported to its disposal location. A portion of the lower bag was used as a wrapper for the tube assembly, after which a new lower bag was provided for subsequent tube removal. Adequate transfer and glove sleeves were provided to facilitate these operations.

The third component removed was the supply tube assembly. Because of high radiation levels on these assemblies, it was necessary to pull them into a large, shielded container to transfer them from the reactor to their water storage location. For this operation, a three-part containment assembly was used. The lower part (Figure A2-11) was first sealed to the removal tool, which was inserted into the BIF housing and latched to the supply tube. The lower part of the bag was fastened to the top of the BIF housing, replacing the remnant of the previous bag. The middle part of the containment was a heavy, wire-reinforced rubber hose which lined the through-port of the shielded transfer container (Figure 21). Metal tubes at the top and bottom of the hose provided both support for the hose within the shield and connection points for the upper and lower parts of the containment. The upper part was a simple plastic sleeve with attached HEPA filter. The bottom of this sleeve was attached to the top of the hose, and the sleeve was fed through the hose and shield; here, the top of the sleeve was sealed onto the removal tool at a collar designed into the tool for this purpose. The lower bag was then attached to the bottom of the hose, and the seal between the lower bag and removal tool was broken. This permitted the supply tube to be drawn up into the shielded container in total containment.

After the supply tube was secured in the transfer container, the lower bag was cut and sealed, and the tube was transported to its storage location to await disposal. The tube was stored wrapped in the three-piece containment. To discharge the supply tube and containment from the shielded container, it was necessary to remove the hose clamp from the top of the hose

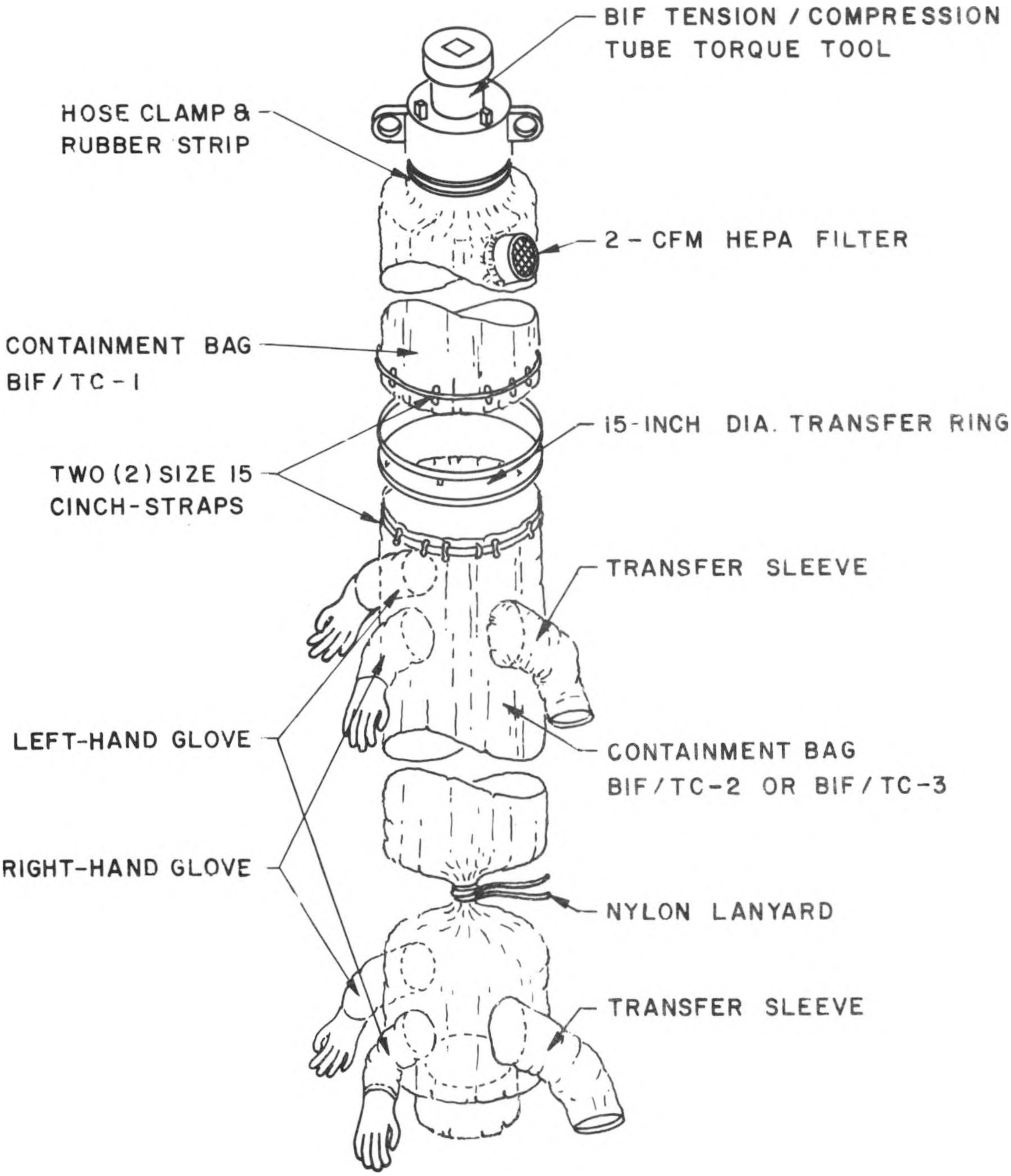


Figure A2-10. Two-Part Containment for BIF Tension/ Compression Tube Removal

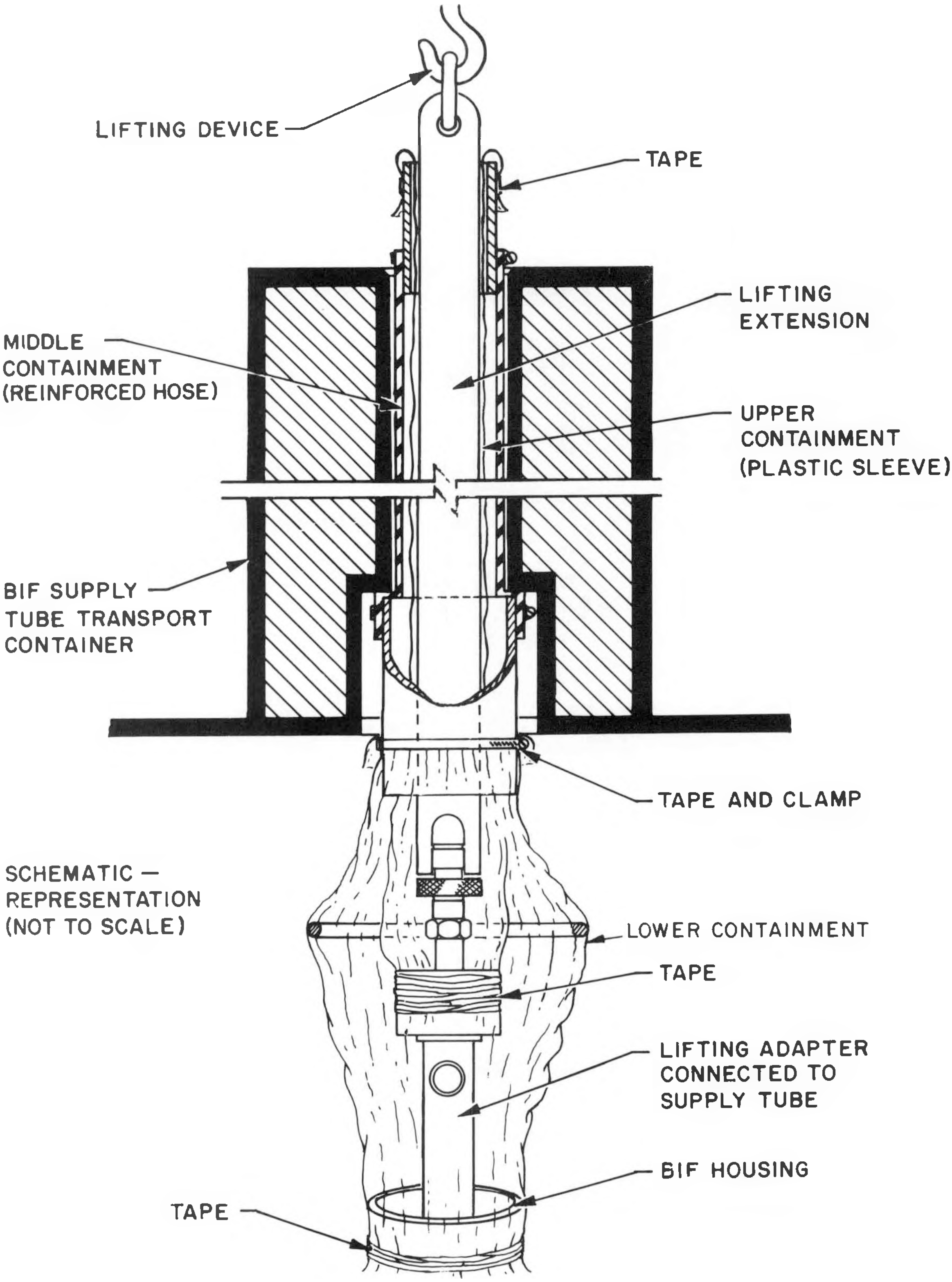


Figure A2-11. Three-Part Containment for BIF Supply Tube Removal which secured it to the upper containment extension and supported it within the container. To provide attachment of the hose to the extension, a heavy layer of tape was wrapped over the joint. When in the storage rack, this joint was under water. The first two supply tubes stored in this manner manifested a problem with this type of attachment; the tape was not waterproof and soon separated from the joint, permitting the heavy rubber hose and bottom containment to sink to the bottom of the canal, exposing the supply tube. Waterproof tape was used on the remaining four containment assemblies and on all other containments exposed to a water environment.

A2.3.5 - Removal of Module Support Components and Module Lowering

Before removing the LWBR closure head, the module translating equipment and compression sleeves had to be removed and the fuel modules had to be disconnected from the breechlock sleeves and lowered to seat on the bottom plate of the core barrel assembly. Three major assemblies were removed from each of the 12 CDM ports; the motor tube assembly, the translating assembly, and the compression sleeve. To disconnect the fuel assemblies from the head, it was necessary first to remove a tensile load from the breechlock sleeve (the tube which supported the fuel module against the head). Finally, the fuel module was disconnected from the breechlock sleeve and lowered. All of these operations were done in containment with provisions made for wrapping items removed from the reactor and controlling spread of radiological contamination by keeping tools that were inserted into the primary system covered through all removal cycles.

A2.3.5.1 - Motor Tube and Translating Assembly

The first component removed was the motor tube. It was not necessary to cover the motor tube removal tool because the tool never crossed the primary system boundary, and containment could be accomplished by sealing the containment to the motor tube itself. A two-part containment was used, with the two sections connected by a transfer ring (Figure A2-12). Before installing the containment on the motor tube, a semipermanent attachment ring was attached to the top of the CDM housing to be used for attaching all successive bags. The top of the bag system was loosely connected to the motor tube so that the

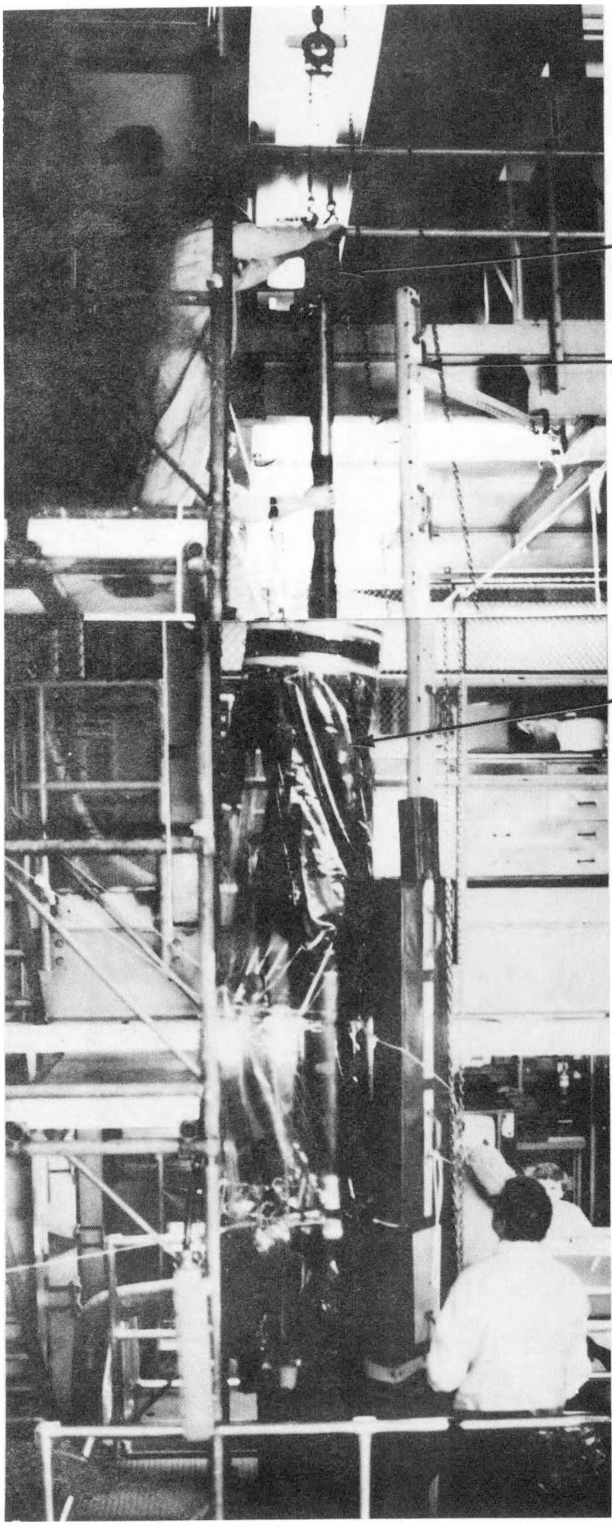


Figure A2-12. Containment Assembly for Motor Tube Removal
(Shown During Checkout with Mock-ups)

motor tube could turn without twisting the bag. The top part of the assembly was used to wrap up the motor tube after removal. The lower part of the assembly was needed because, after removal of the motor tube, the translating assembly extended several feet above the top of the CDM housing and had to remain enclosed. Thus, the lower bag was fully extended and supported by the transfer ring, which had tie-off handles around its circumference. Wire stiffening rings were also added to the lower bag for support and to prevent damage to the bag as the motor tube was withdrawn.

Motor tube removal was relatively straightforward. The motor tube was simply unthreaded and raised. It was wrapped in the upper containment, which was sealed and cut above the transfer ring. A second wrapper, a long bag, was added to the covering to ensure that no water remaining within the bag or motor tube could leak out; then the motor tube was placed in dry storage for later disposal.

In contrast with the relative simplicity of containment manipulation required for motor tube removal, operations to remove the translating assembly were encumbered with up to six containments installed at one time. A total of 10 different containments were used for removing each translating assembly, ranging from a small plastic bag to the elaborate assembly shown in Figure A2-13. Some of these bags are shown in Figure A2-14. The first containment installed on the translating assembly was a long sleeve (sleeve A, with sleeve C attached), closed at one end and weighted at the other, which was installed through a transfer sleeve in the remnant of the previous bag installed above the transfer ring. This sleeve fitted snugly around the translating assembly lead-screw and protected the removal tool/shield from radiological contamination.

