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THE INSTALLATION OF THE LIGHT-WATER BREEDER REACTOR AT THE SHIPPINGPORT ATOMIC POWER STATION

(LWBR Development Program)

MAY 1983

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BETTIS ATOMIC POWER LABORATORY
WEST MIFFLIN, PENNSYLVANIA 15122-0079
Operated for the U. S. Department of Energy by
WESTINGHOUSE ELECTRIC CORPORATION

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BETTIS ATOMIC POWER LABORATORY WEST MIFFLIN, PENNSYLVANIA 15122-0079

OPERATED FOR THE U. S. DEPARTMENT OF ENERGY
BY WESTINGHOUSE ELECTRIC CORPORATION

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 will be 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 have been 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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This report summarizes the refueling operations performed to install a Light Water Breeder Reactor (LWBR) core into the existing pressurized water reactor vessel at the Shippingport Atomic Power Station. Detailed descriptions of the major installation operations (e.g., primary system preconditioning, fuel installation, pressure boundary seal welding) are included as appendices to this report; these operations are of technical interest to any reactor servicing operation, whether the reactor is a breeder or a conventional light water non-breeder. The breeder core was no more difficult to install into the reactor vessel than a conventional light water non-breeder core.

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

(LWBR Development Program)

I. INTRODUCTION

This report describes the installation of a Light Water Breeder Reactor (LWBR) core into the existing pressurized water reactor vessel of the Shippingport Atomic Power Station. The installation was accomplished following the defueling of the previous reactor core, which resulted in the removal of the entire reactor core and core barrel and left only the reactor vessel and thermal shield. The installation was performed with the reactor vessel drained of water and all the new LWBR components were installed directly into the reactor vessel. Since the LWBR components were radiologically clean, no special contamination containments were required during the installation. The installation was accomplished using specially designed handling equipment because of the desire to minimize the risk of damage to the components of the reactor.

During installation a rigorous quality assurance program was followed which included third party verification of proper installation of all components. In many cases, verification of proper installation was obtained by remote indicators on the tooling, since the components being installed were hidden within the reactor and could not be observed.

The prime consideration throughout the LWBR installation was personnel safety, both for the technicians performing the installation and for the general public outside the refueling area. Safety features included the control of personnel radiation exposure and protection against uncontrolled nuclear criticality during the installation operations. The safety aspect was an inherent feature of the design of the refueling facilities and equipment, and was further effected by an extensive program of training personnel and checking out the equipment prior to its use. Section II of this report provides a brief description of the LWBR design and the Shippingport Atomic Power Station facility. Section III provides a detailed description of the LWBR installation including an evaluation of each major phase of the installation. Problems encountered during the installation are also identified and discussed. Section IV provides an overall summary and presents conclusions. Significant features of the installation are discussed in further detail in the appendices.

II. DESCRIPTION OF THE LWBR DESIGN AND THE SHIPPINGPORT ATOMIC POWER STATION FACILITY

This section provides a brief description of the LWBR core and other reactor components that were installed during this refueling and describes the refueling facilities. A more detailed description of the reactor design is provided in Reference 2.

The LWBR core (Figure 1) is contained in a reactor vessel which is approximately 33 feet high with an inner diameter of 9 feet and a nominal wall thickness of 8 7/8 inches. Within the vessel is a core barrel, which is a long cylinder that locates the fuel assemblies within the vessel. The core barrel is supported in the vessel by a large doughnut shaped weldment, called the support flange, that rests on the top of the vessel. This support flange also serves as the entrance point of various types of core instrumentation and safety injection piping through nozzle penetrations. The support flange is clamped in position by the 50 inch thick steel closure head using 6-inch diameter studs which are installed in the mating bolting flanges of the closure head and reactor vessel. The joints between these major components are sealed by welding a preformed seal membrane all around the reactor at the vessel-to-flange and flange-to-closure head interfaces.

The reactor employs two different types of fuel assemblies: seed and blanket, and the reflector assemblies. The fuel assemblies and the reflectors were received and installed into the core barrel of the reactor as manufactured units.

Filler units (see Figure 1, sheet 3 and Figure A-3) were used to adapt the circular cross section of the PWR core barrel to the egg-shaped cross section of the LWBR core. The filler units were made from stainless steel. Passages

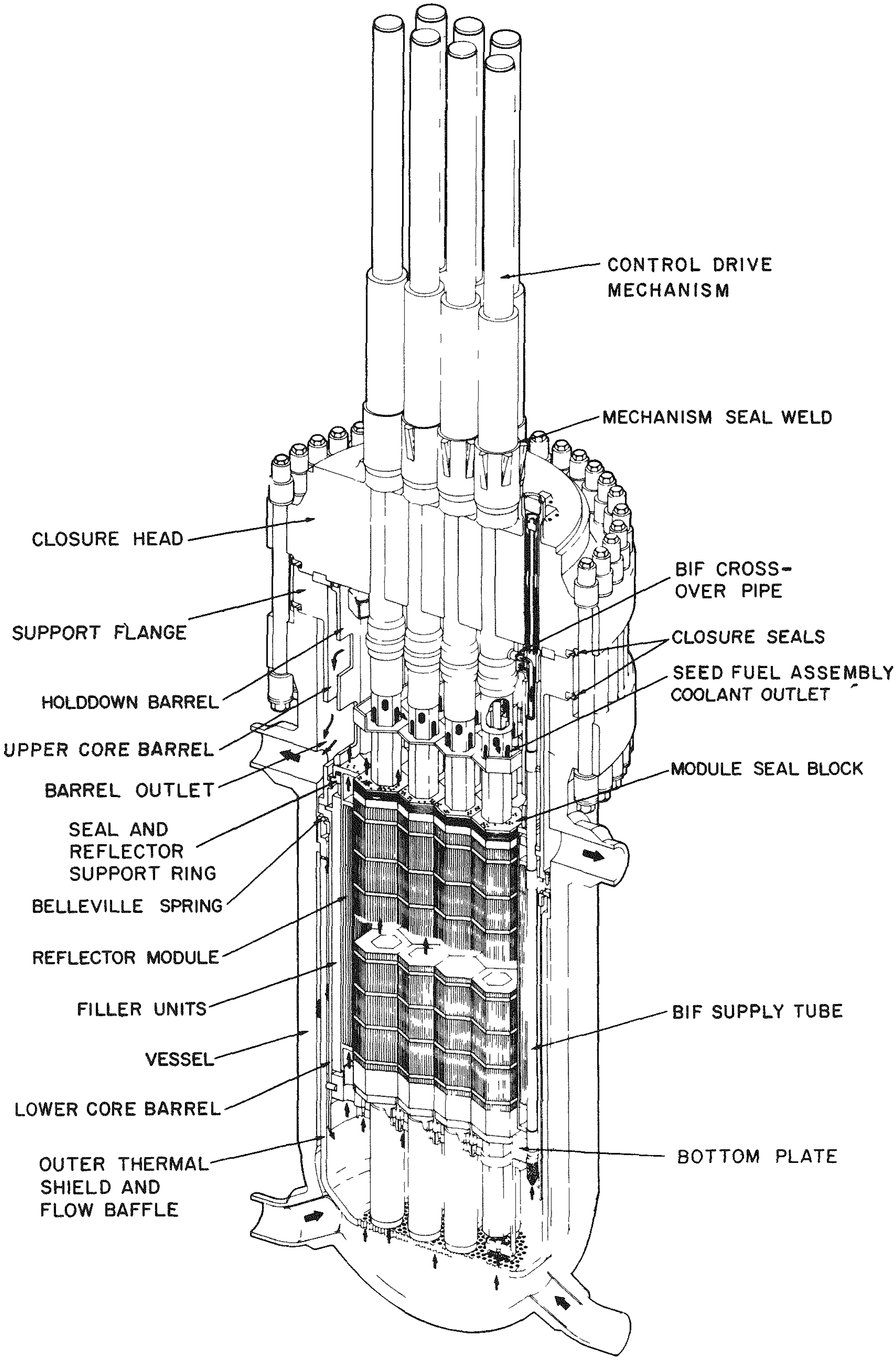


FIGURE I (SHEET I OF 3)
LWBR REACTOR

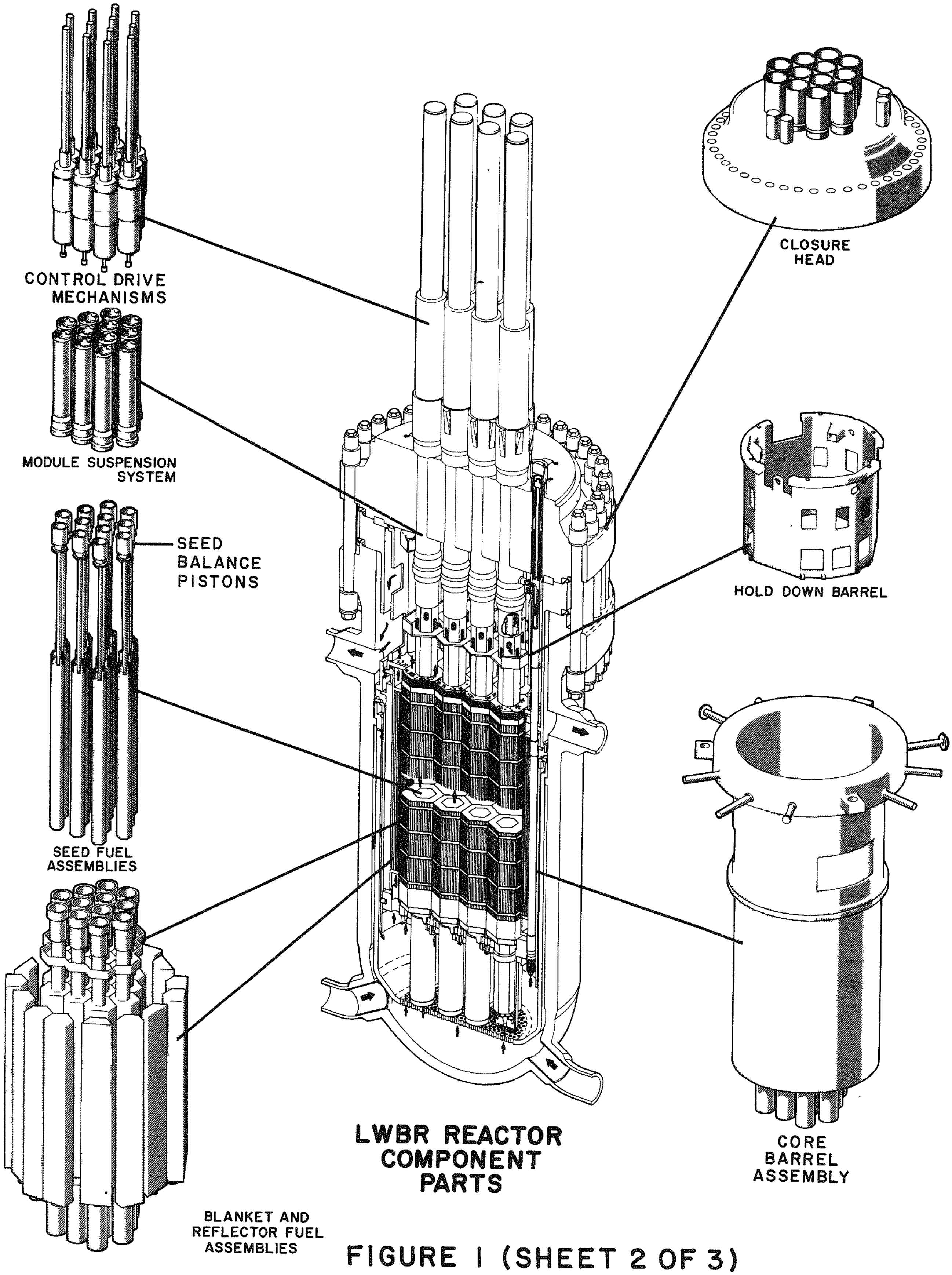


FIGURE I (SHEET 2 OF 3)
LWBR REACTOR

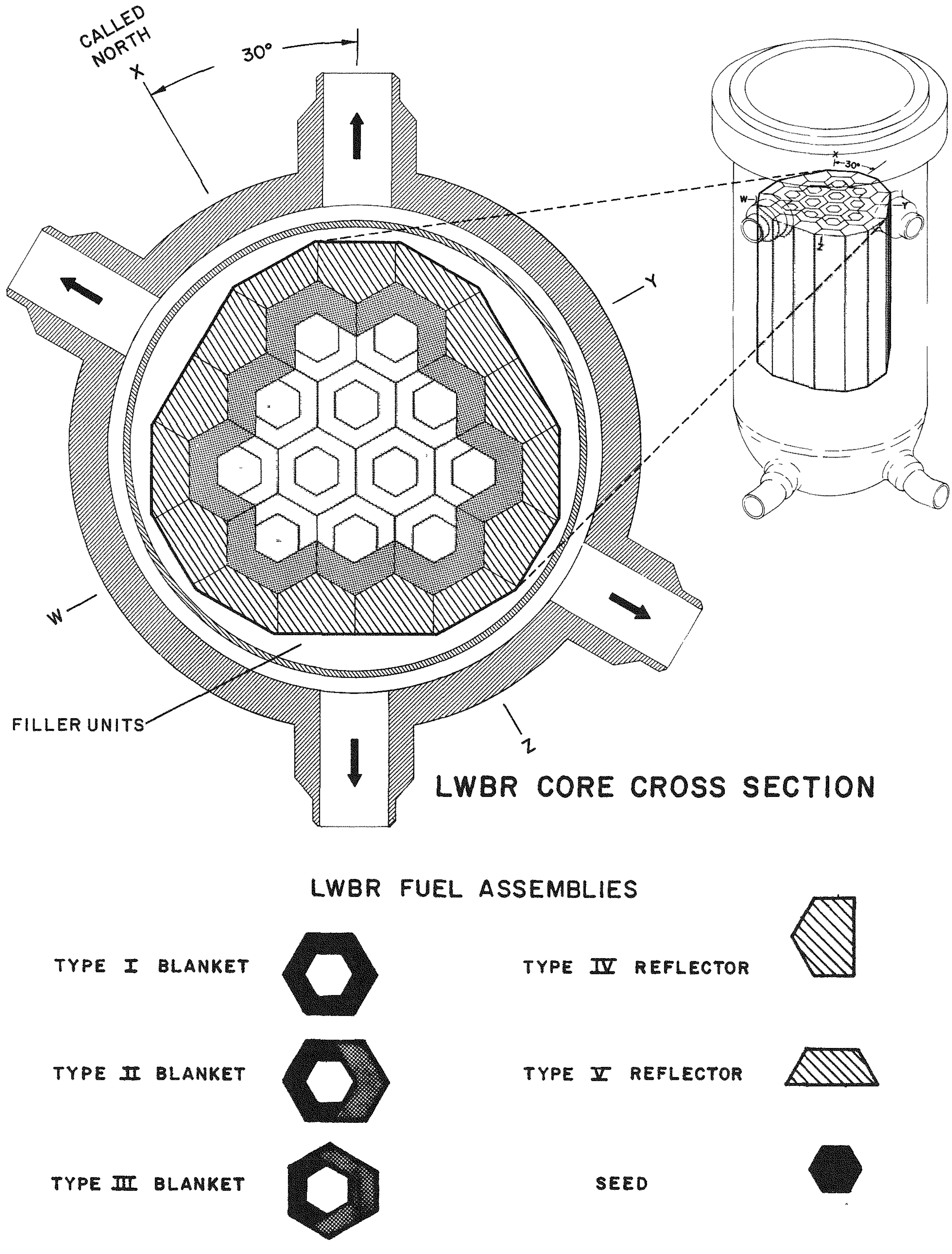


FIGURE 1 (SHEET 3 OF 3)
LWBR REACTOR

through the filler units were provided for the BIF supply tubes, the Safety Injection System Inlet, the flow measuring device tube assembly and the Inlet Temperature Instrumentation.

The reflector fuel assemblies form the periphery of the reactor core; they are suspended within the core barrel by a flanged lip on their top structural member (seal block) and are clamped in position by the holddown barrel. The holddown barrel rests on top of the reflector seal blocks and transmits a clamping force on the reflector assemblies, imposed by the closure head bearing against the top of the holddown barrel. The hexagonal-shaped blanket fuel assemblies fill the space envelope formed by the reflectors. The blankets are suspended within the core barrel from the closure head. Concentric cylinders are used to engage, lock and support the blankets, via their upper support tubes, to the suspension sleeves affixed to the underside of the closure head. Both the blanket and reflector assemblies engage holes machined into the bottom plate of the core barrel which provide both radial positioning and a channel for water flow into the fuel assemblies.

A seed fuel assembly is installed inside the hexagonal opening in the center of each of the twelve blanket assemblies. One of the unique aspects of the LWBR core is that the seed assemblies are moved up and down within the blankets during reactor operation to control reactivity. In the earlier Pressurized Water Reactors (PWR) at Shippingport, reactivity was controlled by changing the position of neutron-absorbing control rods in the reactor core.

Each LWBR seed assembly is suspended within the reactor by a long support shaft extending from the top of the fuel assembly. This support shaft is in turn secured to the leadscrew of the control drive mechanism (Figure 2) by means of the tie rod adapter and nut. The leadscrew is a long threaded shaft which is moved vertically by the rotation of the roller nut assembly within the control drive mechanism's motor tube assembly.

The control drive mechanism (CDM) (Figure 2) consists of a reluctance electric motor which rotates the roller nut to raise or lower the leadscrew to which the movable seed fuel assembly is attached. The roller nut is attached to the motor rotor, which is located within the reactor pressure boundary formed by the motor tube. The motor tube is threaded into the mechanism housing of the closure head and is welded in placed to provide a pressure tight seal. The stator is outside the pressure boundary. Torque is generated within the pressure boundary by the action of magnetic flux on the rotor. The roller nuts are attached to the segment arms of the rotor. Magnetic flux keeps the upper end of the

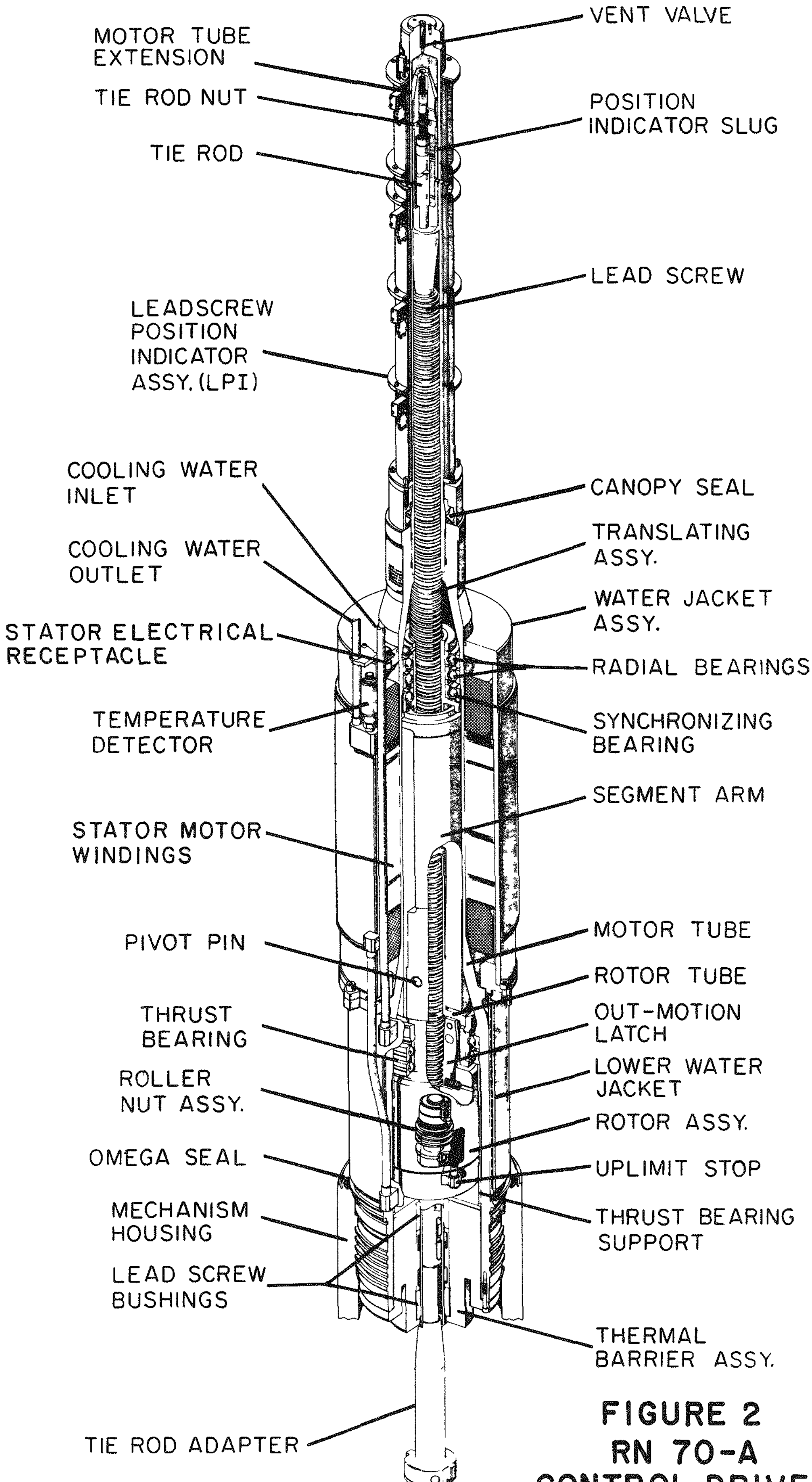


FIGURE 2
RN 70-A
CONTROL DRIVE MECHANISM

segment arms rotated outward in the motor tube. The roller nuts are attached to the lower end of the segment arms. The segment arms pivot on the pivot pins to keep the roller nuts in engagement with the lead screws. The reactor can be rapidly shut down (scrammed) by deenergizing the stator winding, which allows the roller nuts to move outward and disengage from the leadscrew. The leadscrew and attached seed assembly then drop out of alignment with the blanket assembly, causing the reactor to go subcritical.

A bypass inlet flow (BIF) system is used within the reactor to ensure the rapid scram of the movable seed fuel assemblies during reactor operation if the need to rapidly shut down the reactor should occur. The BIF system takes approximately 2 percent of the circulating water from the inlet flow region at the bottom of the reactor vessel, through the BIF supply tube and BIF cross-over pipe, directly to the top of the reactor core to above the seed balance piston, thus bypassing the restrictive flow channels that lower the pressure of the water passing through the core. This system provides a downward hydraulic force on each seed fuel assembly to balance the upward hydraulic force caused by water flow through the seed assembly flow channels. The weight of the seed assembly then provides assurance that the reactor will scram. Reference 1 provides a detailed description of the BIF system.