It was necessary to unthread the tie rod nut which connected the translating assembly to the seed module balance piston (Figure 17) to remove the translating assembly. The tool to accomplish this is shown in Figure A2-13, with the required containments attached. The upper bag was connected to the tool by means of a rotating attachment ring built into the tool. A transfer ring was used to connect the middle bag. The purposes of these bags are

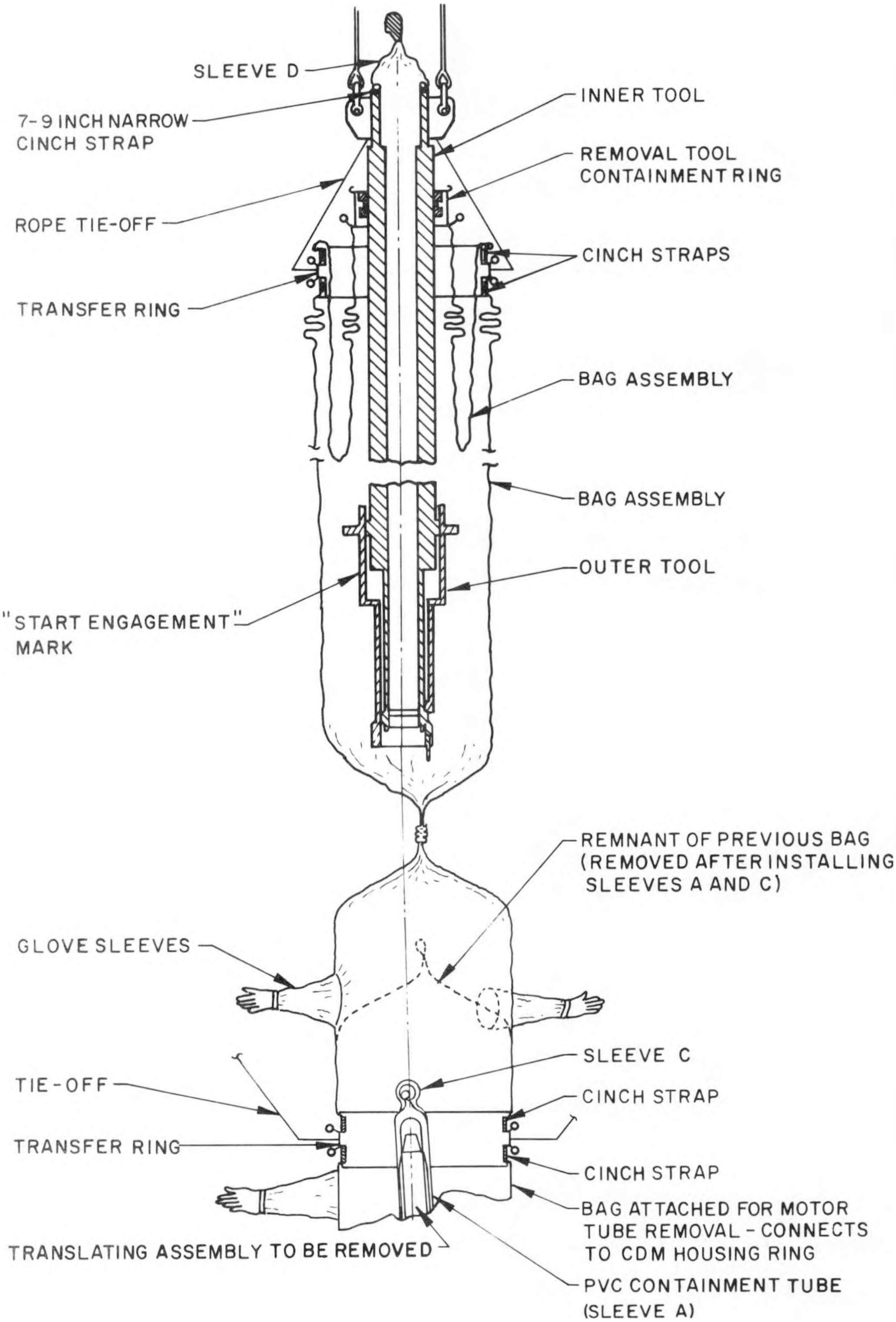


Figure A2-13. Three-Part Containment for Translating Assembly Removal Showing Three Auxiliary Sleeves

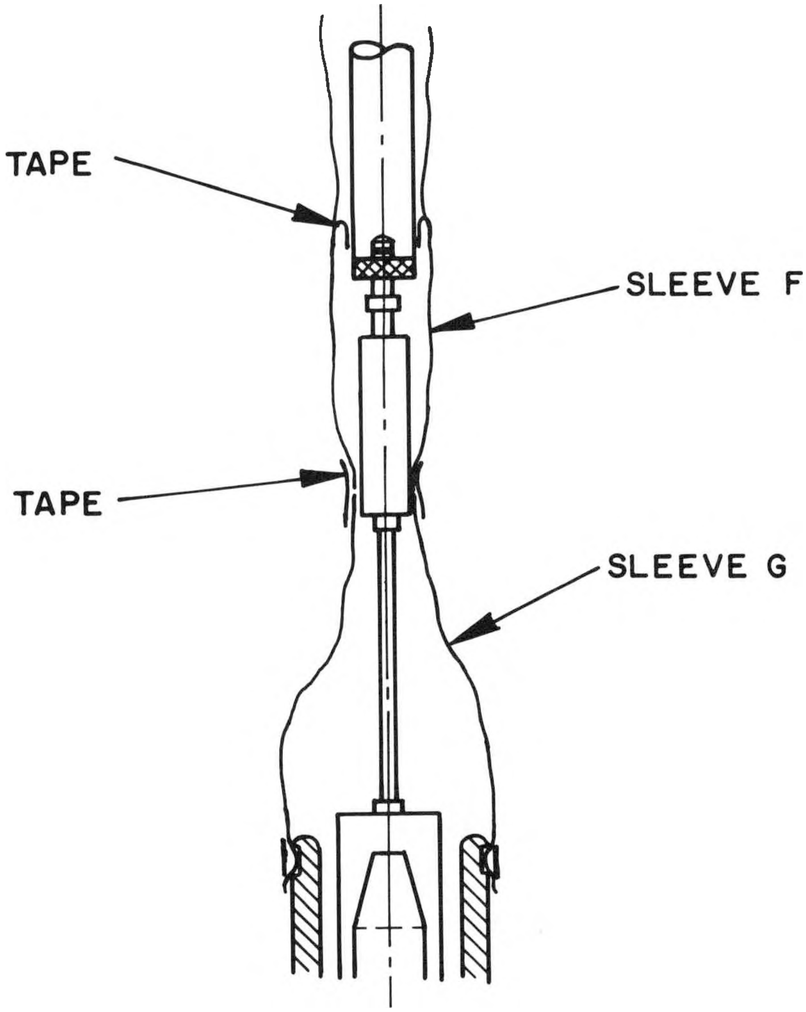


Figure A2-14. Auxiliary Sleeves F and G for Translating Assembly Removal similar to those for other two-part containments described previously (i.e., the upper bag stayed with the tool through all translating assembly removal operations, whereas the middle bag was discharged with the component and was replaced for each cycle of translating assembly removal). The major difference in this evolution is that the middle bag was attached to a transfer ring at the top of the translating assembly, rather than to the CDM housing permanent ring. This produced an array of three long containment bags to work with at one time. It was not feasible to try to attach the upper bag (protecting the tool) to a longer version of the lower bag because of the sealing requirements to contain the removal tool after discharging the translating assembly in its storage location.

During installation of the removal tool onto the translating assembly, two additional small containments were used. These are sleeves C and D in Figure A2-13. The top of the removal tool was open to provide access to the top of the translating assembly for attaching the lifting tool. Sleeve C protected the top of sleeve A as the tool was lowered, considering the possibility of surface contamination on the inner bore of the tool. Sleeve D closed off the direct path from the primary system to the air, thus providing maximum containment of the system. After the tie rod nut was unthreaded, sleeves C and D were removed together to expose a clean surface for lifting adapter attachment. Sleeve E was immediately installed to limit the direct path from the primary system to air that was opened by removal of sleeve D. It was a temporary attachment, fastened only at one end and inserted into the open top of the tool. The lift adapter was then installed on the translating assembly, and another sleeve (sleeve G; Figure A2-14) provided the required containment prior to lifting the translating assembly out of the reactor.

At this time, the translating assembly was raised out of the reactor until all three major containment bags were fully extended. The middle bag was sealed and cut, providing containment for the tool and translating assembly. The translating assembly was then transported to its storage location. Unlike BIF supply tube storage, the translating assemblies were stored unwrapped under water. Over the storage location, the sealed containment was opened a few inches above the water and the translating assembly was lowered into the storage rack by adding extensions to the lift adapter. The final containment was a simple sleeve (sleeve F) used to wrap the extensions and protect them as they passed through the removal tool.

A2.3.5.2 - Compression Sleeve

As noted in Section 3.9, removal of the compression sleeve was done in two steps: removal of the compression bolts and locking ring, followed by removal of the compression sleeve. Each part of the operation required separate containments.

The containment for bolt removal is illustrated in Figure A2-1. It was a simple bag that was suspended over the CDM housing by lanyards and attached to the permanent transfer ring at the top of the CDM housing. All tools and equipment needed to remove the bolts and ring were installed in a transfer sleeve prior to installing the bag over the housing. A second transfer sleeve was available to receive the bolts and ring and other scrap. Glove ports were available for two operators to work together. The stiffener at the top of this bag was a solid plastic ring. After the bolts and ring were removed, the bag was cut and sealed below the sleeves to prepare for compression sleeve removal.

After removal of the compression bolts, removal of compression sleeves was straightforward. A two-part containment (Figure A2-15) was required. The top part was to stay with the tool for removal of all 12 compression sleeves, while the bottom part was changed out for each compression sleeve removed and wrapped. However, after removing a few compression sleeves, the zipper closure at the top of the upper bag began to tear. After several repair jobs failed to effect a permanent repair, it was necessary to replace the bag and add a stiffer support ring at the top of the new bag to relieve the strain on the zippers.

Glove sleeves on the upper bag were used to access a latch handle on the tool for grappling the compression sleeve. Transfer and glove sleeves on the upper part of the lower bag were used for bag change and removal of the remnant of the previous bag from the transfer ring. The glove and transfer

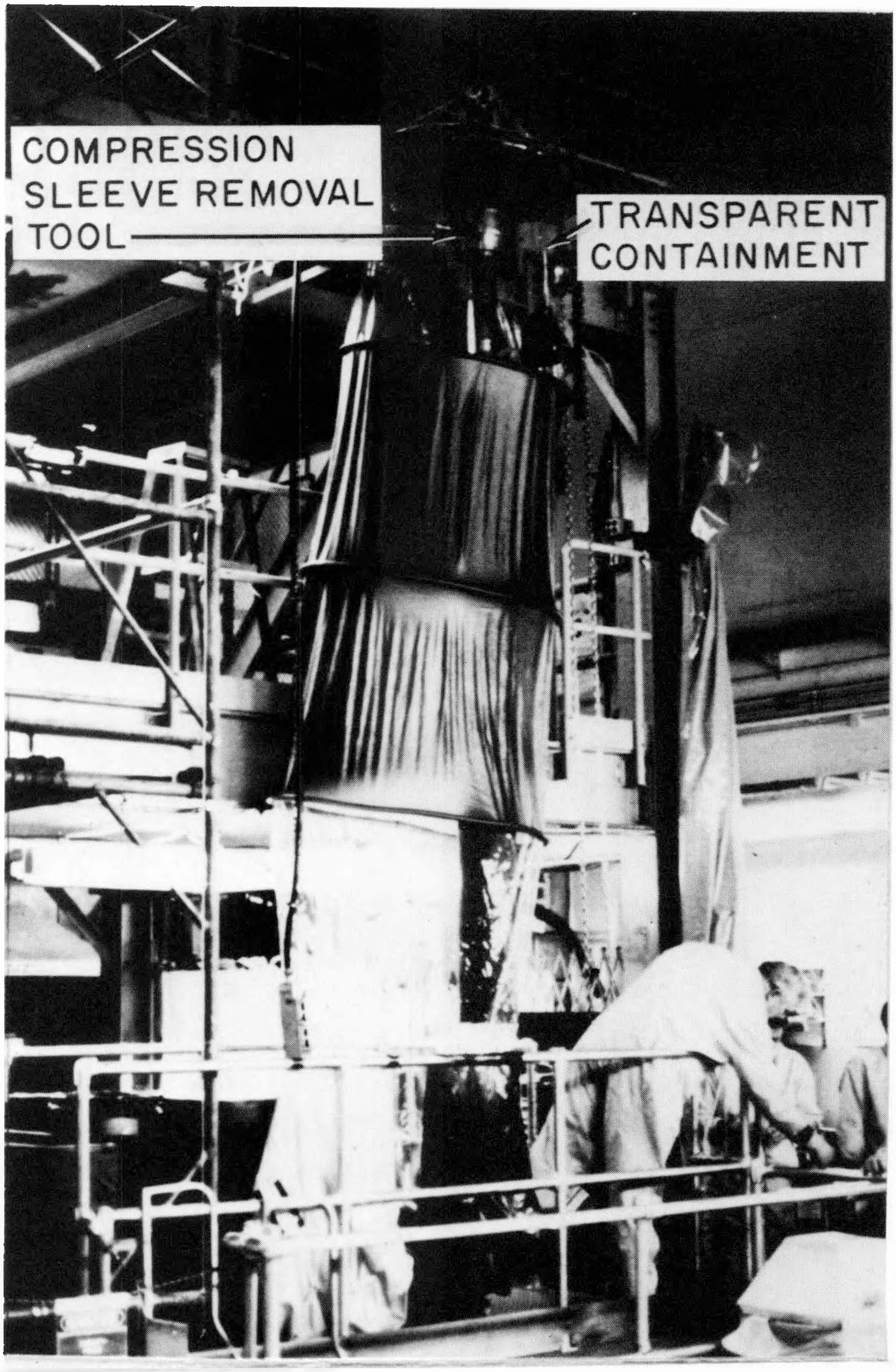


Figure A2-15. Containment Assembly for Compression Sleeve Removal (Shown During Checkout on Mock-ups) sleeves in the lower part of this bag were used to remove a spacer seated on top of the breechlock nut.

A2.3.5.3 - Blanket Module Disengagement from Support System

The next operation was to remove the preload from the breechlock sleeve (Section 3.10). For this operation, the tool was wrapped in a permanent containment (Figure A2-16), which had three glove sleeves to access the dial gages on the tool for adjustment. Two more bags were installed on the base of the tool (Figure A2-17). These bags provided containment for the tool which was used inside the primary system boundary. Both sets of glove and transfer sleeves in the lower bag were used only to access and change remnants on the transfer ring and CDM housing. No components were removed from the reactor during detensioning operations. The middle bag stayed with the tool for all 12 cycles, whereas a new lower bag was used at each CDM housing location.

The final evolution in head area disassembly was to lower the 12 fuel module assemblies and verify seating. As noted in the discussion of this evolution (Section 3.10), all 12 assemblies were cyclically and incrementally lowered, requiring the insertion of 12 tools. The containment for the tool was a simple bag. The top of the bag was attached to the tool at a built-in attachment ring. Glove sleeves were provided to access latching knobs on the breechlock nut tool and to place the spacers on the breechlock sleeves when they were raised above the CDM housing. The spacers were installed in a transfer sleeve prior to attaching the containment to the CDM housing. After completing module lowering, the bag was cut and sealed above and below the sleeves to seal the open port and to wrap the module support tool.

Figure A2-18 shows the containments used with the gage used to verify that all modules were seated. Again, a two-part bag was needed. The upper bag stayed with the tool, while the lower bag was changed for each measurement. Both sets of glove and transfer sleeves were used only to facilitate changing of the bag at the transfer ring and at the CDM housing.