The refueling facility is located in the Fuel Handling Building (Figure 3). The reactor is located within an underground steel chamber below the building. Access to the reactor for refueling following shutdown is obtained by draining the shielding water from the reactor pit above the chamber and removing the steel chamber dome which, during reactor operation, isolates the reactor from the water in the reactor pit. Existing facilities within the building were adapted as storage areas for the major reactor components. At the northwest corner of the building the closure head was stored on its stand. Immediately north of the reactor pit, the new fuel storage facility was installed into a 26-foot deep dry storage pit. This facility was used to store the LWBR seed and blanket fuel assemblies under inert, dry Nitrogen gas blankets during the time interval between their receipt at Shippingport Atomic Power Station and installation into the reactor. The storage racks for the reflector assemblies and for the CDM motor tubes and translating assemblies were located in a dry storage pit at the south end of the building. The clean room for assembling the LWBR core barrel was located at the southeast corner of the building, where it was isolated from the canal area by a large rolling door. The refueling facility is serviced by an overhead bridge crane, with one 125-ton capacity and one 25-ton

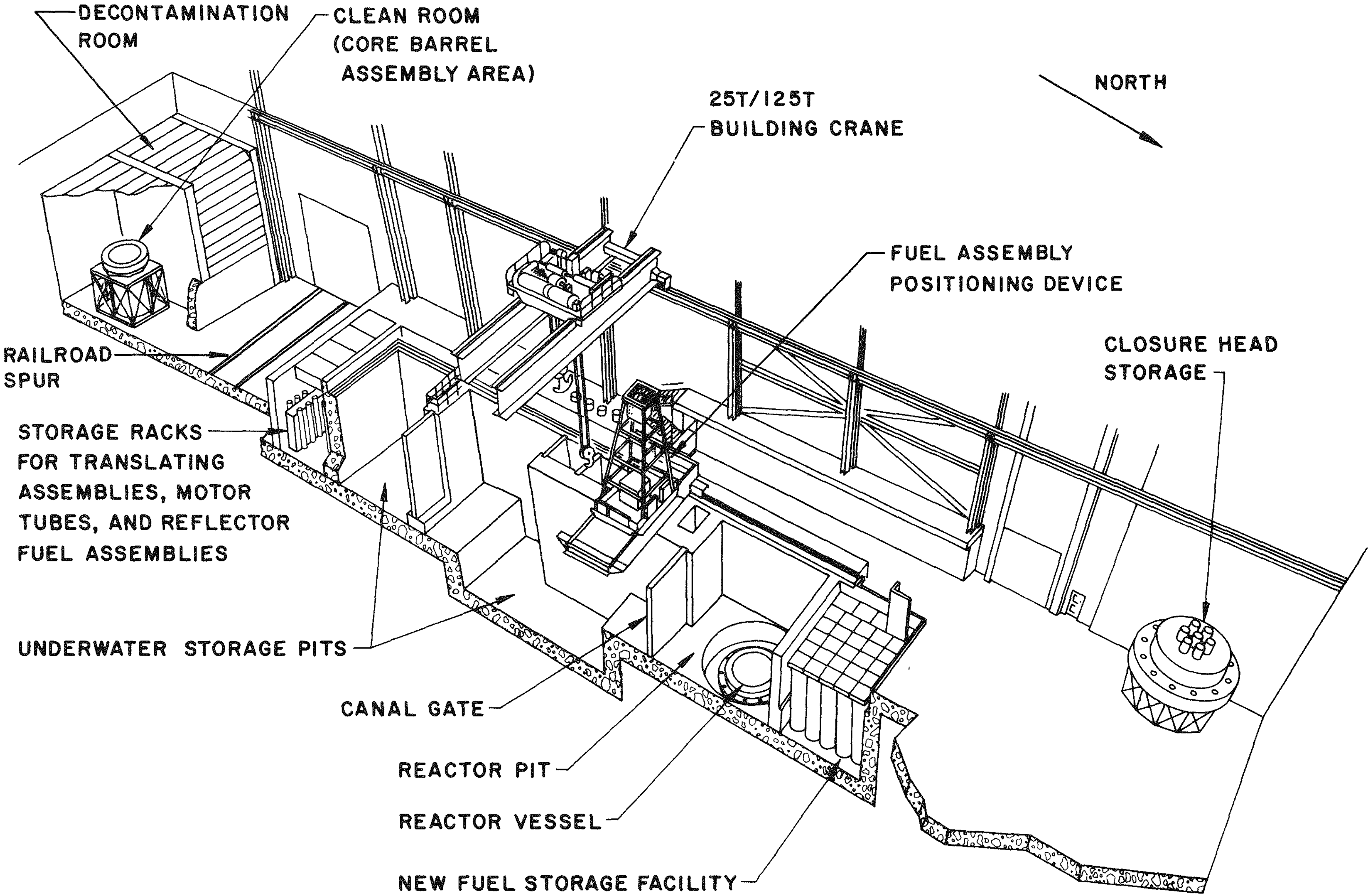


FIGURE 3
THE FUEL HANDLING BUILDING

capacity hoist, and several boom-type jib cranes of 3/4-ton capacity attached to the building columns. Within the center of the building are several underwater storage pits. These are used for storing irradiated and contaminated components following their use in the operating reactor and were not used for the LWBR installation operations. Other auxiliary systems, such as the decontamination room for cleaning contaminated equipment and change room facilities for personnel, are located within the building, as were additional storage facilities for the smaller reactor components and installation equipment.

III. DESCRIPTION OF THE LWBR INSTALLATION

A. Summary

The installation of LWBR entailed the receipt of the individually fabricated components and assembling them into the reactor vessel using detailed written procedures. Strict administrative controls were invoked to assure conformance to the specified procedures. To minimize the risk of any damage to components, extensive planning and development of the installation methods, and in-depth training of personnel, were employed, even though the basic assembly operations were similar to other large reactor assembly operations and clearances between fuel modules were larger than standard commercial practice. The descriptions which follow include the specific tasks which were required in the refueling work together with operations in preparing the reactor for initial criticality and eventual power operation. The method of performing key aspects of the installation and the difficulties that were encountered are discussed as the events occurred. In addition to the figures that accompany the following text, Appendix A presents photographs of the major installation operations that are described in this section.

A major trial fit program was part of the assembly process. In brief, almost every part that mated with another part was trial fitted well in advance of actual assembly into the reactor. Many problems were brought to light early enough to be resolved in a timely manner not delaying assembly of the reactor. See Appendix I for details of the trial fit program.

The LWBR installation occurred in five distinct phases:

Preparatory Phase - Following removal of the previous reactor core (which left only the thermal shield in the open reactor vessel), an in-service inspection of the reactor vessel was performed. Preconditioning and filtering of the entire primary system were then performed to provide a protective oxide film on the plant new primary system surfaces and to remove loose corrosion products from the system. Concurrent with preparing the reactor vessel for the new core, the assembly of the LWBR core barrel was completed in the clean room. Training of personnel, checkout of equipment, and receipt of the seed and reflector fuel assemblies also occurred during this period.

Phase I - The assembled core barrel was inserted into the reactor vessel, and the pressure boundary seal between the core barrel support flange and reactor vessel was welded. As a method of criticality control, the reactor vessel was drained of water and the blanket, seed, and reflector assemblies were then installed in the core barrel. The holddown barrel was installed onto the reflector assemblies.

Phase II - The closure head was placed on the reactor vessel and the suspension system components that engage and lock onto the blanket fuel assemblies were installed to suspend the blanket fuel assemblies from the closure head. The pressure boundary seal between the core barrel support flange and the underside of the closure head was welded.

Phase III - Control drive mechanism components were installed, and the motor tube omega seals on the mechanisms were welded. Exit water thermocouples and flux wire thimbles (dry wells) were installed and welded on the mechanism ports. Initial fill of the reactor vessel was completed.

Phase IV - Remaining head area components were installed and electrical cables connected. Final fill and venting of the reactor was completed and the reactor chamber dome installed. A hydrostatic test of the reactor vessel was performed, completing the installation of LWBR.

B. Preparatory Phase

1. Reactor Vessel In-Service Inspection and Preconditioning and Filtering of the Primary System

Following the removal of the core barrel and fuel of the previous reactor core, an in-service inspection of the reactor vessel was performed. The inspection consisted of dimensional inspection of the reactor vessel, nondestructive testing of various welds on the vessel, and a visual inspection of the accessible portions of the vessel interior. The thermal shield prevented an inspection of all of the vessel interior. The dimensional and weld inspections were performed using standard methods (micrometer measuring equipment, and liquid penetrant and magnetic particle inspection procedures). Visual inspection of the vessel interior was performed using a commercially available underwater television camera. The high radiation levels within the reactor vessel required that the inspection be performed remotely with the vessel full of water. The camera was positioned within the vessel and viewing was performed on a television monitor located outside of the radiation area. A video tape recorder was used to document the entire inspection.

Following the in-service inspection, the reactor vessel and four main coolant loops were filtered and the metal surfaces of the two new heat exchangers were preconditioned. The filtering and preconditioning were performed primarily to minimize the deposition of corrosion products (crud) on the LWBR core components during subsequent reactor operation. A large filter assembly, consisting of a large steel weldment to direct water flow and forty metal edge-type filter cartridges to remove debris, was installed inside the reactor vessel and the vessel was covered using an available hydrostatic test closure head. The reactor plant primary system was filled with water and the water was circulated through the vessel and four coolant loops using the main coolant pumps. The heat input of the coolant pumps was enough to heat the circulating water to normal plant operating temperatures (between 481 to 531F) to precondition the surfaces of the new heat exchangers. Following completion of the water circulation, the test head was removed from the vessel and the material trapped by the filter was inspected; the inspection disclosed no foreign material other than the expected sediment deposited on the filter. After removal of the filter assembly, the bottom of the reactor vessel was vacuumed and inspected again for foreign material. Appendix B describes in depth the preconditioning evolution and the functional characteristics of the filtering equipment.

2. Seed, Blanket and Reflector Shipping, Receipt and Storage

While preconditioning and filtering of the primary system was being performed, the reflectors and seed fuel assemblies were received and stored. The blankets were shipped somewhat later. See Appendix E for details of the shipment of the reflector, seed and blanket assemblies. The two types of reflector assemblies were unloaded from the trailer mounted shipping container and stored in racks at the south end of the Fuel Handling Building. The seed fuel assemblies were stored in the New Fuel Storage Facility at the north end of the building. During receipt of the seed fuel assemblies, a balance piston and buffer cylinder were attached to the top of the seed support shaft before placing the assembly in storage. The balance piston/buffer cylinder assembly was positioned over the seed support shaft and the keys on the balance piston were engaged with mating slots on the seed support shaft, and secured in place using the balance piston nut (Refer to Figure 5).

Each seed module was receipt inspected, and each translating assembly was trial fitted to the seed fuel assembly, prior to placing the seed into storage. The receipt inspection program confirmed there was no shipping damage. The trial fit of the translating assemblies detected one misorientation of a balance piston on a seed support shaft, which was corrected prior to installation into the reactor.

3. Completion of the LWBR Core Barrel Assembly

The assembly of the LWBR core barrel was performed in the clean room facility at the south end of the Fuel Handling Building. Because the core barrel was too large to ship as a unit, it was assembled at the site from a series of machined components supplied by fabrication vendors. These components are shown in Figure 4. All operations were performed in the clean room assembly stand which supported the components during assembly.

One of the important operations during the core barrel assembly was the need to align the three major components (the bottom plate, the lower barrel, and the upper barrel-seal ring assembly) with each other to ensure the dimensional envelope required for the subsequent installation of the fuel and reflector assemblies. To accomplish this alignment, optical alignment equipment, in conjunction with precision machined reference holes in the components, was used during the positioning of the three core barrel components to check the alignment prior to the physical attachment of the components to each other. While precise alignment procedures were used, these procedures were no more difficult or precise than those used to align other large machined assemblies, such as stationary compressors or turbines. Appendix C gives a further description of the optical alignment equipment, its measuring capabilities, and its application to the core barrel assembly.

The first operation in the assembly was the alignment and attachment of the lower barrel to the bottom plate. This attachment is made by twenty-one 2.5-inch diameter pins through holes in the lower barrel into mating penetrations in the bottom plate. The mating holes had been match-drilled by the component vendor prior to delivering the components to the site. Before installing the interference fit production pins, temporary pins were installed and the alignment checked using optical equipment; then the temporary pins were replaced

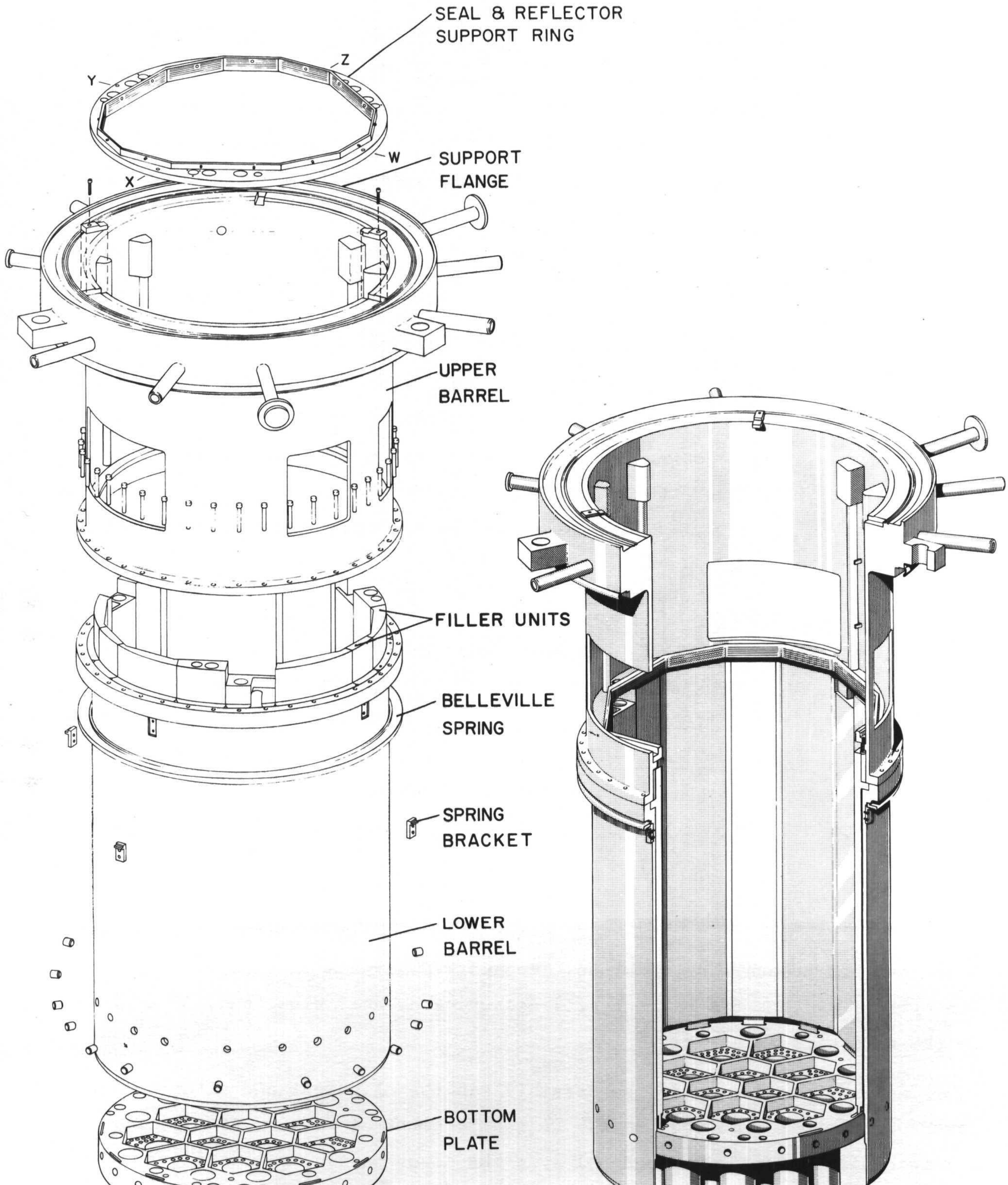


FIGURE 4
LWBR CORE BARREL ASSEMBLY

by the production pins one at a time using liquid nitrogen to shrink the pins for installation. The production pins were lockwelded in place following insertion.

The flow measuring tubing, consisting of two groups of 16 tubes each, was joined between the lower barrel and the bottom plate. This tubing is shown schematically in Figure D-1. This tubing, which was furnished as part of the bottom plate, lower barrel and upper barrel assemblies, was connected by means of sleeves brazed in place on the mating tube sections. The brazing of these pieces within the limited space available necessitated the development and qualification of an inductive brazing method. A description of the brazing method and its development is presented in Appendix D. The core barrel assembly also contains one group of seven guide tubes for inlet water temperature thermocouples. The joints for these tubes, which also occur at the interfaces of the bottom plate and lower barrel, were made by threaded disconnect joints, lock welded in place. The filler units (see Figure 4) were then installed in the lower barrel-bottom plate subassembly. These stainless steel filler units are used to adapt the circular cross section of the core barrel to the egg-shaped cross section of the core. The 15 filler units were installed by engaging a tab at the base of the filler with a slot in the bottom plate while a support flange was seated on a ledge at the top of the lower barrel. The filler units were then secured using lockwelded dowel pins and bolts. Following installation, measurements of the envelope formed by the filler units were obtained to confirm that the proper dimensional envelope existed to accept the fuel and reflector assemblies.

The final core barrel assembly operation was mounting the upper barrel on the lower barrel. Prior to installing the upper barrel, the lower main closure seal was raised up around the upper barrel and secured to the bottom of the support flange. The upper barrel was then lowered onto the lower barrel, guided into rough alignment by two alignment pins through the mating bolt flanges. Optical alignment methods (see Appendix C) were used to align the upper barrel with the lower barrel-bottom plate subassembly. Following alignment, four dowel pin holes on the mating flanges were match drilled to size and dowel pins were interference fit into the holes, located 90 degrees apart around the barrel. Thirty-two 1-inch diameter bolts were then installed and secured by locking cups to complete the joint. Following installation of the upper barrel, the

Belleville spring, which had been placed on the assembly stand prior to placing the lower barrel in the stand, was raised into position on the underside of the lower barrel bolting flange and secured in position.

The 32 flow measuring tubing joints, and seven guide tubes for inlet water temperature thermocouples, between the upper and lower core barrels were joined using the methods described above for the joints between the lower core barrel and the bottom plate.

During the assembly and following the completion of the core barrel, various core components were trial assembled into the core barrel to determine potential assembly problem areas. The components included the blanket module stub tubes, the reflector assemblies, and the BIF supply tubes. An evaluation of the trial assembly is included in Appendix I.

4. Preparation of the Closure Head

The LWBR closure head, following its receipt, was stored on a support stand within the Fuel Handling Building, where it was dimensionally inspected and the instrumentation spacers were installed into the mechanism housings. The instrumentation spacers rest on an internal ledge of the mechanism housings, where the suspension sleeves are bolted to the closure head weldment, and were installed by inserting the spacer into the mechanism housing until an alignment key on the spacer engaged an alignment slot within the housing. No other components were permanently installed to the as-received closure head at this time.

While the closure head was stored, an extensive program of trial fitting the head area components was performed. These components included all the control drive mechanism motor tubes, stators and power cables, the instrumentation cables, the water lines, the BIF port plugs, the service lead support structure (a steel framework that serves as a personnel walkway and also supports the auxiliary piping and electrical cables for the head area components) and the flux measuring guides. With these components installed, measurements were taken to ensure the proper mating of components. The trial assembly operations disclosed some fit-up problems, with adequate time to modify the components before their final installation. An evaluation of the trial assembly program and descriptions of the problems encountered are contained in Appendix I.

5. Evaluation of the Preparatory Phase

The preconditioning and filtering of the reactor vessel and other primary system components were performed without any major problems, and the subsequent filter inspection disclosed only the sedimentary deposits expected. Fuel receipt and storage operations proceeded smoothly, due in part to the extensive training of personnel using fuel assembly mockups that permitted the debugging of the detailed working procedures and handling equipment in addition to familiarizing personnel with the fuel handling operations.

Assembly of the LWBR core barrel also involved several design changes to the as-built components that required either in-place modifications to the barrel components or removal of the components for outside machining. These modifications are covered in the problems encountered section of Appendix J. These modifications were accomplished in a timely manner and did not delay the fuel installation.

C. Phase I - Installation of the LWBR Core Package

1. Core Barrel Installation

The assembled core barrel was transferred from the clean room assembly area to the reactor vessel using the 125 ton crane and a core barrel grapple which had been provided for use with previous PWR cores and specially modified for LWBR use. The core barrel was inserted into the reactor vessel while being aligned with the reactor vessel flange using alignment pins. Upon seating the core barrel and removing the lifting equipment and alignment pins, three large mechanical seating devices were attached between the barrel support flange and the reactor vessel; the seating devices provided a load on the core barrel sufficient to compress the Belleville spring (see Figure 4) and provided metal-to-metal contact of the barrel support flange with the reactor vessel. Compression of the spring was necessary to ensure the core barrel was level during the subsequent fuel installation. (Refer also to Appendix F.) Compression of the Belleville spring at this time also permitted the manual welding of the lower main closure seal between the barrel support flange and reactor vessel.

2. Fuel Installation

The installation of the fuel assemblies required the prevention of an inadvertent nuclear criticality. With the seed fuel assemblies partially inserted into the blanket fuel assemblies, a critical situation could occur in the presence of a moderator (water). (See Appendix H.) Therefore, criticality control was effected by draining the reactor vessel of water and isolating the reactor area from any water sources.

The fuel installation sequence proceeded from the center of the core outward, beginning with the center three blanket assemblies. The installation sequence of the blanket fuel assemblies was important in that it maximized the available space within the reactor vessel during insertion of a particular blanket fuel assembly. This was necessary because of the potentially small (a minimum of 0.014 inch) clearance between adjacent blanket fuel assemblies when they are installed in the core barrel and located on designed module center lines. By inserting the blanket fuel assemblies from the center outward, the blanket being inserted was free of close clearances in the radially outboard direction and never interfaced with adjacent blanket fuel assemblies on more than three sides. A seed fuel assembly was installed after its mating blanket assembly was installed. Reflector fuel assemblies were installed as the installation of adjacent blankets was completed.

Typically, a blanket fuel assembly with a module guide installed was rigged to the 25-ton capacity building crane by its installation tool and a three legged turnbuckle leveling assembly. The blanket was then removed from its storage location and transported to the leveling (plumbing) station mounted on the south wall of the reactor pit (see Figure A-11). The leveling (plumbing) station used eddy current sensors to measure the proximity of the blanket sides to the detectors, and thus measured the verticality of the fuel assembly. Adjustments to plumb the fuel assembly were accomplished by adjusting the turnbuckle leveling assembly.

Plumbing the blanket fuel assemblies was desirable to minimize the potential for contact of the blanket guide posts as the blanket module was lowered within the adjacent assemblies already in the reactor core barrel. As shown in Figure A-12, the blanket fuel rods are exposed on all six sides of the fuel assemblies with the grid supports extending beyond the periphery of the fuel rods at eight locations. Also shown in Figure A-12 are the corner guide posts which extend a minimum of 0.005 inch beyond the grid supports. These corner guide posts prevented grid-to-grid hangup as the modules were lowered into the reactor core barrel. To further minimize the chance of intermodule contact, the blanket fuel assemblies were remotely guided during insertion.

Direct manual guidance of the blanket fuel assemblies was not desirable because of the radiation levels associated with these uranium-233 bearing fuel assemblies resulting from the decay of the uranium-232 impurities.