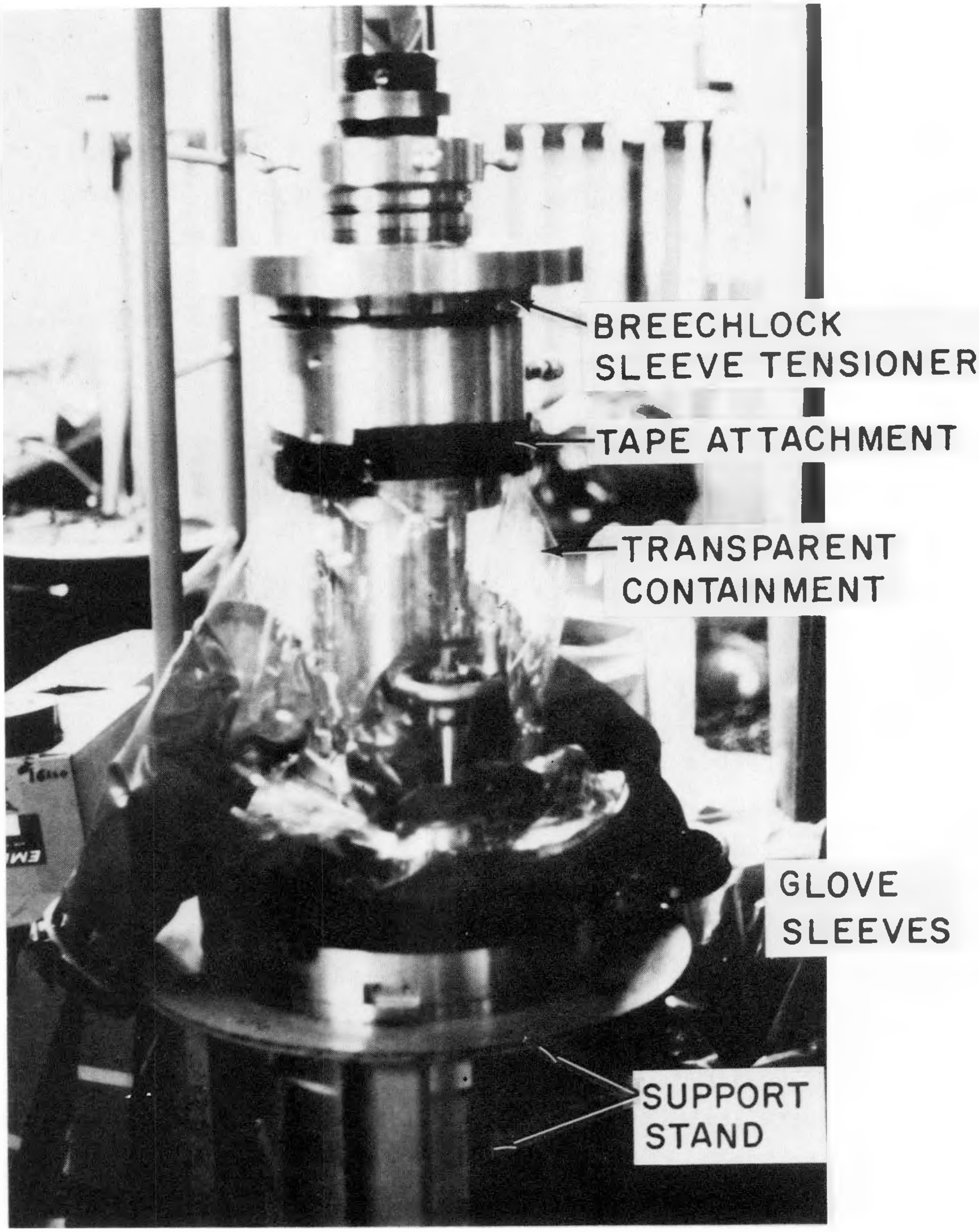


Figure A2-16. Breechlock Sleeve Tensioner in Top Part of Three-Part Containment

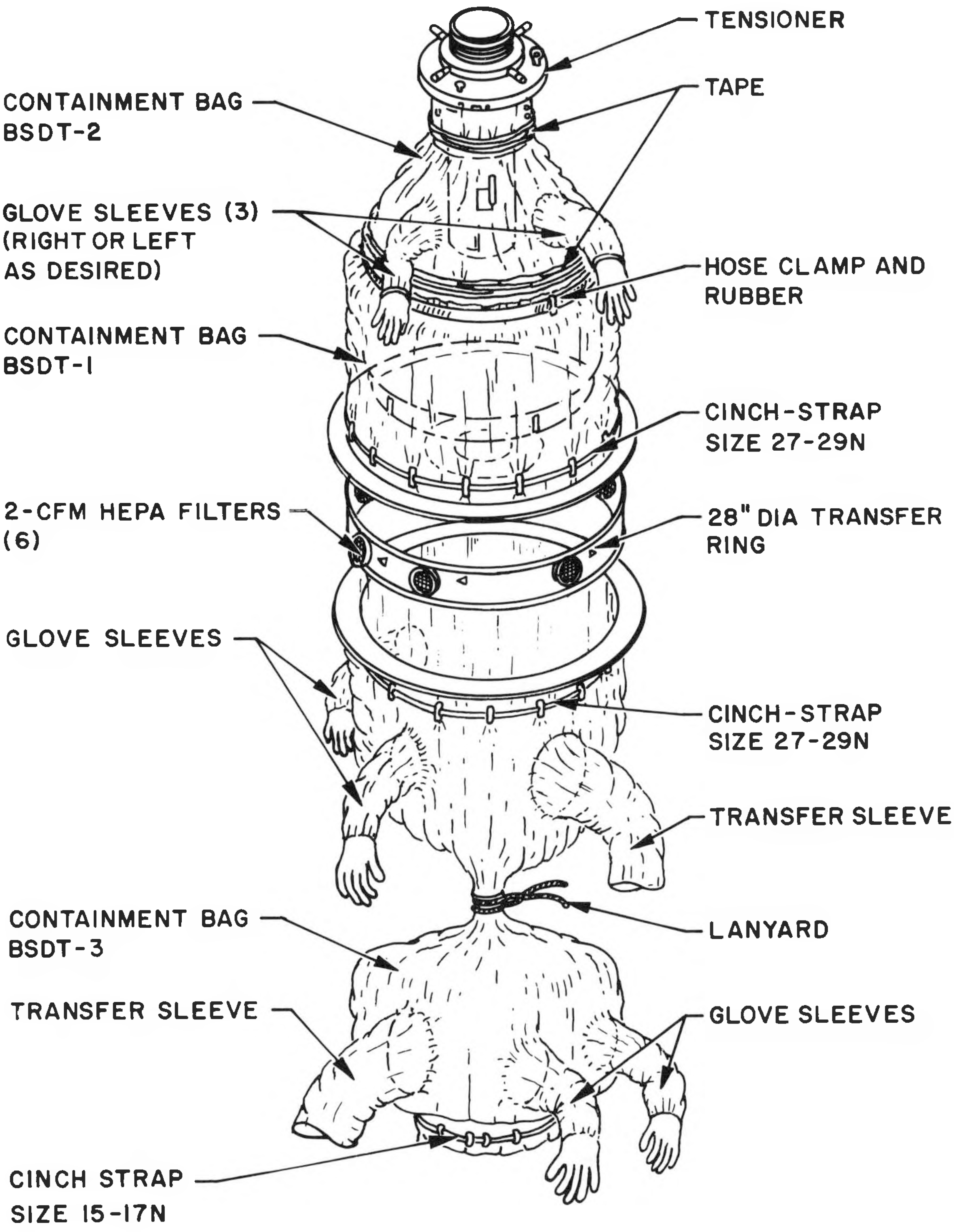


Figure A2-17. Containment Assembly for Breechlock Sleeve Detensioning

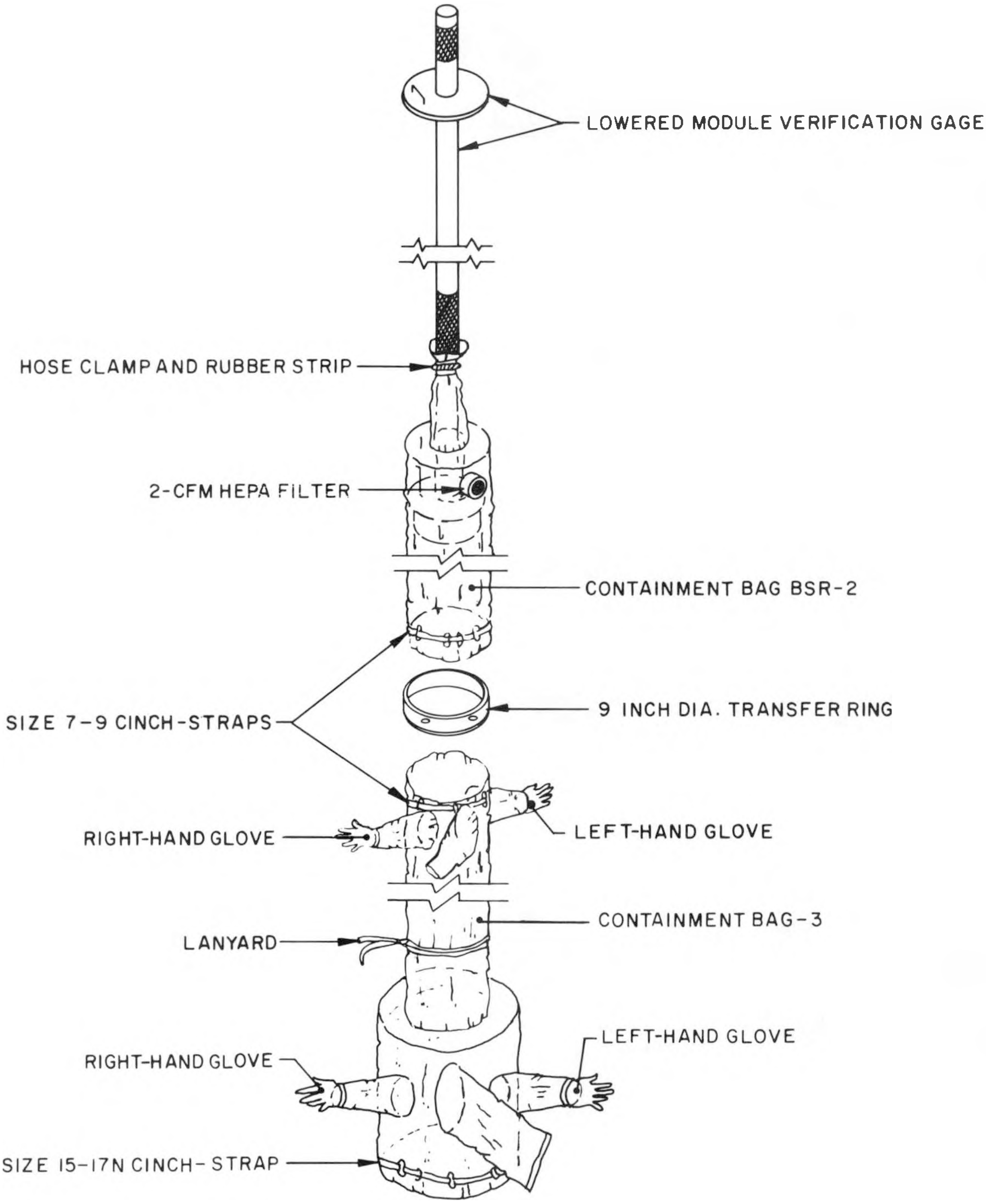


Figure A2-18. Containment for Module Height Verification Gage

A2.3.6 - Main Closure Head Removal

The containment used for closure head removal was a single, large bag 180 inches in diameter by 55.5 feet long (Figure A2-19). Fourteen 40 cubic foot per minute HEPA filters were installed on the bag to ensure ample air flow to prevent collapsing the bag. Two ropes banded the bag to provide a means of closing the bag for sealing and cutting after closure head removal. The extra length of the bag was required because of access restrictions for sealing and cutting. This operation had to be performed outside of the reactor pit, 25 feet above the lower attachment level at the core support flange.

The containment also featured 20 gloved sleeves and 20 transfer sleeves located around the circumference of the core support flange to provide access for decontaminating the flange.

A2.3.7 - Holddown Barrel Removal and Shipping

Operations to remove the holddown barrel from the reactor vessel (Section 3.13) included installing a shipping container in the reactor pit to receive the barrel then, after flooding the reactor pit with borated water, removing the barrel from the reactor vessel and installing it into the container, closing the container, removing it from the water, and shipping it to a disposal site. Regulations for this type of shipment require that the outer surface of the sealed container be radiologically clean. To provide a high degree of assurance that the container surface was clean and to reduce total time required to decontaminate the container, a special contamination barrier bag was designed for all shipping containers that were installed in and loaded under water, including the holddown barrel shipping container and M-130 fuel shipping containers (Reference 2). The bag had two layers. The inner bag was of heavy vinyl construction. All joints were heat-sealable, which provided a high degree of leak resistance. The outer bag was fabricated from nylon-reinforced PVC, which provided the strength required to maintain a slight positive pressure within the bag relative to the pressure outside of the bag. The seams of this bag, although heat-sealable, did not have the high degree of leak resistance of the inner bag and could not be used alone. There were vents at the top of the outer bag to remove air and water from between

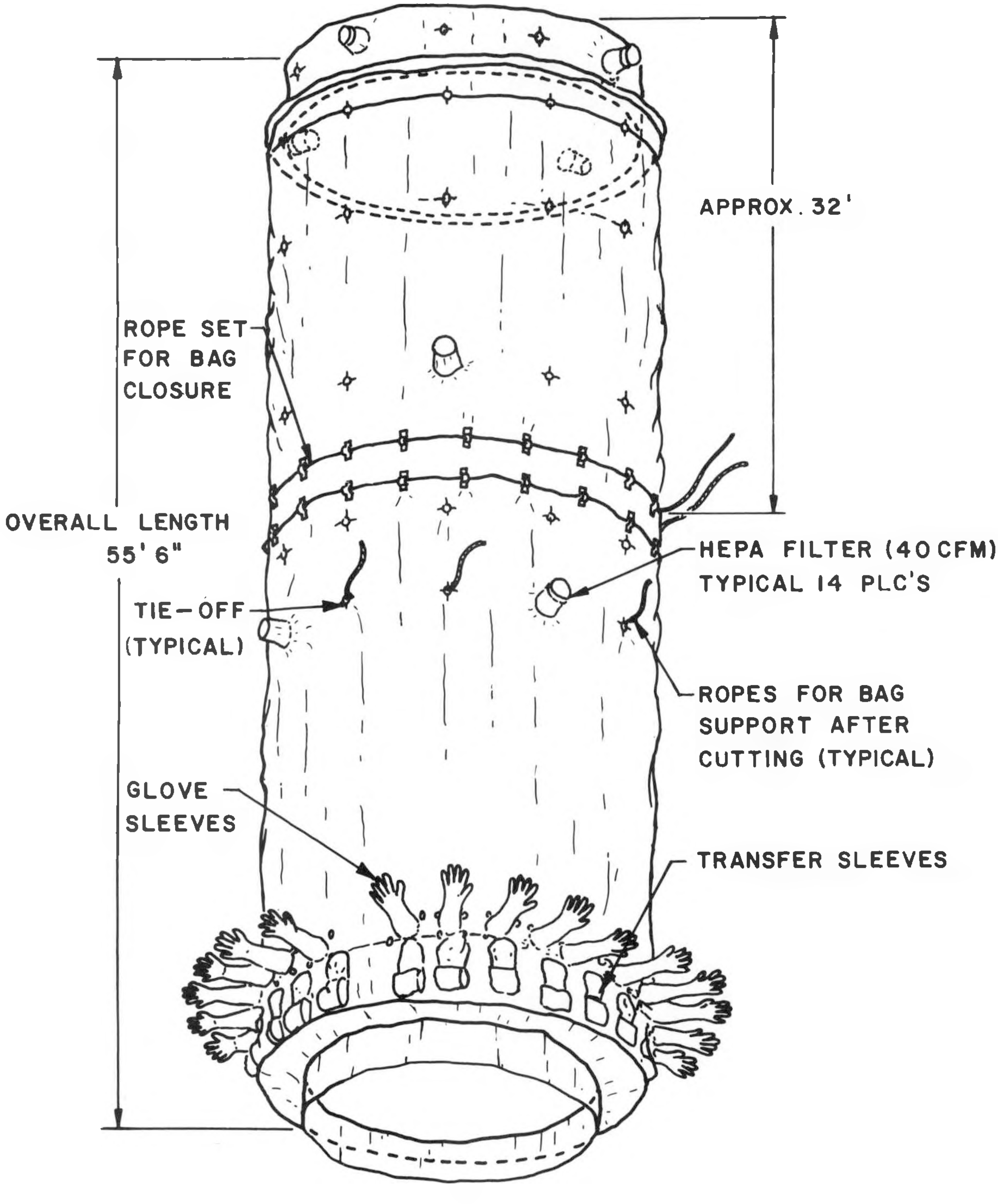


Figure A2-19. Containment for Closure Head Removal the two bags. Thus, the two-part bag had desirable qualities of strength and leak resistance in an easy-to-handle form.