Once plumbed, the blanket assembly was positioned over and lowered into the reactor vessel. Machined guide plates and brackets, which were pinned to machined holes in the core barrel flange, were used to locate and guide the blanket during insertion. The blanket was lowered until its bottom extension tube engaged and seated within the mating cavity in the core barrel bottom plate. The seed fuel assembly was then installed into the blanket. Because the seed has a symmetrical cross section and a smooth shell exterior, the seed hung vertically without rigging adjustments, and could be inserted into the blanket without guiding devices other than the blanket guide tube. The seed was lowered into the blanket until the buffer cylinder seated in the blanket module support tube, suspending the seed within the blanket. A positioning post was then installed in the blanket module support tube, and the upper end of each seed-blanket assembly was positioned toward the center of the core to provide maximum clearance for the next blanket or reflector to be installed. The reflectors were rigged and plumbed similar to the blanket fuel assemblies, but were manually guided by personnel instead of using module guide plates and brackets. This was acceptable since the reflectors, containing only thoria (no uranium), gave off a very low radiation dose rate and proximity of personnel to the reflector was allowed during the entire lowering operation. In addition the reflectors, like the seed fuel modules, had a smooth exterior which prevented module hangup on adjacent blanket fuel modules.

Throughout the fuel installation operations, strict administrative controls were imposed to ensure placement of the fuel assemblies in their assigned locations within the core barrel. These controls included independent verifications of each fuel assembly serial number and its installed location by persons separate from the production organization. Proper operation of the reactor was assured by having each specific module in the correct location and rotational orientation in the core because of different fissile fuel loading within these blanket fuel assemblies.

Appendix F provides a more detailed description of the design and use of the leveling (plumbing) station and module guide plates.

3. Holddown Barrel Installation

Upon completion of the fuel installation, the barrel seating devices were removed and the vessel prepared for installation of the holddown barrel. The holddown barrel was installed into the reactor vessel using the core grapple (as was used for installing the core barrel) and was aligned during lowering so that the keyways on the holddown barrel engaged the three keys protruding from the inside of the core barrel and the flux thimble guide tube on the holddown barrel engaged the mating tube in the one instrumented reflector. Once the holddown barrel was seated to rest on the reflector seal blocks, measurements were taken and six compression discs were custom machined such that when they were installed on the top surface of the holddown barrel, the installation of the LWBR head would provide the correct predetermined preload on the reflectors. A problem with machining of the discs to length is described in Appendix J.

4. Evaluation of Phase I Operations (Installing the LWBR Core Package)

The core package installation operations were performed with no problems compromising the nuclear safety of the operations or integrity of the core components. Some minor problems with the servicing equipment were encountered, involving initial seating of the core barrel and malfunctions of the leveling station readouts resulting from damaged electrical connectors, but these nonrecurrent problems were resolved easily. These equipment problems are further described in Appendix J.

The actual fuel installation period covered three months and involved no significant problems. This time span was controlled by the receipt of the blanket fuel assemblies during the fuel installation period. Each blanket was received, unloaded from its shipping container, receipt inspected, and placed in storage prior to its installation. A significant time reduction could have been obtained by having all fuel assemblies available on-site at the start of fuel installation.

The receipt inspection at Shippingport of all seed and blanket fuel assemblies, and of the reflector assemblies, found no shipping damage. The precautions taken during shipping, as described in Appendix E, were adequate to ensure retention of fuel and reflector assembly integrity during highway truck shipment from the Bettis Laboratory to Shippingport, a distance of approximately 55 miles.

D. Phase II - Installation of the Closure Head and the Module Suspension System

In preparation for installation of the LWBR head, an attempt was made to confirm proper location of all penetrations of the head by taking precision photographs of the lower end of all penetrations, using a precision grid, plumb bobs, and photogrammetric techniques. The attempt was not wholly successful because the head was supported too close to the floor to take precision photographs.

The LWBR closure head was installed on the reactor using the 125-ton building crane, and was aligned over the vessel and core barrel using large alignment pins that engaged holes in the closure head bolting flange with related holes in the core support flange lugs. As the head approached its seated position on the core barrel support flange, three machined keys on the support flange engaged mating machined keyways on the closure head to provide precise alignment. With the closure head seated on the support flange, the holddown barrel was seated against the reflector seal blocks and the twelve module suspension sleeves were located just above the blanket support tubes. Each seed-blanket assembly was then raised into engagement with the closure head suspension sleeves and held in place by the breechlock sleeve and compression sleeve installation. The suspension system arrangement is shown on Figure 5.

1. Breechlock Sleeve Installation

The blanket fuel assemblies are suspended from the closure head, as previously identified. The breechlock sleeve and nut are the components which support and lock the blanket fuel assembly into the closure head suspension sleeve. Installation is accomplished using a tool with two lifting heads (Figure 6). The upper tool head engages the lifting holes in the breechlock sleeve while the lower tool head engages the lifting holes in the blanket support tube. A gear drive assembly permits raising and lowering the upper tool head relative to the rest of the tool to effect lowering the breechlock sleeve into its installed position. The installation requires precise alignment of the blanket support tube with the closure head suspension sleeve, and alignment of the mating lugs on all three components. The installation required that all operations be performed using remote position indicators on the tool since all mating components are contained below the closure head. Briefly, the installation was performed as follows:

a. The breechlock sleeve was attached to the installation tool (Figure 6) and supported by the upper tool head.

b. The installation tool, with the breechlock sleeve, was lowered into the mechanism port and the lower tool head engaged with the blanket support tube. The seed-blanket assembly was then raised by the tool until the blanket support tube seated within the closure head suspension sleeve (Steps 1 and 2 of Figure 7). Alignment was effected by a key on the support tube engaging a keyway in the suspension sleeve.

c. The breechlock sleeve was then lowered using the tool gear drive mechanism, while the blanket support tube remained supported from the main tool body. As the breechlock sleeve was lowered, the six support lugs on the breechlock sleeve passed between the mating lugs on the blanket support tube (Step 2 of Figure 7).

d. The breechlock sleeve was then rotated to position the six support lugs on the exterior of the breechlock sleeve directly beneath the internal

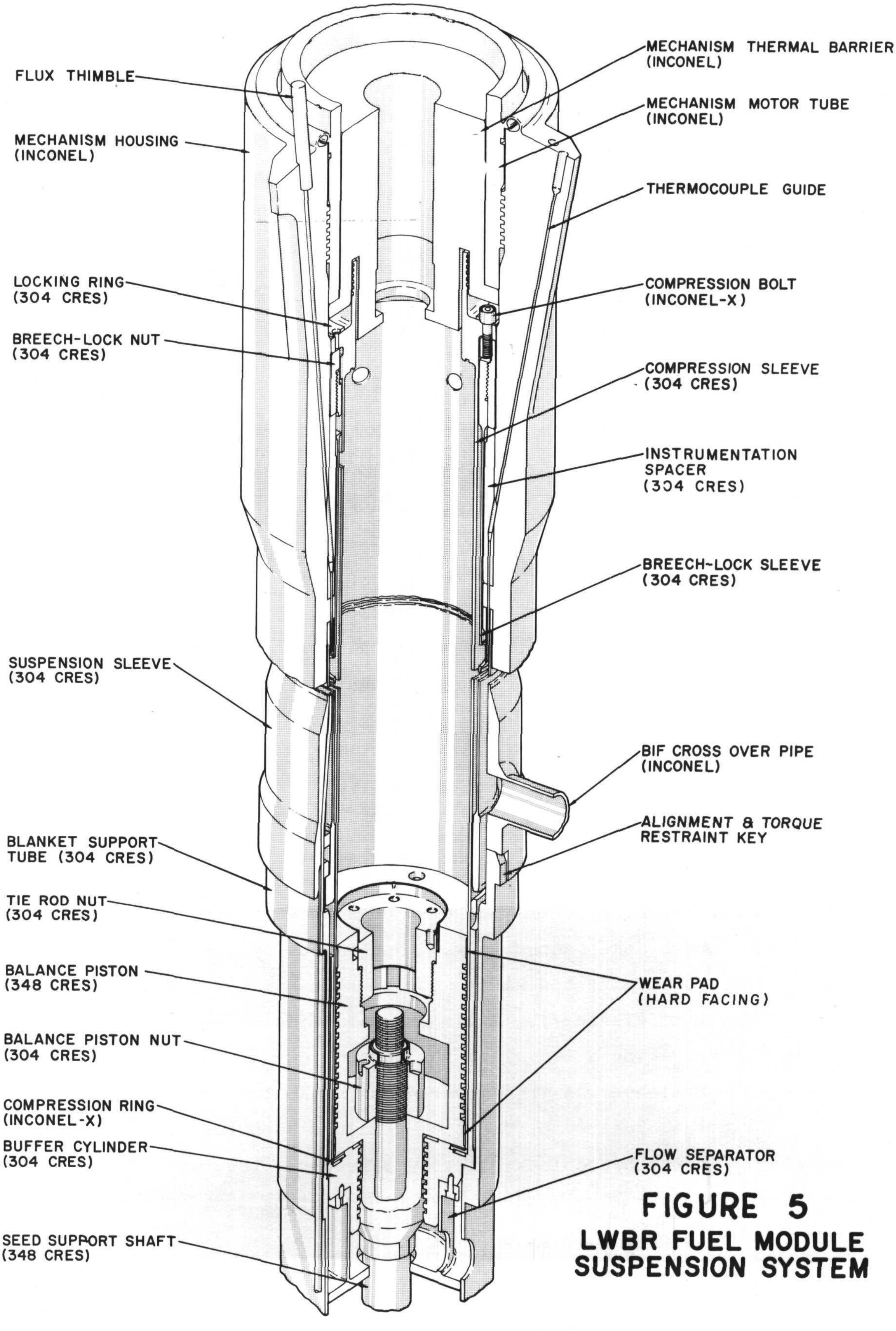
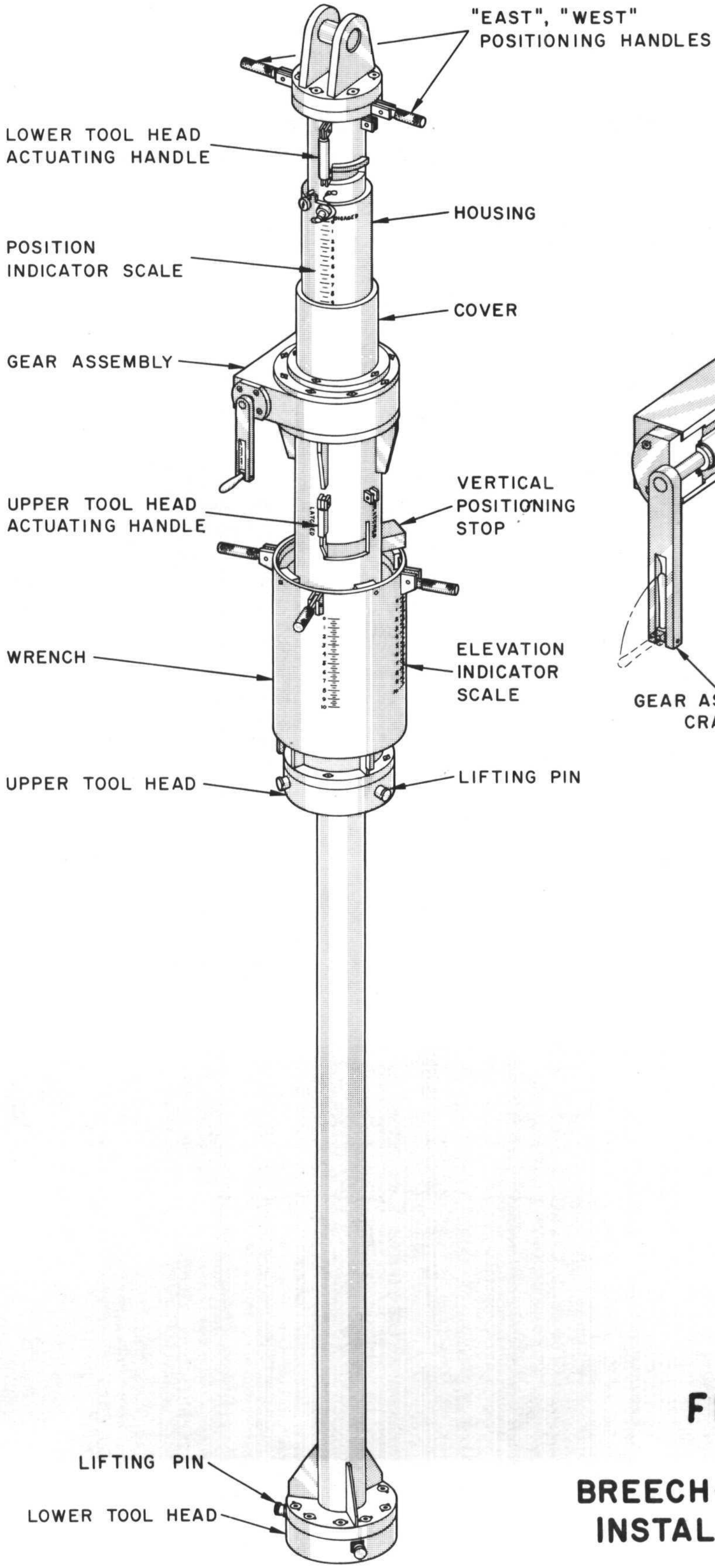
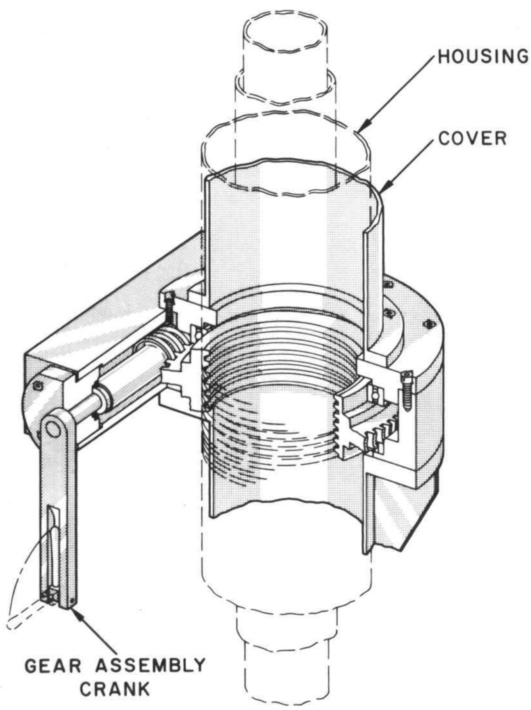
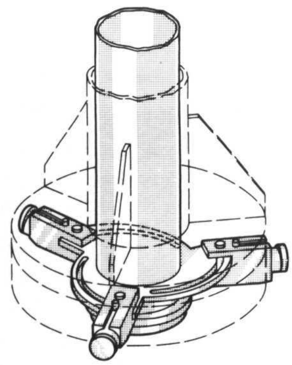


FIGURE 5
LWBR FUEL MODULE SUSPENSION SYSTEM



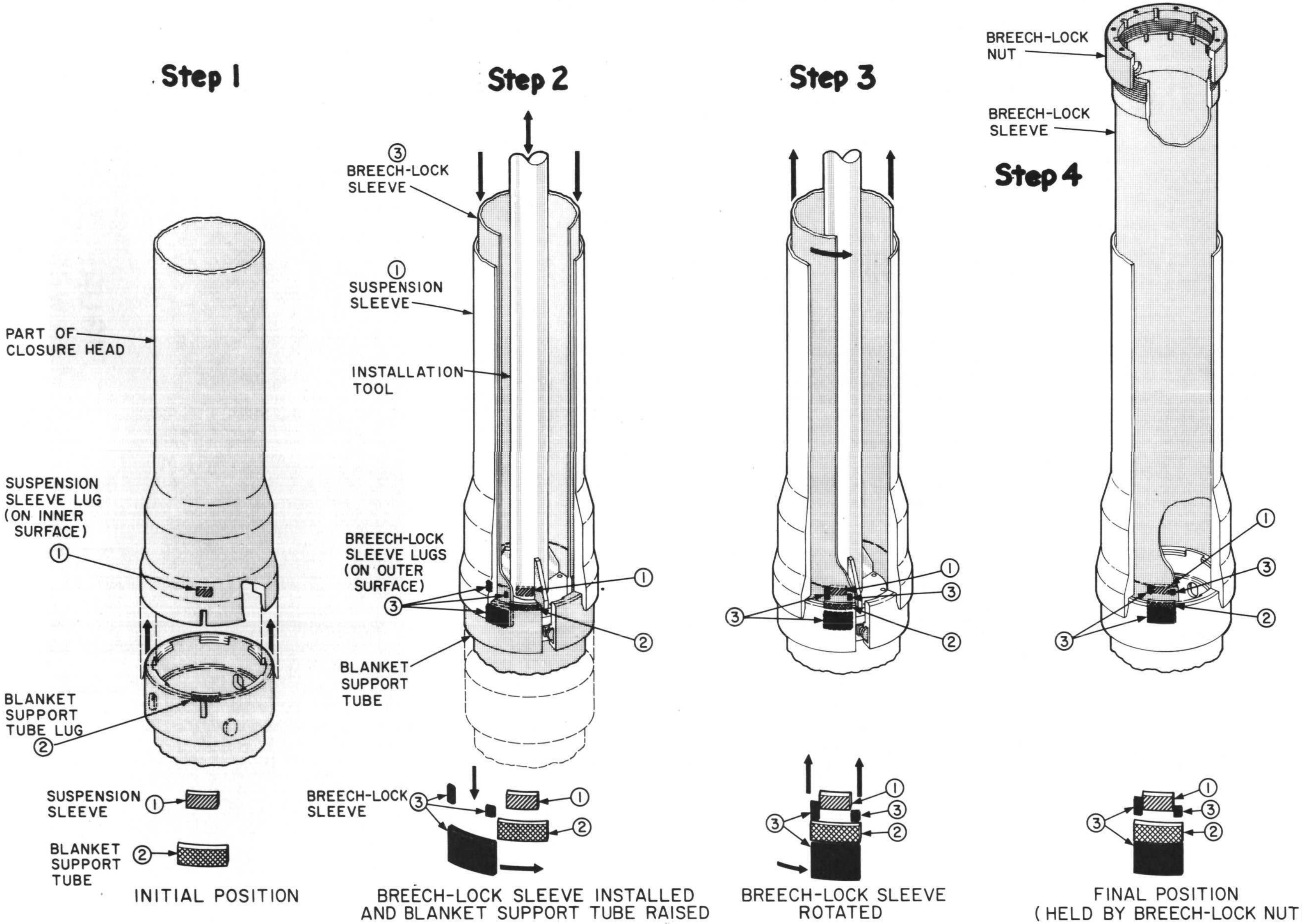


GEAR
ASSEMBLY



LOWER
TOOL HEAD

FIGURE 6
LWBR
BREECH-LOCK SLEEVE
INSTALLATION TOOL



LWBR BLANKET MODULE SUSPENSION SYSTEM (SHOWING LUG POSITIONS)

FIGURE 7

support lugs on the blanket support tube. Rotation was limited by the larger of two small locking lugs on the breechlock sleeve contacting the single lug on the closure head suspension sleeve (Step 3 of Figure 7).

e. The breechlock sleeve, with attached blanket fuel assembly was then raised using the tool gear drive mechanism until the six support lugs contacted the six lugs on the blanket suspension sleeve, thus raising the blanket fuel assembly approximately three inches. Simultaneously, the two small locking lugs on the breechlock sleeve passed around the lug on the head suspension sleeve, thus preventing further rotation. The breechlock nut was turned down using the tool wrench sleeve to lock the items in position. The installation tool was then removed (Step 4 of Figure 7).

2. Breechlock Sleeve Tensioning

Each breechlock sleeve was tensioned using a hydraulic tensioner. The tensioner rested on a thread protector installed in the mechanism port and was engaged with the breechlock sleeve lifting holes. A prescribed pressure was applied to the breechlock sleeve tensioner, resulting in a predetermined stretch of the sleeve to yield the desired preload. While the pressure was maintained, the breechlock nut was seated using a wrench integral to the tensioner; then the nut was backed off until one of the slots on the breechlock nut aligned with one of the slots on the breechlock sleeve. The pressure was then released and the tensioner removed from the mechanism port.

3. Compression Sleeve Installation

The compression sleeve, which provides the passage for translation of the seed fuel assembly balance piston, is concentric with the breechlock sleeve. The bottom of the compression sleeve bears against the compression spring within the buffer cylinder. A bolting flange on the upper end of the sleeve is secured to the breechlock nut previously installed and provides the axial load necessary to effect the watertight seal at the base of the compression sleeve.

The compression sleeve was installed using a tool similar in design to the breechlock sleeve installation tool. The compression sleeve was attached to the upper tool head and the sleeve/tool combination was lowered into the mechanism port. The lower tool head was then engaged with the balance piston on the seed fuel assembly and the seed raised slightly (no more than 1/4 inch) to "float" the seed within the blanket and permit unobstructed lowering of the compression sleeve. A gear drive mechanism lowered the upper tool head, with the compression sleeve, until the sleeve seated on the compression spring. During lowering, a key on the outside of the compression sleeve engaged the aligned slots of the breechlock sleeve and breechlock nut previously installed to lock these components together. The seed was reseated and the installation tool removed.

4. Compression Sleeve Preloading

A hydraulic preloading tool was used to compress the compression sleeve, thus providing a controlled deflection of the compression spring at the base of the sleeve. The spring deflection had to be controlled since the spring could not be deflected so much as to go solid against the buffer cylinder. This would reduce the preload between the blanket support tube and the suspension sleeve. However, the deflection must be enough to prevent excessive flow leakage of the BIF system and to prevent upward movements of the buffer cylinder.

The preloader was bolted to a thread protector installed in the mechanism housing, and a hydraulic pressure was applied to compress the sleeve and compression spring. The bolts that connect the compression sleeve flange to tapped holes in the breechlock sleeve nut were installed and torqued to maintain the preload, and the preloader was depressurized and removed.

5. Evaluation of Phase II Operations (Installing the Closure head and Module Suspension System)

All of the Phase II operations were performed expeditiously. All equipment operated satisfactorily, resulting from the detailed training and check-out operations performed prior to the actual installation. Minor tool modifications had been completed well ahead of the Phase II evolution.

During installation of the first two compression sleeves, seating measurements (required before installing the preloader) were out of tolerance, for the III-4 and III-3 core locations. The out-of-tolerance condition resulted from the accumulation of small dimensional deviations of the as-built assembly. This required the addition of spacers, requiring removal and reinstallation of these two sleeves. This problem is discussed in Appendix J. The design of the bypass inlet flow (BIF) system is described in detail in Reference V.1.

E. Phase III - Installation of Closure Head Components and Initial Fill of the Reactor Vessel

The Control Drive Mechanism (CDM) components (translating assembly and motor tube) were installed on the twelve mechanism ports, and the omega seals for these motor tubes were welded. The fill piping for adding water to the reactor was installed and initial fill of the reactor vessel was performed, using neutron sources temporarily inserted into the core to assist monitoring core reactivity during fill. Following the initial fill, which had used the BIF ports for installing the fill piping, the BIF system components (supply tubes, tension-compression tubes, and port plugs) were installed.

Concurrent with these major operations, the core instrumentation (thermocouples and BIF system pressure taps) was installed into the mechanism port penetrations and welded in place. The upper main closure seal was manually welded between the closure head and core barrel support flange, and the forty-two main closure studs that secure the closure head to the reactor vessel were installed.

1. Installation of Translating Assemblies and Motor Tubes

The translating assembly is supported and keyed into a recess at the top of the seed balance piston and held in place by a tie rod nut clamping the translating assembly bottom flange to the balance piston. Installation and torquing of the tie rod nut was performed remotely using a long installation tool that fit over the entire translating assembly. Following installation of the translating assembly, the CDM motor tube/rotor assembly was lowered and threaded into the mechanism port. During tightening the motor tube was centered within the clearance of the large Acme threads so as to align the omega seal halves on the motor tube for subsequent welding operations.