The shipping container was inserted into the two-part bag, and the bag was sealed to the top of the cylindrical surface of the container with a rubber gasket and double steel bands.

The bagged container was placed in the reactor pit in a convenient location for loading the holddown barrel (Figure 36), then the reactor pit was flooded. As the pit was flooded, the space between the inner bag and shipping container was filled with clean, borated water through hose connections in the bag. Throughout the loading process and cover installation, a flow of clean water was maintained at a positive pressure of 1 to 2 inches of water. After loading was completed, the container and bag were lifted to the water surface where the bag was stripped away, leaving a clean surface on the container for shipping. The holddown barrel shipping container surfaces were smooth and relatively easy to decontaminate. The bag used for this operation saved a significant amount of time and decreased personnel radiation exposure. The anticontamination enclosure concept was essential for M-130 fuel shipping operations (Reference 2), inasmuch as the M-130 fuel shipping container surface was finned and contained a large number of crevices and hidden surfaces which be difficult to decontaminate.

A2.4 - CONCLUSIONS

The development of radiological containments for LWBR head area disassembly operations required an extensive, time-consuming program. The major problem encountered was development of the basic engineering requirements for containment (i.e., what degree of containment is required). Ideally, the perfect defueling system would permit accomplishing the defueling using relatively simple, reasonably priced equipment, in a minimum amount of time, while providing 100-percent total containment and limiting man-rem exposure to as low as reasonably achievable. Unfortunately, these four objectives can conflict. For example, the use of containment bags makes any operation more difficult and time consuming. To minimize problems, containment design must be checked out on a full scale mock-up utilizing actual access conditions.

Without the use of this type of a checkout program, it is unlikely that a complex, large-scale containment system would go directly from the drawing board to actual use without experiencing problems.

It became obvious early in this program (and it was further reinforced during the development of the program) that, if localized containment was necessary, the reactor servicing equipment should have provisions for containment. A requirement that the tooling with its containment system provide 100-percent total containment should have been included as a basic engineering design objective. When a tool was designed without provision for containment, the containment bags tended to be very complex and cumbersome. This was the situation for a number of LWBR defueling operations where LWBR installation tools that were not designed for use with containments were reused for defueling. Sometimes design modifications, such as adding a rotating ring or increasing the length of surface to which taping is required, could be all that is needed to improve the operation; however, it is better for the tool designer to incorporate containment into the tooling at the outset of the design.

The most important lessons learned during this program were:

1. A refueling or defueling system needs to be developed to fit the particular needs of the refueling or defueling program. Parameters such as component size, irradiation history, complexity of components, physical access, and radiation fields affect the final design.

2. The use of full scale mock-ups, including access mock-ups, is recommended for checkout of the design and training of personnel. Experience gained in the LWBR program shows that this is mandatory for both design and personnel checkout.

3. The provision for simple and effective radiological containment can and should be factored into the tooling design.

APPENDIX A3 - LWBR MODULE POSITIONING EQUIPMENT

A3.1 - MODULE REMOVAL INTERFERENCE EVALUATION

The LWBR module positioning system was developed to eliminate interference between Type IV reflector modules and upper core barrel features during reflector module removal and between modules during blanket and reflector module removal.

Evaluations of fuel performance during reactor operation predicted that interferences could occur at the end of life because of module bow. Bowing predictions indicated that interferences of 0.043 inch at the bypass inlet flow (BIF) bracket and 0.075 inch at the flow instrumentation riser cover could exist for the Type IV reflector module seal blocks as they passed through the upper barrel during removal (refer to Figure 38). The blanket module-to-module clearance and the blanket construction was such that, as one module was lifted, its grids could hang up on adjacent blanket module grids as they passed each other. Although the removal sequence permitted removal of a blanket module only after three adjacent modules had been removed (to minimize the potential for hangup), this measure by itself would not provide assurance that hangup could not occur. Therefore, it was necessary that equipment be available during defueling to relieve these interferences and to ensure that blanket and reflector modules could be removed from the core without damage.

A3.2 - DESCRIPTION OF THE MODULE POSITIONING EQUIPMENT

The LWBR module positioning system consisted of two separate systems which performed slightly different functions. The blanket spreader and reflector positioning tool (Figure A3-1) was designed for use during removal of the first pair of adjacent Type IV reflector modules (core locations IV-4 and IV-7), located near the BIF brackets. The blanket module spreader engaged the blanket modules adjacent to the Type IV reflector module to be removed and provided side forces of up to 1500 pounds to move the blanket modules away from the reflector modules to provide the maximum removal envelope. The reflector positioning feature provided the means of manipulating the reflector being removed so that it passed the close clearance features in the upper core barrel.

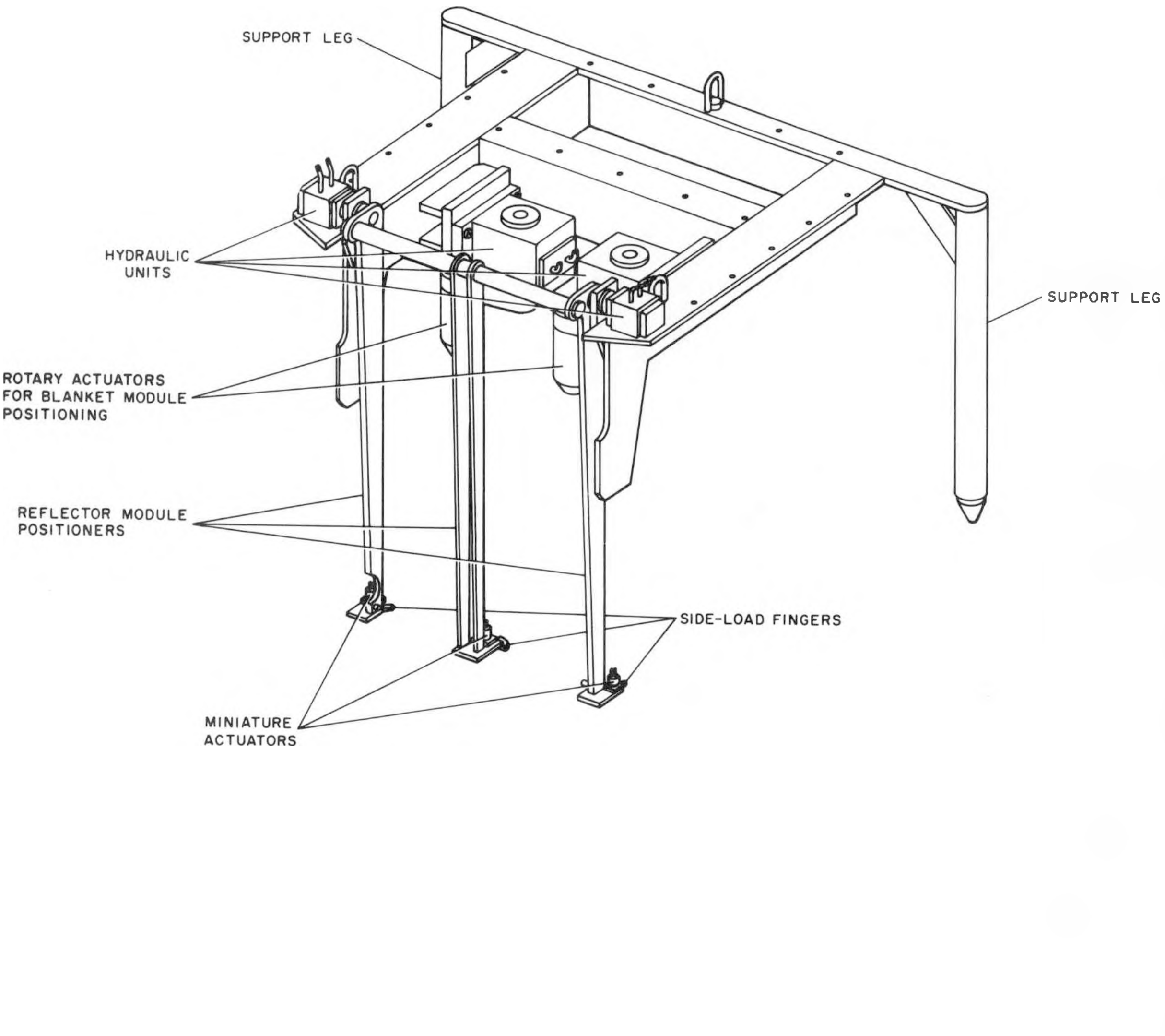


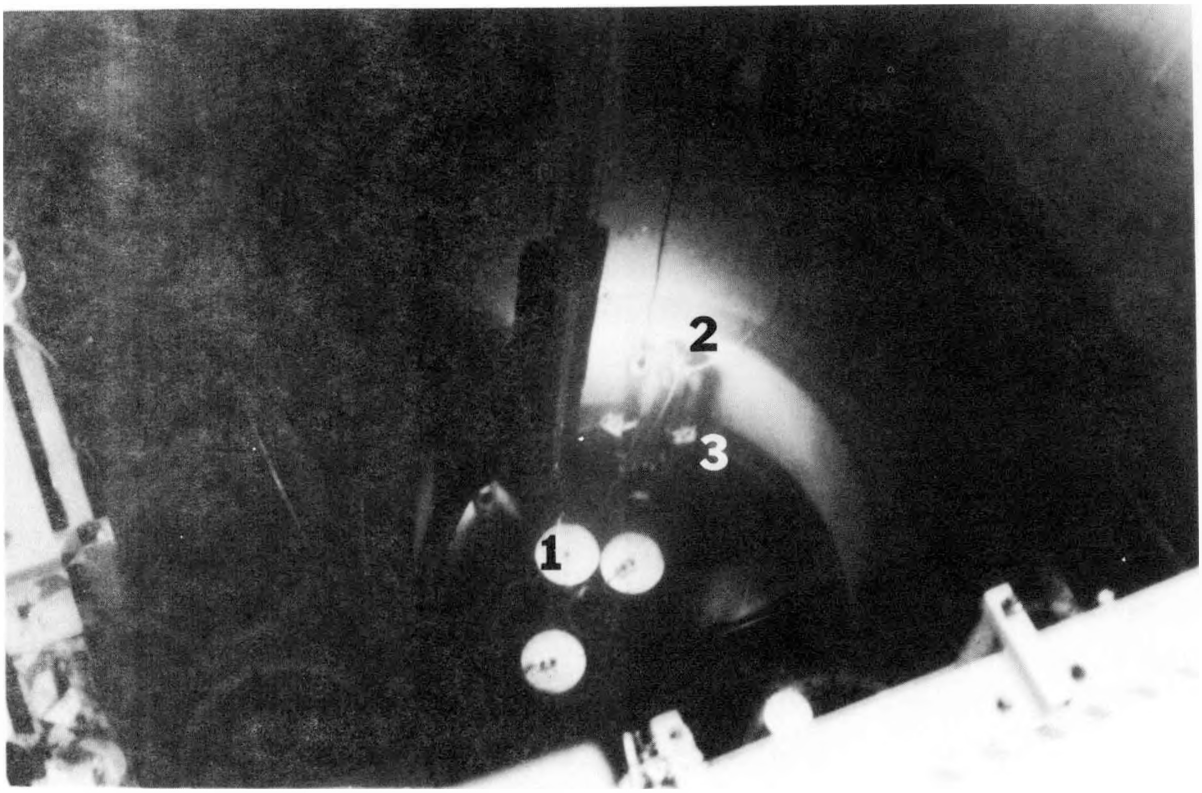
Figure A3-1. Blanket Spreader and Module Positioning Tool

The module positioning tool (Figure A3-2) consisted of two assemblies which engaged blanket modules and applied pulling loads to move them away from the reflector or blanket module being removed. This equipment was used to provide removal clearance for the second adjacent pair of Type IV reflector modules (core locations IV-6 and IV-9) and for the first four blanket modules removed.

A3.2.1 - Module Spreader and Reflector Positioning Tool Details

This tool (Figure A3-1) was a structural frame which supported two hydraulically operated rotary actuators. Crank arms mounted on the shaft of these actuators engaged the support tubes of the two blanket modules which were adjacent to the reflector module to be removed and applied a side force of up to 1500 pounds to the blanket modules. Referring to Figure 38, modules III-1 and II-1 were engaged for removal of reflector module IV-4, and modules II-1 and III-6 were engaged for removal of reflector module IV-7. Also mounted on the structure was a rotating support with legs which extended into the upper core barrel to permit applying 200-pound radial (inboard) and 30-pound tangential forces to the shell of the reflector module being removed at an elevation below the BIF vibration damper. This rotating support was operated by a second, smaller set of rotary actuators. Three miniature actuators mounted on the bottom of the rotating support legs provided the side load. The purpose of providing these radial and tangential manipulations was to guide the reflector module around or away from potential interferences on the core barrel.

The operating components of this tool were rotary actuators which converted fluid pressure into rotary power and developed torque in either direction. Two actuators were mounted on the main support structure. This structure was supported by two 5-inch diameter tube legs which engaged and sat on the BIF support brackets on the opposite side of the core, and by two lips which overhung the core support flange near the location of the two reflector modules to be removed. A positioning crank was mounted on the output shaft of each actuator so that the cranks engaged the blanket module support tubes of two adjacent blanket modules. The reaction structure for this jacking force



LEGEND:

Item	Description
1	Blanket Module Caps (used to apply pull force to modules)
2	Cable Cylinder Assembly (identical unit positioned 120° CCW)
3	BIF Vibration Damper Brackets

Figure A3-2. Reflector Module Being Removed from Reactor With the Aid of Module Positioning Equipment was transmitted to the core barrel which was engaged by a bearing pad on the support structure of the positioning tool at the same elevation as the crank arm. The rotating support consisted of three legs welded to a 3-inch diameter cross arm. The rotating support was supported by bearing plates and bushings and was positioned by a pair of rotary actuators mounted on the support structure. The legs extended below the vibration damper so that they pushed on the reflector shell when the top of the reflector module was below the BIF support bracket. Three miniature rotary actuators provided a tangential force on the module for minor sideway adjustment.

The hydraulic control system for this tool consisted of a console and three hydraulic pump systems. The two rotating support actuators were operated in parallel since their output shafts were directly coupled. The other two actuators operated independently of each other. Each pump system consisted of a hydraulic hand pump, pressure gage, relief valve, and interconnecting hoses.

A3.2.2 - Module Positioning Tool Details

The module positioning tool (Figure A3-2) consisted of two cable cylinder assemblies, each having two hydraulic cylinders and two pull cables. The pull cables were attached to blanket module caps which fitted over the top of the blanket support tubes to provide the attachment to the blanket modules.

The cable cylinders were double-acting hydraulic cylinders having 2.5-inch bore and 50-inch stroke. The piston was connected to an endless wire rope system that passed over pulleys at each end of the cylinder. Driving the piston down provided a pulling force directly proportional to the pressure. These cylinders were rated for a 730-pound pull at 150 psig.

Two cable cylinders were mounted on a single support structure. The support structure engaged, and was supported by, the BIF supply tube holes in the BIF vibration damper support bracket, which was located in the upper barrel (Figure 37). A cable assembly with a terminal eye was attached to the moving cable of the cable cylinder. This cable attached to a blanket module cap to apply force to the blanket module.

Either cable cylinder assembly could be installed at any one of the three BIF vibration damper support brackets, which were 120-degrees apart around the upper barrel. This permitted installing the cable cylinder assemblies at locations such that up to three adjacent blanket modules could be pulled away from a blanket or reflector module being removed from the vessel.

The control console consisted of a manually operated hydraulic pump with pressure gage and valves, which permitted operating any one or more of the hydraulic cylinders.

A3.3 - OPERATING EXPERIENCE

The module spreader and reflector positioning tool was awkward to install and remove; however, because it was used only once, this characteristic had no significant effect on defueling. The module positioning tool was also somewhat awkward to use. In some configurations, the cable lengths and hydraulic piston travel needed to be longer. Also, the method of handling and storing pull cables when they were not being used resulted in a case where a cable holder was snagged on a fuel module being removed, requiring additional operations to free the tool. The LWBR module positioning equipment was found to be usable, and the fuel modules were removed without any damage or hangup due to grid interference.

APPENDIX A4 - ASSESSMENT OF BORATION OF THE CANAL WATER SYSTEM FOR REACTIVITY CONTROL, AND THE BORON CONCENTRATION MONITORING SYSTEM

A4.1 - BORON CONCENTRATION MONITORING SYSTEM

In preparation for defueling, the reactor vessel and canal were separately borated using potassium tetraborate (PTB), then interconnected to form a homogeneous body of water for reactivity control during fuel transfers. Defueling and shipping operations were completed without any criticality incidents.

The boron concentration monitoring system consisted of eight conductivity instruments for determining boron concentration in the canal and the reactor vessel. Six of the conductivity cells were static types, placed about 1 foot below the water surface, to provide redundant monitoring of the boron content in the canal water in three general areas along the entire length of the canal. These were designated channels 1 through 6. Two of the cells, designated channels 7 and 8, were flow-through types, which sensed the conductivity of a stream withdrawn from the reactor vessel which was subsequently pumped back into the reactor vessel at a location sufficiently displaced from the withdrawal point to prevent intermixing. Periodic analyses of water samples from the canal verified that the automatic conductivity readout was correct.

Channels 7 and 8 were placed in operation just before the removal of the reactor head and kept in continuous operation until the last blanket fuel module was removed from the reactor vessel. The flow rate in the system flow-through cells was about 0.05 gpm and represented an approximate 7-minute transit time from the seed module source to the conductivity cell. The only significant problems with channels 7 and 8 were confined to the pumps, which experienced small leakages until the packings were specially lubricated, and to several broken connecting gear shafts that were readily replaced. Transported crud was not a major problem. The instrumented train's 15-micron filters were changed only a few times throughout the full continuous operating period which lasted more than a year. At all times, the continuous cell readouts were within 5 percent of the canal fixed cell readouts (channels 1 through 6) and laboratory sample analyses. The overall monitoring system verified that the potassium tetraborate was well mixed and uniformly distributed throughout the reactor vessel and canal volume. The canal boron concentration was satisfactorily maintained in the band of 4400 ±200 ppm throughout the entire defueling period.

In addition to the electronic boron concentration monitors, administrative controls were invoked to ensure that boron concentration would remain within specified limits during defueling operations. A borated/fresh water inventory log was maintained to provide a current status of the quantity of borated and nonborated water transferred to and from the canal water system. From information in this log, the amount of fresh water that could be added at any given time was calculated. The major source of fresh water was the draining of M-130 shipping containers after flushing operations prior to shipment of fuel modules to the Expended Core Facility. A major factor tending to increase boron concentration in the canal was evaporation. Up to 200 gallons of water evaporated per day. This accounted for most of the gradual increase in boron concentration over the defueling period. Low boron concentration was never a problem during defueling and shipping operations.

Plant water systems were adjusted to provide double-valve isolation for the exclusion of fresh water from borated water areas, including the borated water supply tanks. Use of fresh water in these areas was controlled administratively through procedural guidelines. As a visible adjunct to these guidelines, signs were posted at several locations around the canal reminding personnel of restrictions on fresh water.

APPENDIX A5 - MODULE VISUAL INSPECTION STATION

A5.1 - DESCRIPTION OF THE INSPECTION SYSTEM

The module visual inspection station (MVIS) was an underwater television camera and drive system designed to aid defueling personnel to visually inspect all external surfaces of seed, blanket, and reflector modules immediately following their removal from the reactor core and to provide a permanent record of the condition of each module. The MVIS was also used for verification of module serial numbers and for performing the blanket module verticality check prior to installing the modules into the fuel shipping container, fuel storage rack, or seed/blanket disassembly stand.

The frame of the MVIS (Figure A5-1) was about 25 feet long and approximately 30 inches wide to fit between the flanges of the 36- by 12-inch I-beam of the LWBR seed/blanket disassembly stand. Slots were provided in the top and bottom for attaching the station to mounting pins on the disassembly stand.

The TV camera drive system consisted of a vertical guide structure, a camera carriage, and a cable drive. The vertical guide structure consisted of two 1.25-inch diameter ball bushing shafts running nearly the full length of the MVIS, on which the camera carriage rode by means of three linear, adjustable bearings. The underwater camera and lights were mounted on a removable bracket on the carriage, which permitted easy removal for maintenance or replacement with the MVIS suspended from the Fuel Handling Building crane. The cable drive consisted of a 1/3-horsepower, variable-speed gear motor and cable drum. The camera carriage descended under its own weight as the cable paid out. Limit switches inside the gearbox attached to the cable drum prevented running the cable off of the drum or removing the lights from the water. Operation of the gear motor produced a variable vertical camera speed of 0 to 83 inches per minute.

The control console consisted of: (1) the gear motor control, which had an up-down switch, a variable speed control, and a bump mode switch; (2) two underwater light variable-intensity controls that controlled each light separately; (3) a high-resolution TV monitor (chosen to view the largest side

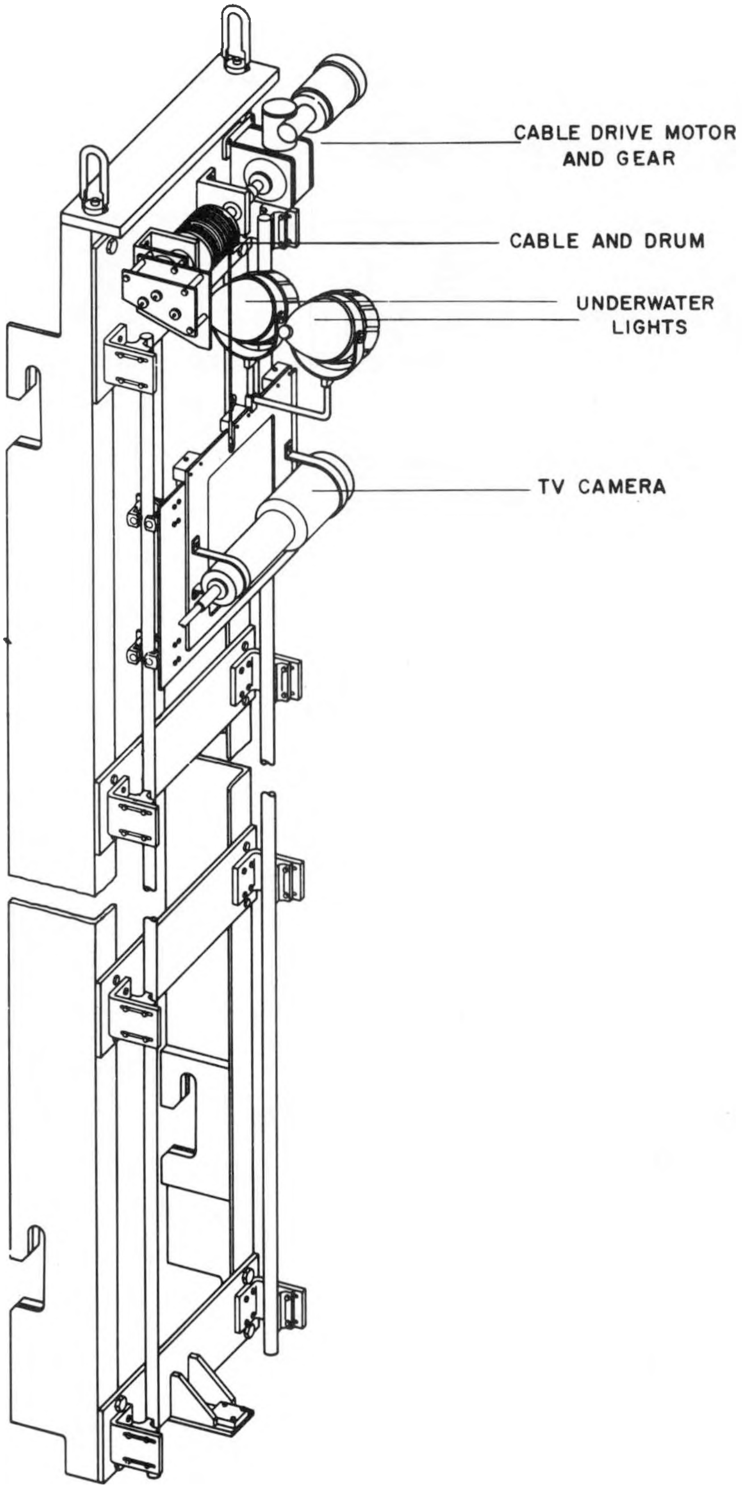


Figure A5-1. Module Visual Inspection Station of any module at 1X magnification); (4) the TV camera power supply; (5) a video cassette recorder with audio recording equipment; and (6) a limit switch override key to reset the limit switch for resuming camera movement in the opposite direction.

A plumb line was positioned in view of the camera and was used as a reference for leveling fuel modules.

A vertical scale was also used in conjunction with module inspections to provide a vertical reference on video tapes of each inspection operation.

Immediately after removing a fuel module from the reactor, a visual inspection was performed on it by placing the module in proper orientation with respect to the TV camera. The first operation was to verify an engraved serial number on the module, then the entire outer surface of the module was scanned for unusual features that may have developed during reactor operation. This early inspection ensured that if any unusual features were found, they would not have occurred as a result of anything other than reactor operation.

A5.2 - DESIGN CONSIDERATIONS

One of the drive system concepts was to power the vertical travel of the camera using a ball screw. Cost and lead time for procurement were the major factors in eliminating this method. The other concept was a roller chain drive. When compared to the cost and simplicity of the cable drive system, the roller chain drive was too expensive and elaborate.

Of two cameras tested, an 800-line, high-resolution camera provided significantly better image quality than a 600-line camera. The 600-line camera was capable of viewing a 0.005-inch wide scratch standard, but during tests, resolution of the 800-line camera clearly provided a better image of rod scratches and grid details of the test fixture. In addition to its superior resolution, the 800-line camera had a remote zoom lens system that permitted adjustments in magnification not available with the 600-line fixed focal-length camera. The zoom feature eliminated the need to precisely position the module at a defined distance from the camera to obtain a required magnification.

Similar commercial inspection systems include a device which supports the module during inspection and is capable of rotating the module. The MVIS had spacial limitations which prohibited the use of this type of device. Instead, the module being inspected was suspended from the Fuel Handling Building main crane, and rotation and alignment of the module to the proper face was accomplished manually. Although there was some module swinging motion after each module adjustment, the motion damped out quickly (few seconds) in the canal water and did not interfere with the examinations. The major drawback to this method was that the module was not suspended on an axis of symmetry but on the center of gravity. After each adjustment, the module had to be translated to align it with the camera because the camera could not be adjusted side-to-side.

During testing of the MVIS camera, it was observed that lighting was the most significant factor in obtaining the optimum picture. The optimum lighting arrangement found during testing was two lights above and two lights below the camera, angled at 45 degrees toward the target. This configuration was impossible to obtain in actual usage due to space limitations. A pan and tilt mechanism attached to both the camera and lights was considered. Since the camera was equipped with a zoom lens and the module was easily repositioned, the pan and tilt mechanism was not used. For future designs, to ensure production of the best picture possible under any condition, it is suggested that the lighting system be equipped with a pan and tilt mechanism.

A5.3 - PERFORMANCE SUMMARY AND PROBLEMS ENCOUNTERED

The original TV camera used with the MVIS system manifested a gradual deterioration of picture quality until, by the twenty-seventh module, it was necessary to remove the camera from operation and to make repairs. During the repair period, a backup camera without the zoom feature was used. Inspections were performed at a fixed 3X magnification and required up to three scans to complete one side of the blanket and reflector modules. Repairs to the original camera consisted of adjusting and peaking electric circuits in the camera. When the camera was returned to service, it was found that minimum magnification was 1.2X, as opposed to 1X prior to the repair work. A magnification of 2X was used for the remaining inspections to have an easily referenced factor. The lack of a pan and tilt mechanism at this point resulted in significant inconvenience. Because of limits of travel, tops and bottoms of the longest modules (seeds and blankets) could not be viewed on a single scan; it was necessary to raise or lower the modules to obtain a complete inspection at the 2X magnification.

Another factor leading to gradual reduction in the quality of inspections was the condition of canal water, which increased in cloudiness as a result of defueling activities stirring up dirt and crud.

The overall performance of the MVIS was satisfactory. Routine maintenance, such as changing light bulbs, was performed with minimal down time and effort. The major objective of producing a videotaped record of the condition of all LWBR fuel modules removed from the reactor was accomplished. The inspections demonstrated that the modules were in excellent condition and that there was no damage to the fuel modules as a result of defueling. The videotape records provide a basis for determining the effect of shipping on fuel modules.

APPENDIX A6 - FLEXIBLE LINK/LOAD INDICATOR FOR FUEL HANDLING

A6.1 - ASSEMBLY DESCRIPTION

The flexible link/load indicator assembly was specially designed for fuel handling during the LWBR defueling operations. The LWBR defueling method required remote underwater handling of fuel assemblies under conditions of limited access and limited visibility. It was considered that if an interference would be encountered, an excessive vertical force could be applied which might damage the fuel assembly or rigging. The flexible link/load indicator assembly provided a means for detecting load changes; it inserted a spring into the fuel handling rigging which provided a deflection capability in the event of a hangup, while minimizing the axial length it added to the rigging. All lifting or lowering operations where limited clearance existed were accomplished with a manual chain hoist, which was operated slowly and carefully. These two features ensured that loads changed gradually, instead of abruptly, so that interference could be detected and hoisting could be stopped before damage occurred. The flexible link/load indicator was effective in preventing damage in both the lifting and lowering directions.