2. Welding of the Motor Tube Seals

The twelve mechanism ports on the LWBR closure are closely packed. This was necessary because of the core design which has a movable seed within each stationary blanket, and because of the large control drive mechanisms required to handle the heavy (over 2000-pound) movable seeds. To permit access for welding, the inner three motor tubes were welded before any other motor tubes were installed. Welding was performed using an automatic welding machine that fit over the motor tube and occupied the space normally taken by the CDM stators. The rotating welding machine fused a consumable insert to the omega seal halves to provide the primary pressure boundary seal. A detailed description of this welding process and development is contained in Appendix G.

3. Initial Fill of the Reactor Vessel

The reactor vessel was filled in a two-part process: the initial fill added water to cover the fuel assemblies, and the final fill and venting (which filled the vessel up to the top of the motor tubes) was performed after completion of the reactor assembly.

Initial fill was accomplished using a slow fill rate, approximately five gallons per minute. A separate, continuously operating, recirculation pump operating at 15-20 gallons per minute provided the capability to stop the fill and drain water from the vessel, if necessary, to provide negative reactivity insertion. While the recirculation pump maintained adequate flow, it consistently pumped less than expected. This was postulated to be caused by entrained gases from the nitrogen purge which gas bound the pump.

During the fill, the reactivity of the core was monitored using the installed nuclear instrumentation system. Artificial neutron sources were temporarily inserted into the core to bring the neutron flux rate within the range of the core neutron detectors since the natural flux of the core was too low to be monitored. Core reactivity was continually monitored during the initial fill, with both automatic and manual methods available to stop the water addition should the count rates show an approach to criticality. (Alternate methods of reactivity control, such as cocked movable fuel assemblies and boron injection, were considered, but were undesirable as explained in Appendix H.)

4. Installation of the BIF System Components

The long BIF supply tubes, which provide the flow path for the inlet primary coolant, were inserted into each of the six BIF ports in the closure head. Each supply tube was guided and aligned by a long guide tube as it passed through the support brackets on the inside of the core barrel and entered the opening in the core barrel bottom plate (see Figure 1). Alignment of the BIF supply tube outlets with the piping on the underside of the closure head was accomplished by a key on the supply tube engaging a keyway on the closure head penetration. A tension-compression tube assembly was then installed into each port. These tubes engage and lock the supply tubes in position within the closure head and suspend the BIF supply tube from the head.

One of the necessary steps to obtain proper preload of the BIF tension-compression tube assembly was the torquing of each locking nut three times. To avoid performing all three preloading operations in the reactor, which would have delayed the assembly, all BIF tension-compression assemblies were sent to the Bettis Laboratory where two of the three preloadings were performed.

Following installation of the BIF tension-compression tubes, a closure plug was installed into the BIF port and the omega seal was manually welded to close the primary system boundary.

5. Evaluation of the Phase III Operations (Installing the Closure Head Components)

The operations for installing and welding the CDM components proceeded very smoothly, as did the manual welding of the main closure seal and instrumentation plugs. BIF system components were installed without any problems, and the hydraulic tensioners used to preload the main closure studs operated without incident.

Installation of the neutron sources into the reactor core required modification of the temporary source guide tubing and the flux thimble penetration in the closure head, which was determined well in advance of actual insertion during trial insertion exercises using dummy sources. The modification required redesigning the temporary guide tube adapters and boring the flux thimble end connectors in place on the closure head. The end connector opening had apparently shrunk from welding the flux thimbles to the closure head. This problem is further described in Appendix J. Following resolution of these difficulties, the neutron source insertion and initial fill proceeded without problem.

F. Phase IV - Installation of Reactor External Components, Final Fill and Venting, and Hydrostatic Test

1. Completion of the LWBR Reactor Assembly

The final CDM components were installed at this time. A stator was lowered and seated over each of the twelve motor tubes. Energy absorbers (shown in Figure A-22) were placed over each stator, and large holddown beams were placed horizontally across the stators and bolted to the closure head. The energy absorbers and holddown beams are used to prevent outward motion of the control drive mechanisms and movable seed assemblies in the event of a rupture in the pressure boundary in the control drive mechanism or head housing. The position indicator coils (which are used to measure the height of the translating assembly during core operation, and thus measure the axial movement of the movable seed fuel assemblies) were placed over the motor tubes and clamped in place. The service lead support structure, which is used to support and guide the numerous electrical cables to the reactor, was secured to the closure head and electrical connection to the thermocouples, the CDM stators, and the position indicator coils were made. Cooling water piping for the CDM components (also supported by the service lead support structure) was connected to the mechanism stators.

Final fill of the reactor was completed, using a vent valve in the top of each CDM motor tube to allow water to exit the reactor and ensure the release of entrapped air. Following the fill, the valves were shut, the valve actuators removed (the valve itself is integral with the motor tube) and a plug manually welded into each motor tube to complete the reactor primary pressure boundary. During this period, the stator cooling water lines were also installed, and the installation and checkout of the axial flux measuring system guide tubing were completed.

The reactor chamber dome was installed to complete the reactor installation, and a series of cold and hot hydrostatic tests of the reactor was performed to ensure the integrity of the reactor primary system pressure boundary. The completed LWBR reactor was then released to the plant operations personnel for further testing in preparation for initial core criticality and power operation.

2. Evaluation of the Phase IV Operations

The only problem area encountered during the final assembly of the external reactor components was the assembly and checkout of the axial flux measuring system (AFMS). This system, which consists of eight tube paths connecting the flux thimble penetrations in the reactor closure head with a drive unit outside of the reactor chamber, is used to guide a flux wire into and out of the reactor core for exposure to the core neutron flux.

During testing of the system, severe resistance to passing the wire through the tubing occurred which required reworking the mechanical tubing joints and fabricating and field fitting replacement tubing sections. Upon completion of the rework, the system functioned satisfactorily. This problem is further discussed in Appendix J.

IV. SUMMARY AND CONCLUSIONS

The LWBR installation was completed successfully with no major assembly problems and without compromise of the nuclear safety of the operations or the safety of personnel. Minor equipment problems were discovered and resolved during the trial fit of most components, and during the detailed training and checkout operations performed prior to actual use of the equipment.

The most significant departure of this reactor installation from previous core installations at the Shippingport Atomic Power Station was the leveling (plumbing) of the blanket fuel assemblies and the reflector assemblies prior to installation. Plumbing of these assemblies was performed to reduce the risk of inadvertent damage as an assembly was inserted adjacent to the previously installed fuel assemblies. Inadvertent damage was considered to be unlikely because there was more clearance between the grids of the blanket fuel assemblies than in commercial Light Water cores, because there are guide posts on the blanket fuel assemblies, and because the seed and reflector assemblies have continous metal shells around the fuel rods. But since the LWBR core was a developmental core, it was deemed prudent to reduce the risk of such damage. This requirement led to the application of eddy current sensors to ensure the modules were plumb and the fabrication of machined guidance equipment for lowering these fuel assemblies into the core. There was no damage to any fuel assembly during LWBR installation.

Other features of the reactor design included the development of specific processes to accomplish the required operations such as applying optical alignment equipment for aligning the core barrel components during assembly. These processes are covered in more detail in attached appendices.

The LWBR core was no more difficult to assemble than conventional Light Water non-breeder cores.

V. REFERENCES

1. P. R. Bengel, S. W. Sinderson, J. R. Turner, "Design and Performance of the LWBR Bypass Inlet Flow Balancing System," WAPD-TM-1143, July, 1979.
2. D. R. Connors, S. Milani, J. A. Fest, R. Atherton, editors, "An Introduction to the Light Water Breeder Reactor Design," WAPD-TM-1208, January, 1979.

APPENDIX A

PHOTOGRAPHIC RECORD OF THE LWBR INSTALLATION

Figures A-1 through A-25 provide a photographic record of the major operations that occurred during the LWBR installation. These figures are presented in approximate chronological order and are consistent with the sequence of operations discussed in the text.

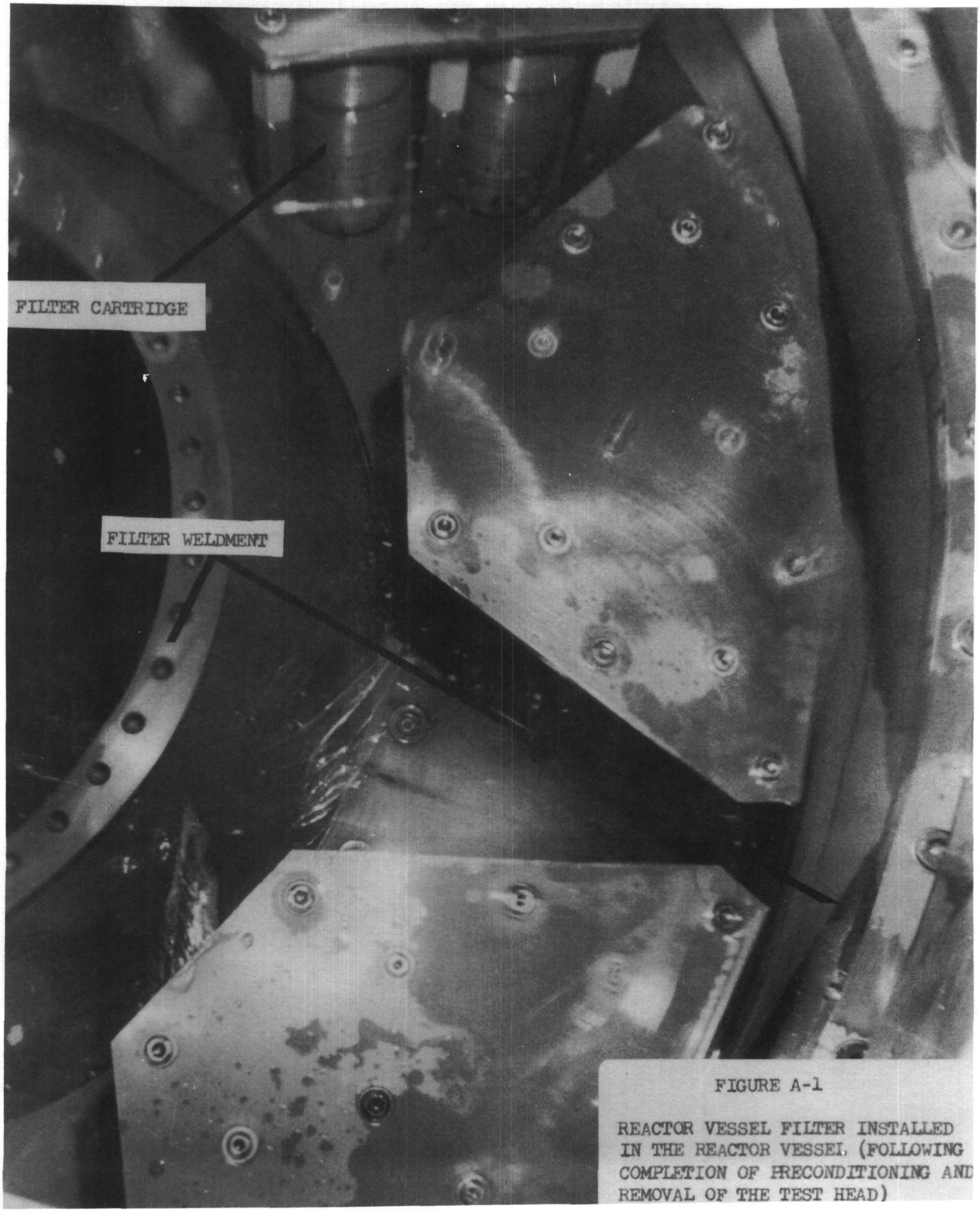


FIGURE A-1

REACTOR VESSEL FILTER INSTALLED IN THE REACTOR VESSEL (FOLLOWING COMPLETION OF PRECONDITIONING AND REMOVAL OF THE TEST HEAD)