The flexible link/load indicator had three plates: the upper, middle, and lower plate (Figure A6-1). The load connection between the lower and middle plates was made by a 20,000-pound capacity load cell, which transmitted the load from the lower plate to the middle plate. The three safety bolts passing through the lower plate and threading into the middle plate did not carry any load unless the load cell failed. The load connection between the upper and middle plates was made through six safety link bolts and six coil springs. As the middle plate was loaded, the six coil springs transmitted the load through the safety link bolts to the upper plate. These springs each had a spring rate of 1000 pounds per inch; collectively, the six springs had an effective spring rate of 6000 pounds per inch. In the event that the applied load was greater than the maximum design load of 15,000 pounds, a larger-diameter step in the safety link bolts would serve as a stop by limiting the maximum deflection of the springs, then transmitting the additional force

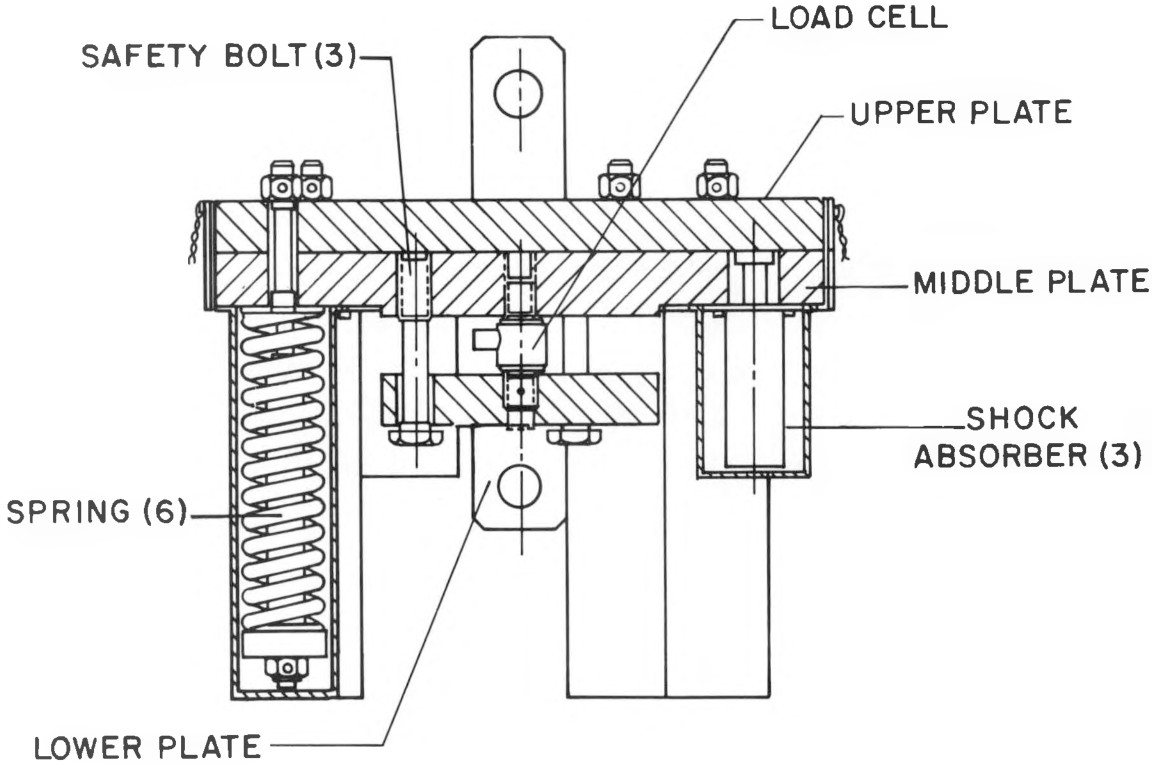


Figure A6-1. Flexible Link/Load Indicator for Fuel Handling Rigging directly to the upper plate. The stops also functioned to support the load in case of spring failure. Three shock absorbers provided damping to prevent damage in case an interference or hangup was suddenly released. The springs were contained in sheet metal covers to ensure that no parts were lost in the reactor vessel in case a spring should break. The three shock absorbers had similar covers to contain any fluid leakage and to capture any parts since these shock absorbers were commercial units and did not meet defueling equipment specification requirements unless they were covered.

A6.2 - PERFORMANCE SUMMARY

The flexible link/load indicator assembly performed well during the defueling operation. It detected interferences in both lifting and lowering operations and allowed the chain hoist operation to stop in time to prevent overload and damage due to hangup prior to seating. There was no known instance of damage to fuel assemblies or reactor components due to hoisting operations during LWBR defueling.

APPENDIX A7 - DISPOSAL OF REACTOR COMPONENTS

A7.1 - DISPOSAL METHODS

Disposal of LWBR nonfuel reactor components occurred continuously throughout the defueling. Three methods of component disposal were employed:

1. Shipment off site for disposal.
2. Shipment off site for examination and/or storage.
3. Retention at Shippingport for later disposal by the decommissioning and disposal contractor.

A7.1.1 - Off-Site Disposal

Two different categories of reactor components were shipped off site for disposal. The first category involved low specific activity (LSA) components. These items were packaged in specially designed boxes or air-tight drums. Items included closure head external components such as stator water jackets, position indicator coils, the sound monitoring system, the containment air cooling system, component cooling water lines, and the service lead support structure. Also in this category were motor tubes, translating assemblies, bypass inlet flow (BIF) tension/compression tubes, hand tools, and used defueling equipment. Thirteen truckloads of these LSA components were shipped to a licensed burial ground. The second category involved shipment of components that did not meet LSA shipment requirements. These pieces were loaded along with the PWR-2 lower core barrel and shipped to Savannah River for burial. A two-piece structure (Figure A7-1) was installed into the barrel to support the disposal pieces. Components disposed of with the PWR-2 lower core barrel were six of eight LWBR flux thimbles, five of six BIF supply tubes, 11 of 12 seed support shafts, and six of 12 blanket support tubes.

A7.1.2 - Off-Site Examination and/or Storage

Components were also shipped off-site for examination and material testing. Two each of the stator water jackets, motor tubes, and translating assemblies were packaged in LSA boxes and shipped to the Naval Reactor Facility Expended Core Facility (ECF) in Idaho for examination. Other components

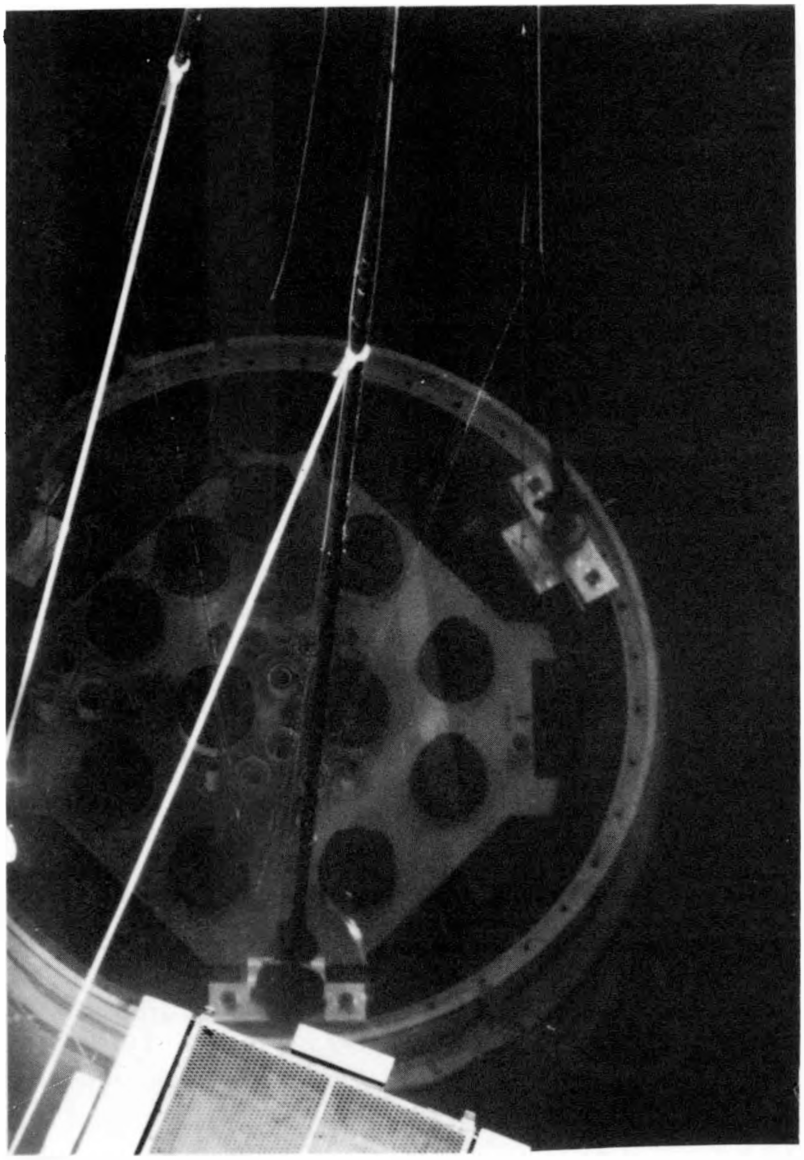


Figure A7-1. Structure Installed in PWR-2 Lower Core Barrel to Contain Reactor Components for Scrapping shipped to ECF for examination were one seed support shaft, two flux thimbles, and one BIF supply tube. Because these pieces were highly irradiated, they were loaded into a special shipping fixture that was installed into the last reflector module shipping container (Reference 2) and shipped to ECF via rail with three reflector modules. Several components were shipped to Bettis Laboratory for examination. Included were blanket top base plate bolts, reflector seal block bolts, blanket guide tube extension bolt remnants, and a portion of the IV-2 flux thimble (Section 3.8). These pieces were loaded into specially prepared, air-tight drums and shipped by truck to Bettis.

A7.1.3 - Disposal by the Decommissioning and Disposal Contractor

Many components were retained at Shippingport for disposal by the decommissioning and disposal contractor (Reference 5). To provide storage space for the irradiated fuel module components, specially designed racks were installed on the reactor pit walls to store standard Vandenburgh CNS 3-55 disposal cask liners. The fuel module components were loaded into these liners (Figure A7-2).

The filled liners were covered with a permanent lid then, after shipout of the irradiated components and PWR-2 lower core barrel, were transferred to the deep pit for storage. Components disposed of in the liners included the remaining six blanket support tubes, the blanket stub tubes and guide tube extensions, the blanket and reflector seal blocks, and all of the fuel module bolts not saved for examination. Dividers were installed in the liners for space-efficient loading of the guide tube extensions.

Other major components left at Shippingport for the decommissioning contractor to dispose of were the LWBR closure head and installed breechlock sleeves (Section 3.11) and the suspension system compression sleeves (Section 3.4). The closure head and breechlock sleeves were stored in a large concrete pit at the north end of the Fuel Handling Building. The compression sleeves were stored in a smaller pit at the south end of the building (Figure 45). Both pits required preparation and installation of specially designed equipment before storage of the components.

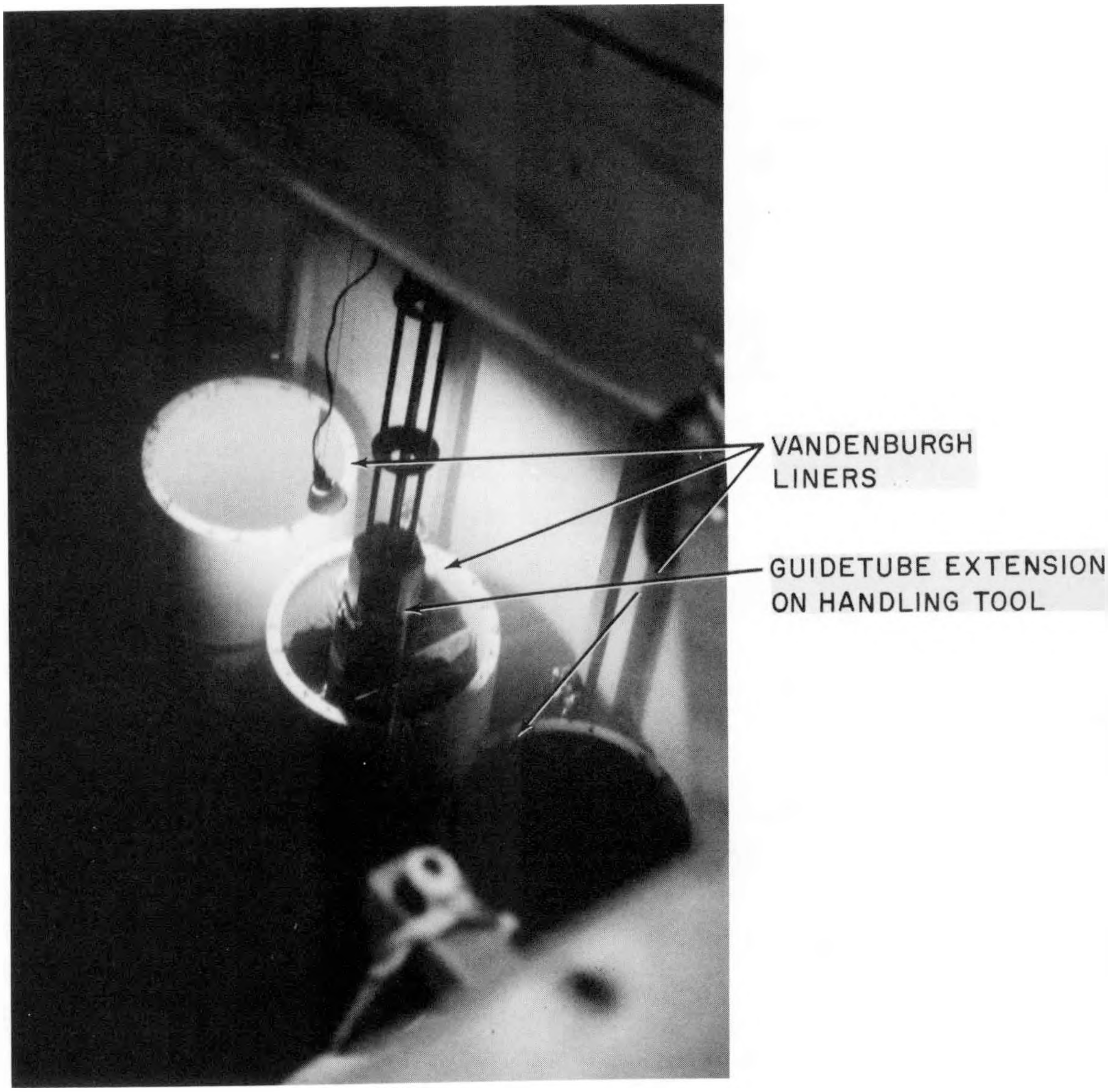


Figure A7-2. Disposal Liners for Reactor Component Storage and Disposal

APPENDIX A8 - BREECHLOCK SLEEVE TENSIONER AND BREECHLOCK SLEEVE DISASSEMBLY TOOLS

A8.1 - BREECHLOCK SLEEVE TENSIONERS

The breechlock sleeve tensioner was used to relieve the residual stress which resulted from the 0.067-inch mean final elongation of the breechlock sleeve at installation. As shown in Figure A8-1, the tool consisted of four main subassemblies: a support structure, a tensioning assembly, a torquing assembly, and a measuring assembly.

The support structure seated on the control drive mechanism (CDM) housing and centered the breechlock sleeve tensioner within the CDM housing. The force and torque exerted by the breechlock sleeve tensioner reacted through the support structure to the CDM housing. The support structure also provided a datum from which changes in the length of the breechlock sleeve could be measured.

The tensioning assembly consisted of a grappling mechanism and a hydraulic cylinder. The grapple contained retractable lifting lugs mounted between the flanges of an inner and outer shaft. The lifting lugs were keyed to the flange of the inner shaft and were actuated by the action of a cam on the flange of the outer shaft. The inner shaft was prevented from rotating by a sliding key on the support structure which allowed vertical, but not rotational, motion. The outer shaft was manually rotated by means of a latching handle located below the hydraulic cylinder. The grappling mechanism could be positioned vertically by a jacking nut. The jacking nut seated on a bearing and two spherical washers which, in turn, seated on the piston of the hydraulic cylinder. When the hydraulic cylinder was pressurized, the piston exerted a force on the grapple through the jacking nut, and the lifting lugs of the grappling assembly transferred this load to an internal ledge of the breechlock sleeve.

The torquing assembly consisted of a gear box, drive gear, and nut driver. The gear box was mounted on the support structure and actuated the drive gear at an 8:1 gear ratio. The drive gear was doweled and bolted to the

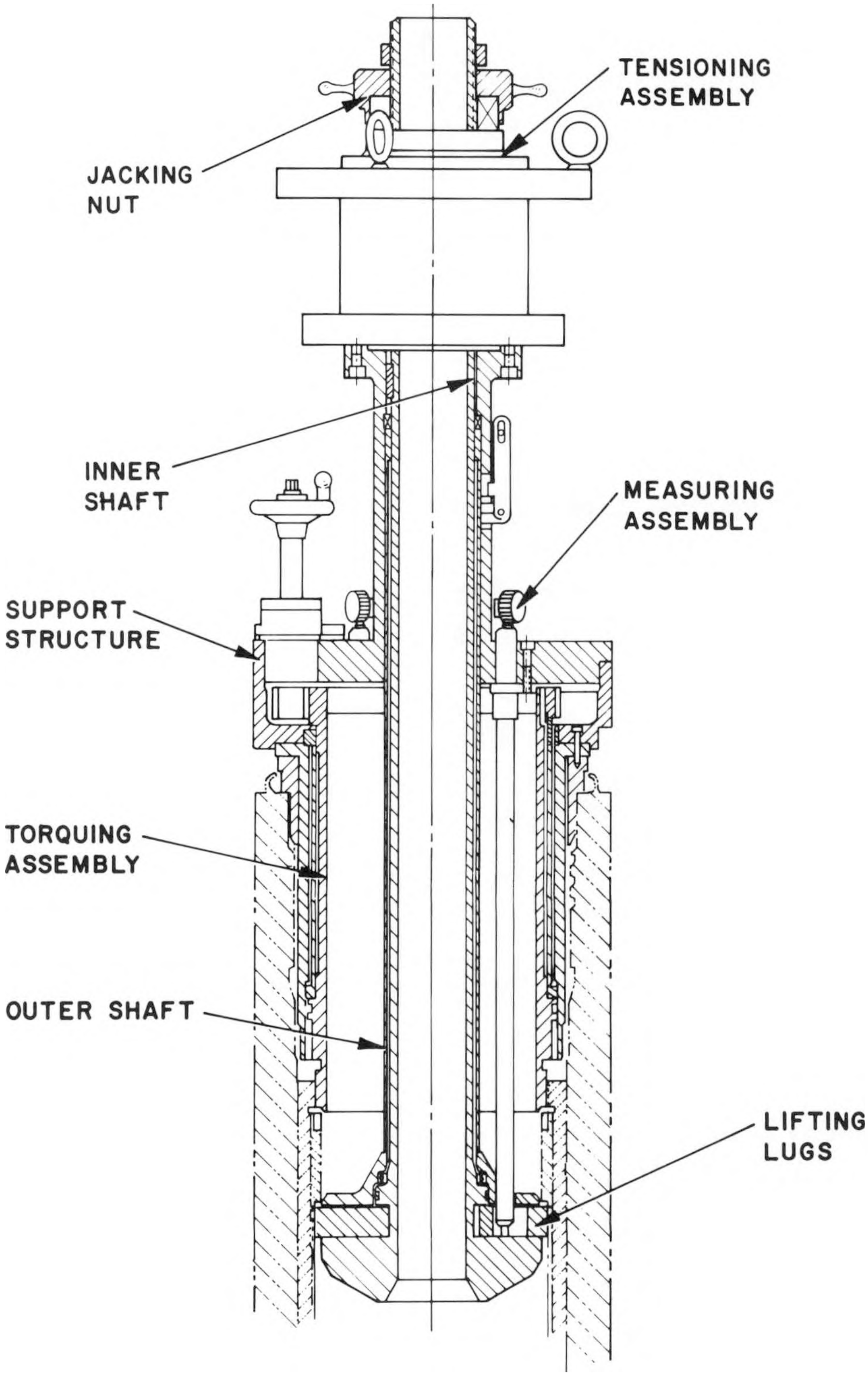


Figure A8-1. Breechlock Sleeve Tensioner nut driver. The nut drive incorporated four keys at its base, which engaged slots on the inside diameter of the breechlock nut. (The procedural limit for applied torque on the breechlock nut was 160 ft-lb., but the nut driver and drive gear were designed for 1000 ft-lb. torque as a contingency. However, all breechlock nuts were backed off with less than 160 ft-lb. torque.)

The measuring assemblies were three spring-loaded plungers inside guides spaced at 120-degree intervals on the support structure. The plunger rested on the flange of the inner shaft of the grappling assembly. Dial indicators were used to record the travel of these plungers during detensioning. The recorded values for change in elongation during detensioning were comparable to those obtained during initial installation.

A8.2 - BREECHLOCK SLEEVE DISASSEMBLY TOOL

The breechlock sleeve disassembly tool (Figure A8-2) was used to disengage the breechlock sleeve from the blanket support tube and to lower the fuel assembly to the core bottom plate. Consequently, the breechlock sleeve disassembly tool was composed of three separate tools as subassemblies. The breechlock nut tool was used to rotate both the breechlock nut and breechlock sleeve to disengage from the segmented lugs of the blanket support tube. The module support tool was used to remove the weight of the fuel assembly from the breechlock sleeve and to lower the fuel assembly in increments until it seated on the core bottom plate. The jack assembly provided the capability of lifting and lowering the breechlock nut and sleeve through the CDM housing so that a spacer could be inserted below the breechlock nut.

The breechlock nut tool was mounted on, and free to slide along, the shaft of the module support tool. The breechlock nut tool (Figure A8-3) was composed of a cylinder with heavy top and bottom plates and three heavy stiffeners. The thickness of the plates and stiffeners was based on radiation shielding requirements in the CDM housing, not on weight-carrying capability. A vertically adjustable square key and two threaded rods were mounted on the tool body. The square key engaged a slot in the breechlock nut and served to align the two threaded rods with threaded holes in the breechlock nut. The

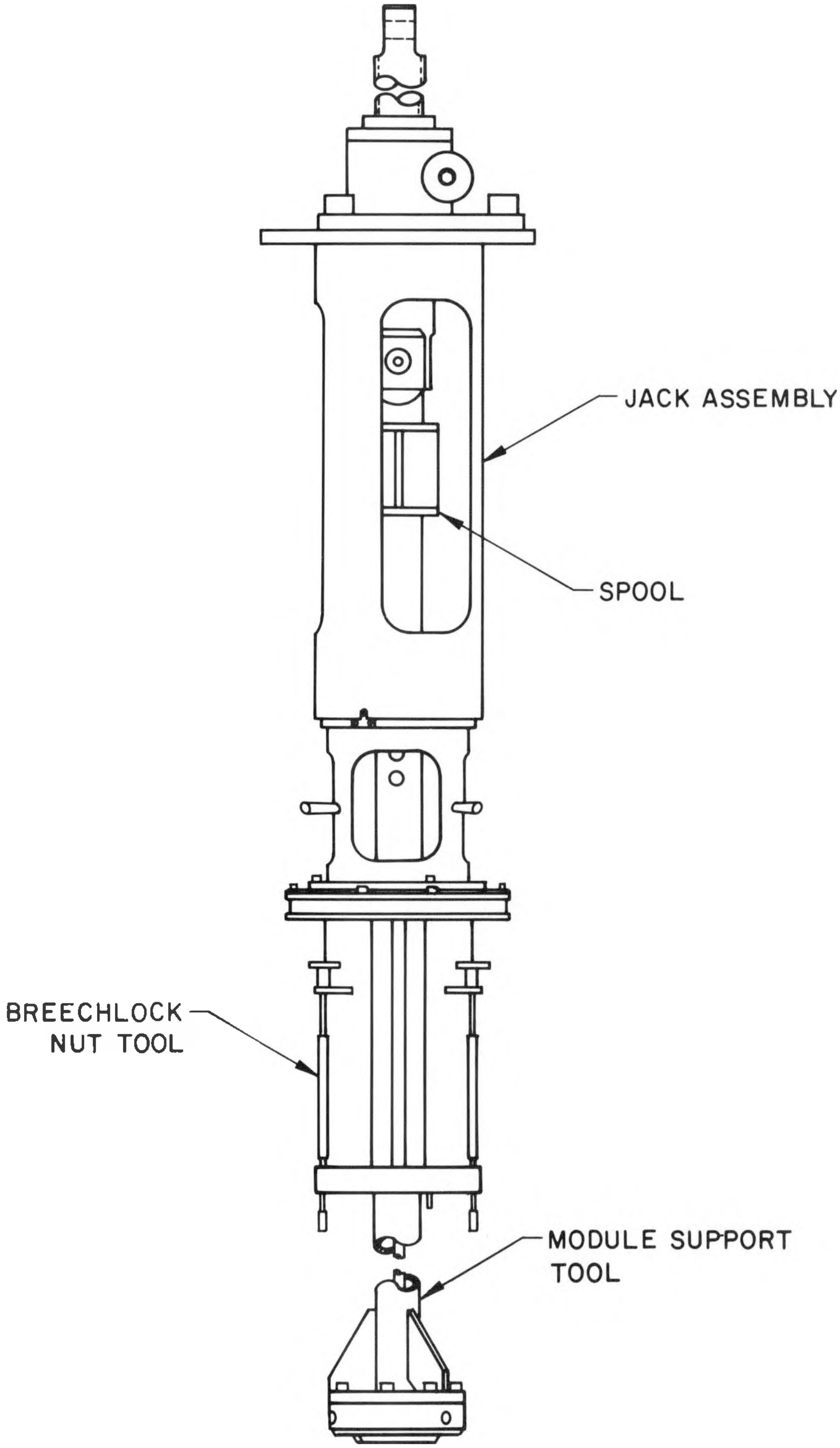


Figure A8-2. Breechlock Sleeve Disassembly Tool

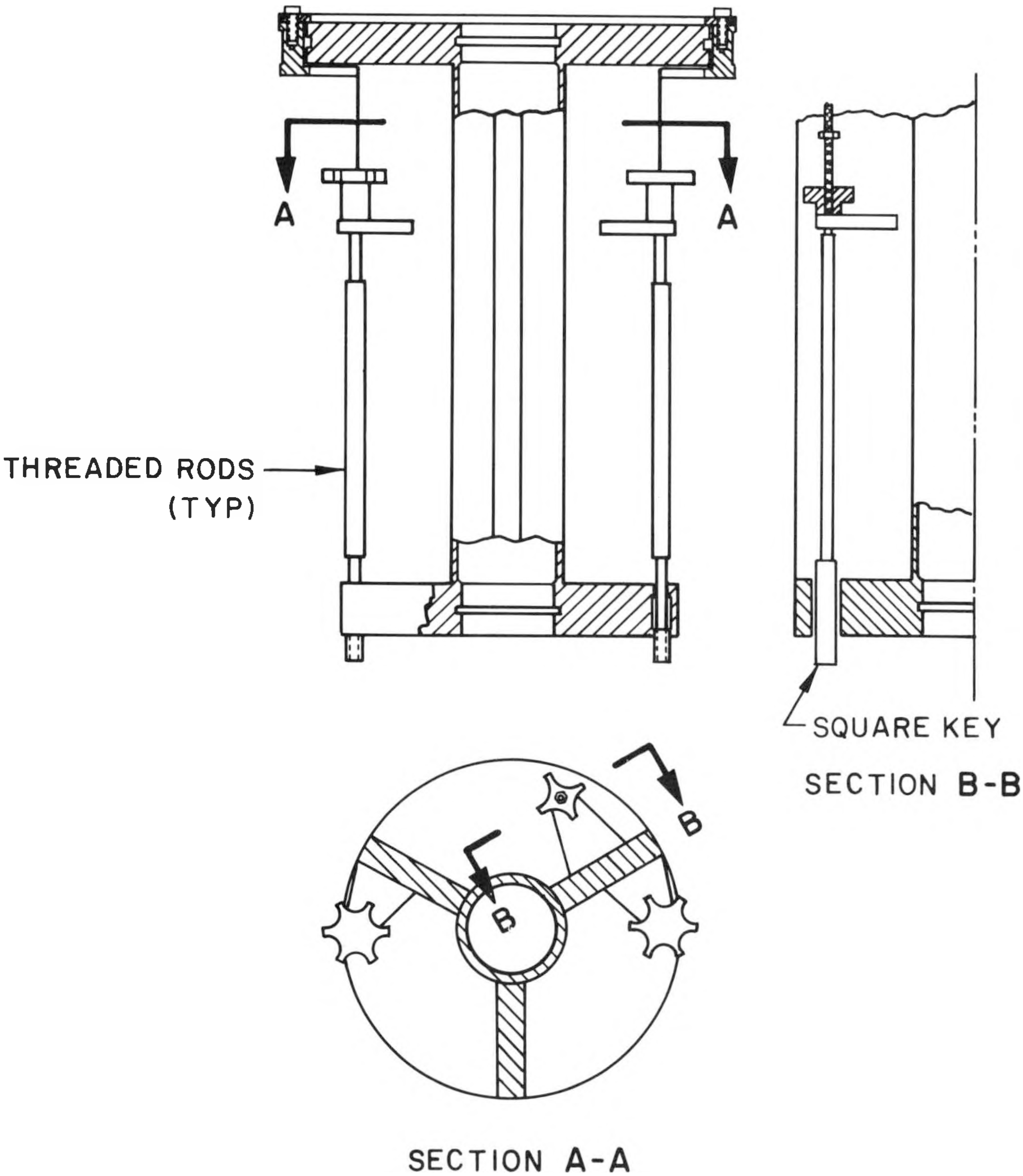


Figure A8-3. Breechlock Nut Tool

threaded rods served to attach the breechlock nut tool to the breechlock nut. When fully retracted, the square key would engage only the breechlock nut. When fully extended, the square key would also engage a slot in the breechlock sleeve, locking the breechlock sleeve tool, sleeve, and nut together and allowing the breechlock sleeve to be rotated to disengage from the blanket support tube.

The module support tool (Figure A8-4) incorporated a grappling head with retractable lifting lugs at its base. A square key projecting from the base of the grappling head engaged a keyway on the balance piston, aligning the lifting lugs with the lifting holes in the blanket support tube. The lugs were actuated by a cam driven by an internal shaft, which was manually rotated with a removable handle. The shaft could be locked with the lifting lugs fully extended or retracted by means of a locking screw captured in one of two pilot holes. A spool was also mounted on the shaft of the module support tool above the breechlock nut tool (Figure A8-2). This spool could be lowered to seat on the breechlock nut tool to provide a bearing surface for a rod inserted through the module support tool. Three holes were bored through the top of the module support tool, with a 1.00-inch spacing between center lines. The module support tool seated on a rod inserted through these holes during the first through third module lowering increments (Section 3.10).

As shown in Figure A8-5, the jack assembly consisted of a keyed screw jack mounted on a fixed housing. At the base of the fixed housing was a rotating housing used to turn the breechlock nut tool. The jack assembly lift adapter bolted to the clevis on the module support tool, and the lower rotating housing bolted to the breechlock nut tool.

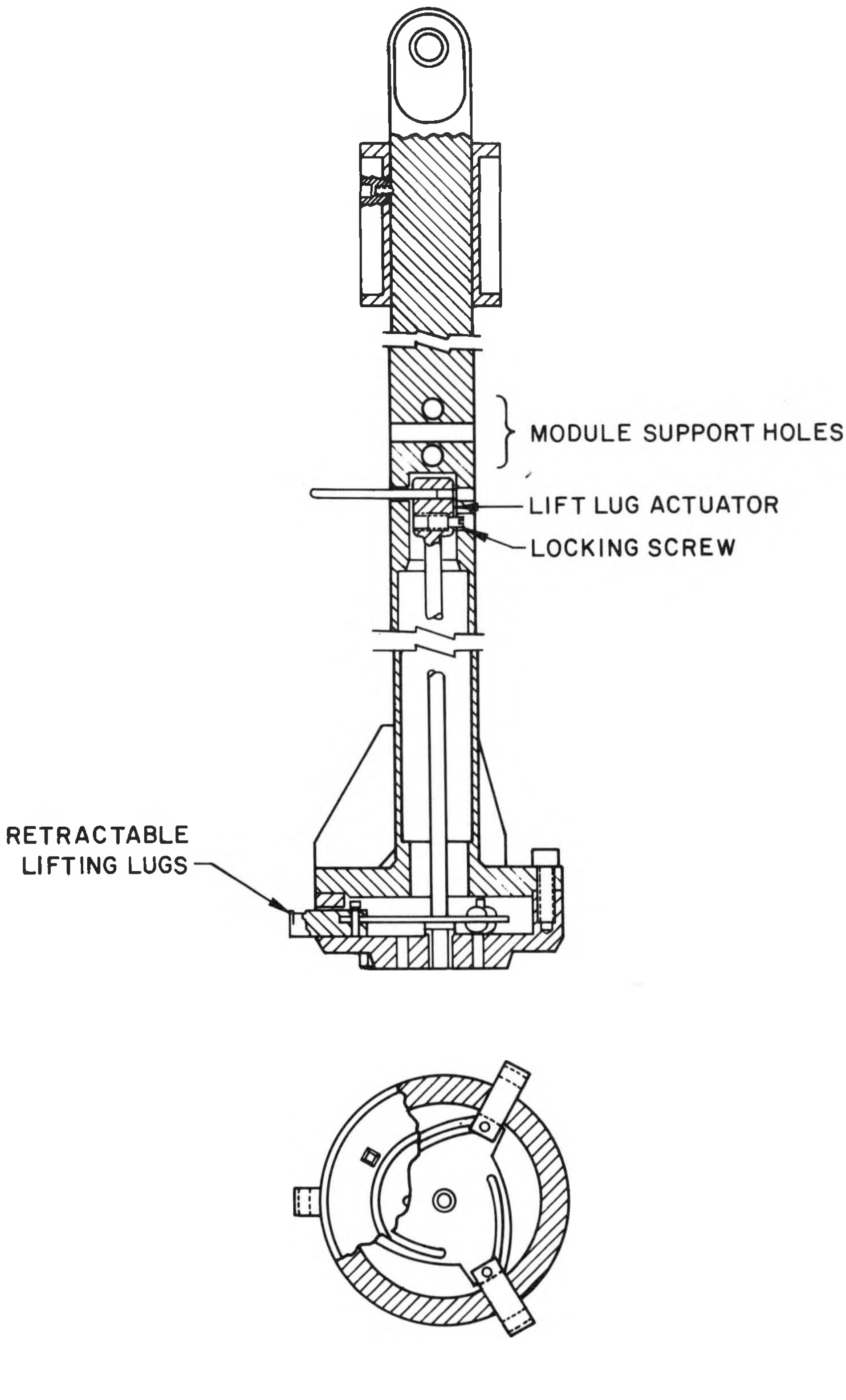


Figure A8-4. Module Support Tool

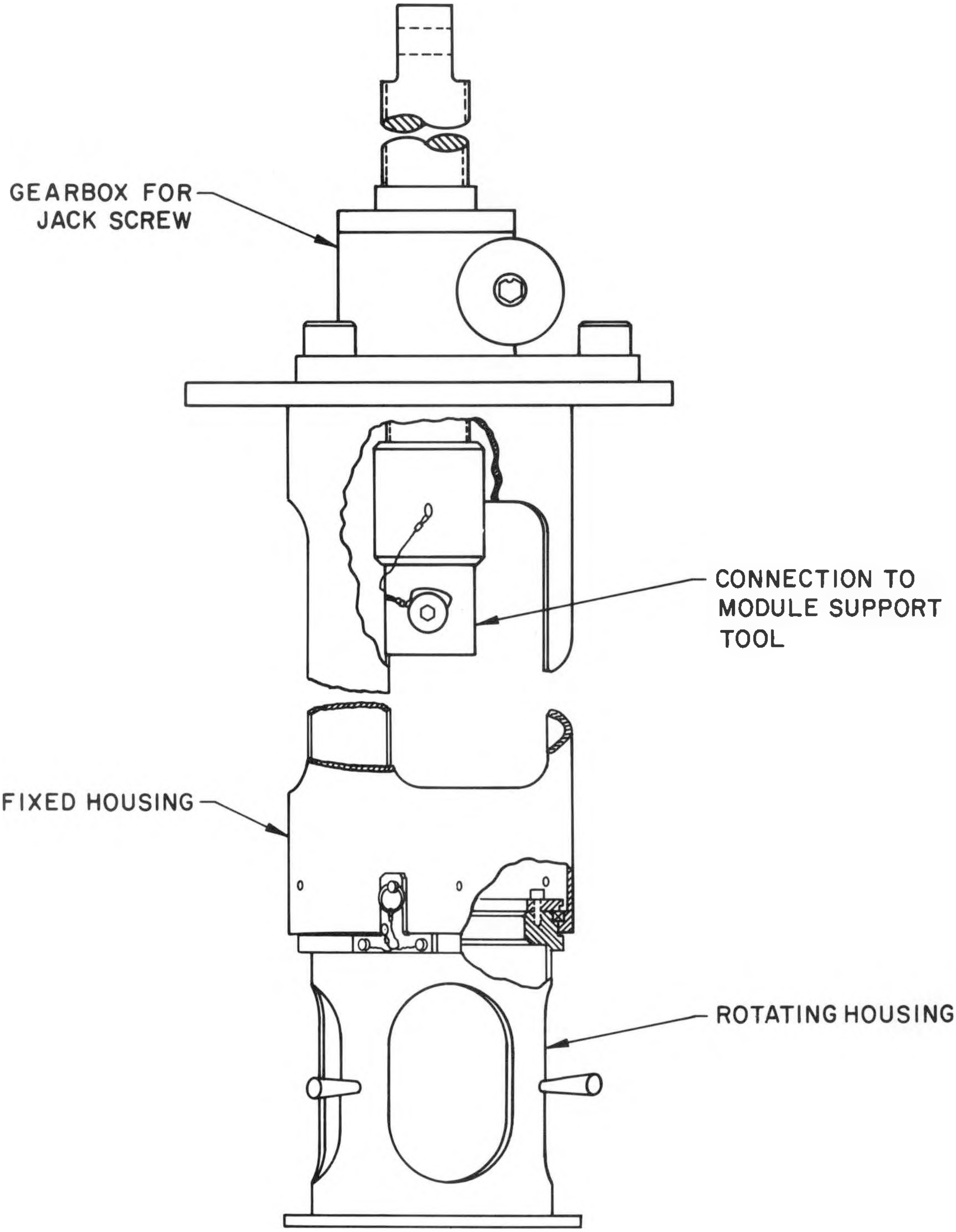


Figure A8-5. Jack Assembly

APPENDIX A9 - SUMMARY OF PROBLEMS DURING LWBR DEFUELING

A9.1 - GENERAL

LWBR defueling was completed without any problems that would have presented a hazard to personnel or the environment. Most of the problems that did occur were minor, representing ambiguities in written procedures due primarily to slight differences between mock-ups used in checkout and training and actual equipment. Operator errors stemming from inexperience or lack of attention to details resulted in several minor problems. A few problems were related to tool design or tool malfunctions that occurred after functional checkout. Many of these problems are discussed in the main text. A few problems had significant impact on defueling or resulted in schedular delays and deserve more detailed treatment than was appropriate in the main text. Summaries of these problems are presented here.

A9.1.1 - Use of Chelating-Form Resin in the Canal Water Demineralizers

On March 4, 1983, both canal water system demineralizers were recharged with boron-form chelating resin. This resin was selected to remove metal ions and chloride without affecting the boron dissolved as potassium tetraborate (PTB) in the canal. From March 29, 1983 to April 7, 1983, only the deep pit section of the fuel handling canal was borated. As a result of this borating, canal water activity increased from approximately 2×10^{-7} μCi/ml to 6×10^{-6} μCi/ml due to nonionic cobalt. Since the activity was nonionic, it was not removed by the resin. Portable filter columns loaded with activated charcoal were installed in the canal water system and were successful in removing the activity caused by the cobalt.

A9.1.2 - Antimony-125 Activity in the Canal Water

Significant concentrations of antimony-125 (2×10^{-4} μCi/ml) were measured in the canal water following boration of the reactor coolant and canal water and initiation of defueling. This radioactivity apparently came from neutron activation and subsequent decay of tin, which is an alloying constituent of the fuel rod Zircaloy cladding. Some of this activity was removed by canal water system temporary charcoal filters. However, the chelating-form resin in the canal water demineralizers was not effective in removing antimony-125. As a result, canal water activity increased from the 10^{-7} μCi/ml range, before boration, to about 2×10^{-4} μCi/ml. The radioactive waste processing system thin-film evaporator was utilized to reduce canal water activity as low as practical before plant turnover for decommissioning, while maintaining the boron concentration required for defueling. At the end of defueling, the activity was approximately 1×10^{-4} μCi/ml with antimony-125 the major contributor.

A9.1.3 - Closure Head Removal Sleeve

A large polyvinylchloride sleeve (Appendix A2, Figure A2-19) was installed between the LWBR closure head and core support flange to provide radiological containment when the head was removed. Several minor problems with bag handling and preparation for closure head removal resulted in a delay in operations of about six shifts. The minor problems were mainly related to defueling procedure sequencing. For example, it was required that two continuous rubber bands be placed around the head and core support flanges (Figure 31). However, the bands were to be placed before removing the nitrogen purge hoses, which was physically impossible. Shortly after this problem was noted, problems with operations sequencing, an improperly fabricated piece of equipment, and a request by Radiological Controls supervision for changes affecting containment handling resulted in a decision to conduct more comprehensive training on closure head removal operations, aimed specifically at containment sleeve operations.

Training was conducted on all three work shifts after the sleeve was installed in the reactor pit on top of the closure head. There were several long ropes on the containment which were used to close the bag after removing the head. The bag itself was over 55 feet long and 14 feet in diameter. Manipulation of the ropes and bag was practiced, and operations to attach the bag to the reactor were discussed. During the training, several problems with the bag became apparent, which resulted in a delay beyond that intended for the training operations:

1. Pulling on the ropes which were attached to the bag at six locations by belt loops resulted in torn belt loops and tangled ropes. In a few cases, torn belt loops also resulted in tears in the bag. A decision was made to eliminate the six ropes from the bag and use only two ropes, which would not be fastened to the bag but would be laid out around the bag and cinched up only after the head was removed.
2. Handling of the heavy bag almost inevitably resulted in further damage. Each time the bag was extended for practice operations, additional tears were noted and repaired. The bag had been thoroughly inspected and accepted prior to installing it in the reactor pit. A further complete inspection was performed during attachment of the bag to the core support flange after training was completed.
3. During training, a problem was noted concerning the 40 CFM high-efficiency particulate air filters attached to the sleeve to provide a means of air passage for preventing collapse or ballooning during head removal. These filters were attached to the bag on short sleeves. It was noted that the weight of the filters and the length of the sleeves combined to constrict free passage of air. It was necessary to provide tie-offs for several filters to ensure that the bag would operate as planned.

After training was complete, lessons learned were incorporated into the procedure. Actual operations began immediately thereafter and were completed with no further problems with the containment.

A9.1.4 - Refueling Seal Leakage

After the two-part refueling seal was installed over the reactor vessel (Section 3.12), a leak test was performed at two of the three joints (core support flange-to-adapter and adapter-to-main seal) using air pressure applied within the space created by the redundant seals. The joint between the adapter and main seal did not pass the test. Figure A9-1 shows the joint schematically. Air pressure was applied in the small space between the upper seal gasket and the silicone rubber sealant. Leakage was detected below the

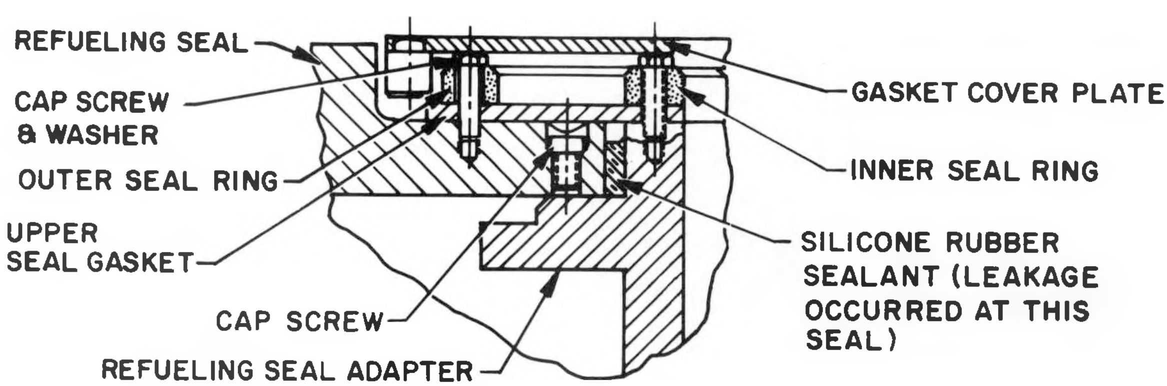


Figure A9-1. Leaking Seal on Refueling Seal-to-Adapter Joint sealant and at several bolt holes around both inner and outer seal rings, which compress the upper seal gasket. To obtain primary sealing, the bolts were tightened but, upon retesting, one bolt hole still leaked. The seal ring segments were removed in the vicinity of the leak, and it was found that several holes had been double-punched due to imprecision in the original measurements. This was repaired by applying a gasket putty around the affected bolts. Upon retesting, a good seal was obtained at the upper seal gasket.

It was considered that removal of the upper seal gasket to repair the secondary seal was not desirable because of problems encountered in installing the gasket originally (hence, the need for double-punching) and the real probability of damaging the primary seal. An attempt was made to provide a secondary seal by filling the gap at the underside of the joint between the adapter and main seal with a gasket putty and encircling the joint with a buna-N O-ring. A large hose clamp was wrapped around the O-ring to provide strength to the seal. This method did not work, even with different arrangements of O-rings and hose clamps.

Because the reactor pit was to be filled only for the duration of defueling, a period of approximately 16 months, it was judged that the primary seal alone would be adequate. A new test was devised to check the integrity of the primary seal. A trough was built up around the gasket and filled with water. No leaks were detected during this test. Other factors contributing to the acceptability of this contingency were that water pressure on top of the gasket could only improve the seal, and the gasket cover plate would provide adequate protection against any possible damage to the gasket.

The most probable cause of leakage in the secondary seal was that, because of the thick cross section (0.25 inch by 1.5 inches), the sealant did not cure properly, and left blow holes to provide a leakage path. A two-component urethane potting compound with viscosity index much lower than the silicone rubber sealant might have provided a usable seal in this case. A visual check of the third joint (defueling seal-to-floor joint) was made after a small amount of water had been pumped into the reactor pit. A slow leak was noted, but it stopped on its own. The joint was monitored throughout the period that the reactor pit was flooded but there was no recurrence of the leak. There was no spread of contamination as a result of this leak.

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