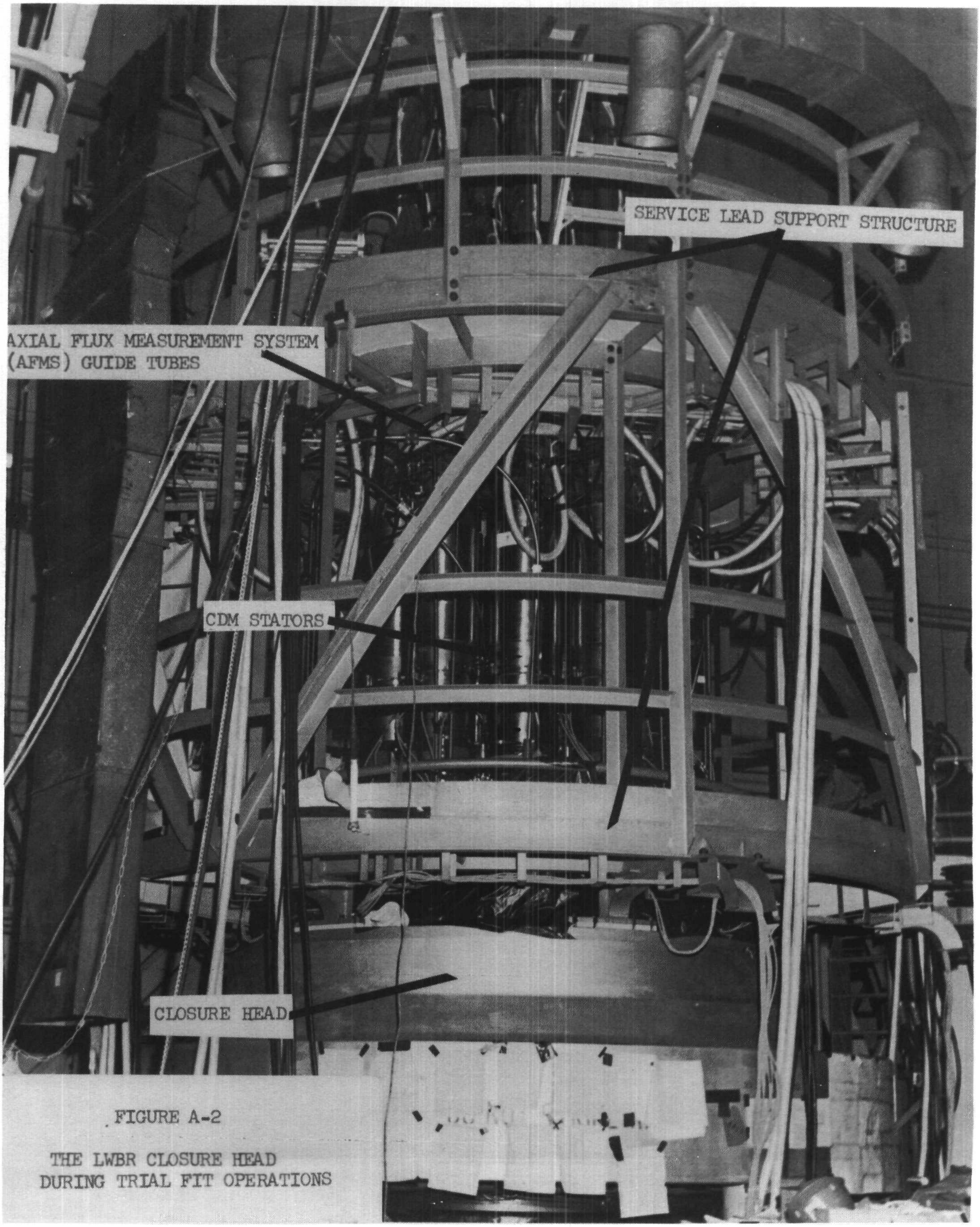


FIGURE A-2

THE LWBR CLOSURE HEAD DURING TRIAL FIT OPERATIONS

FIGURE A-3

INSTALLATION OF FILLER UNITS
IN THE LOWER CORE BARREL

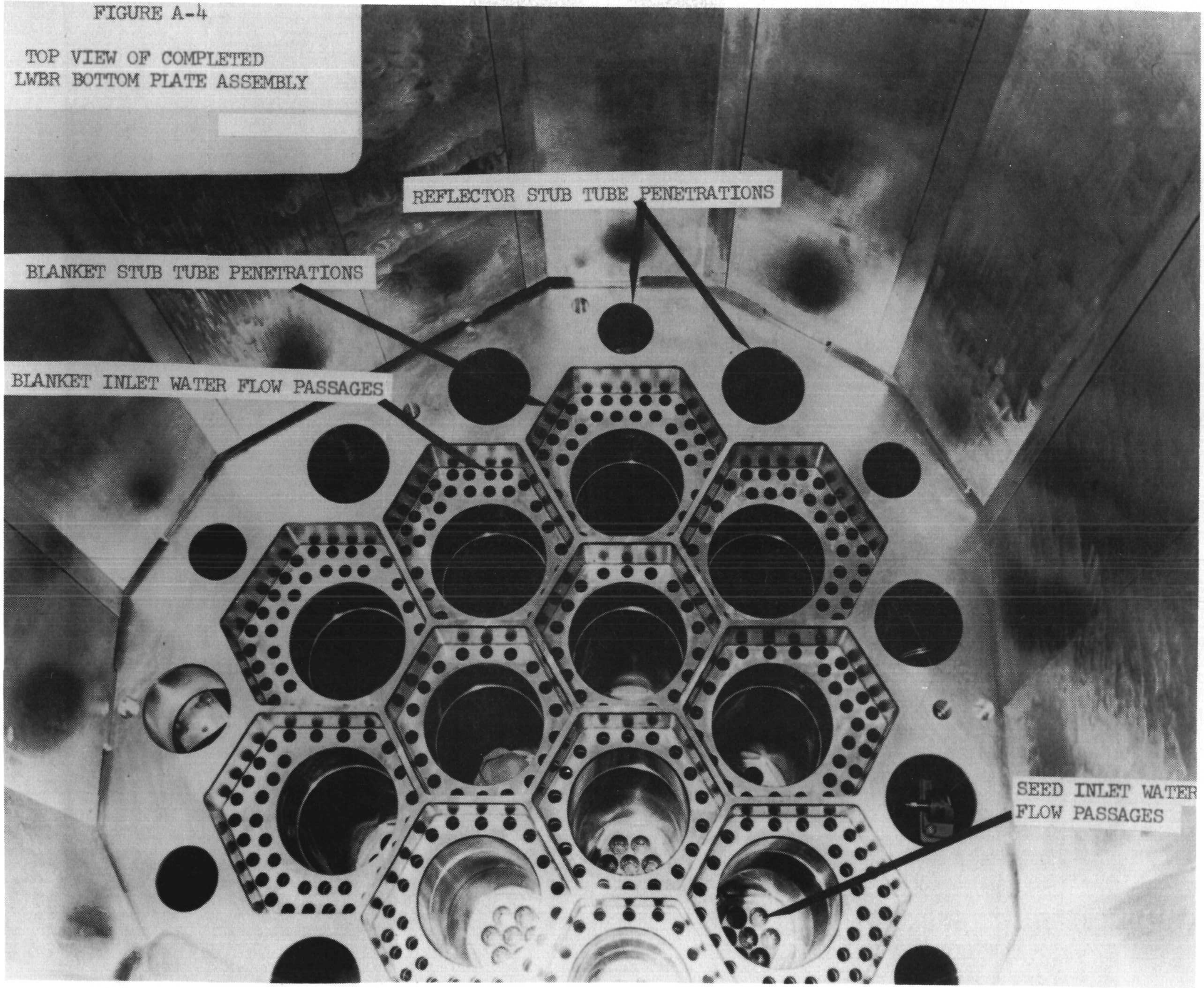


FIGURE A-4

TOP VIEW OF COMPLETED
LWBR BOTTOM PLATE ASSEMBLY

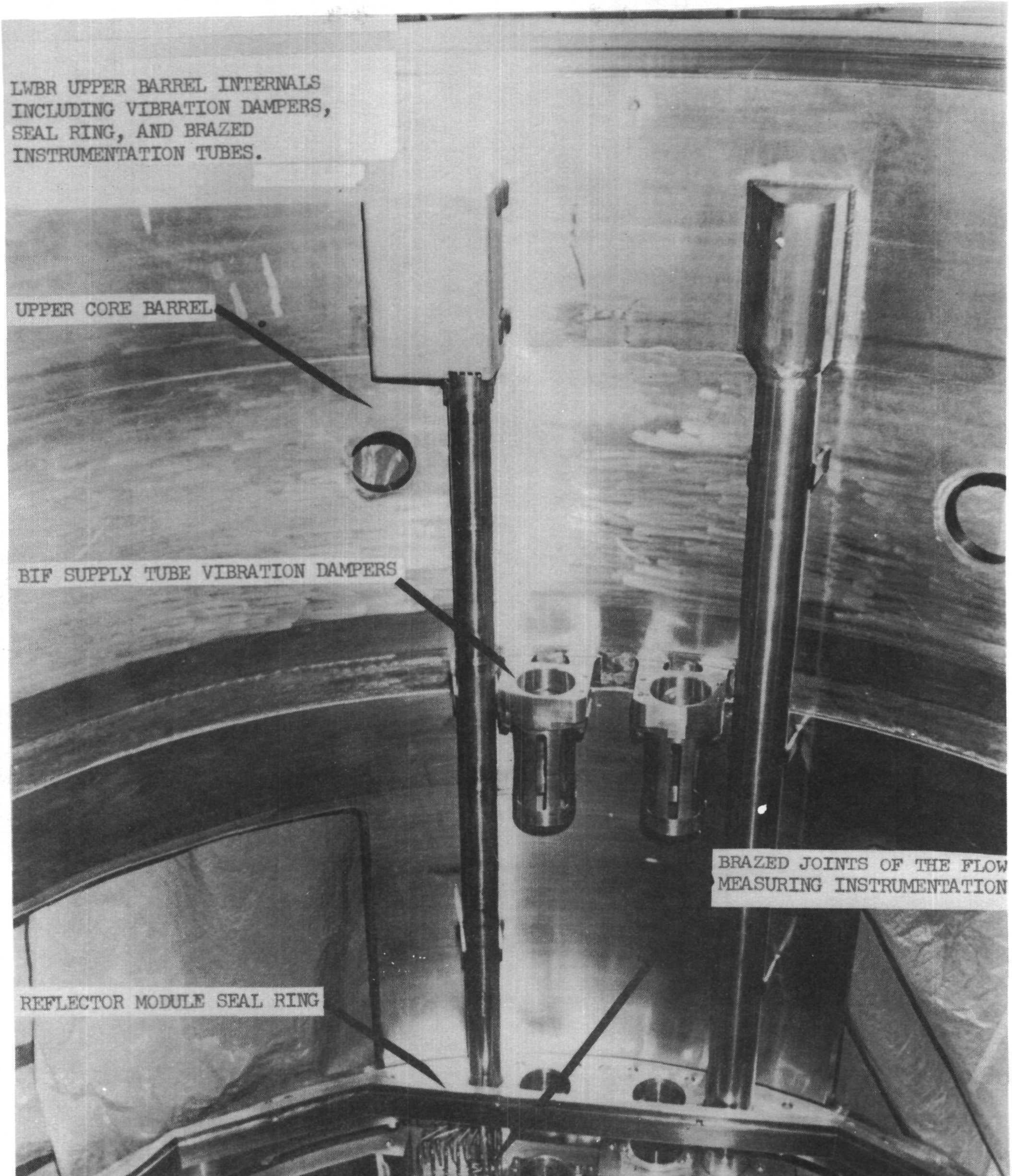


FIGURE A-5

LWBR UPPER CORE BARREL INTERNALS

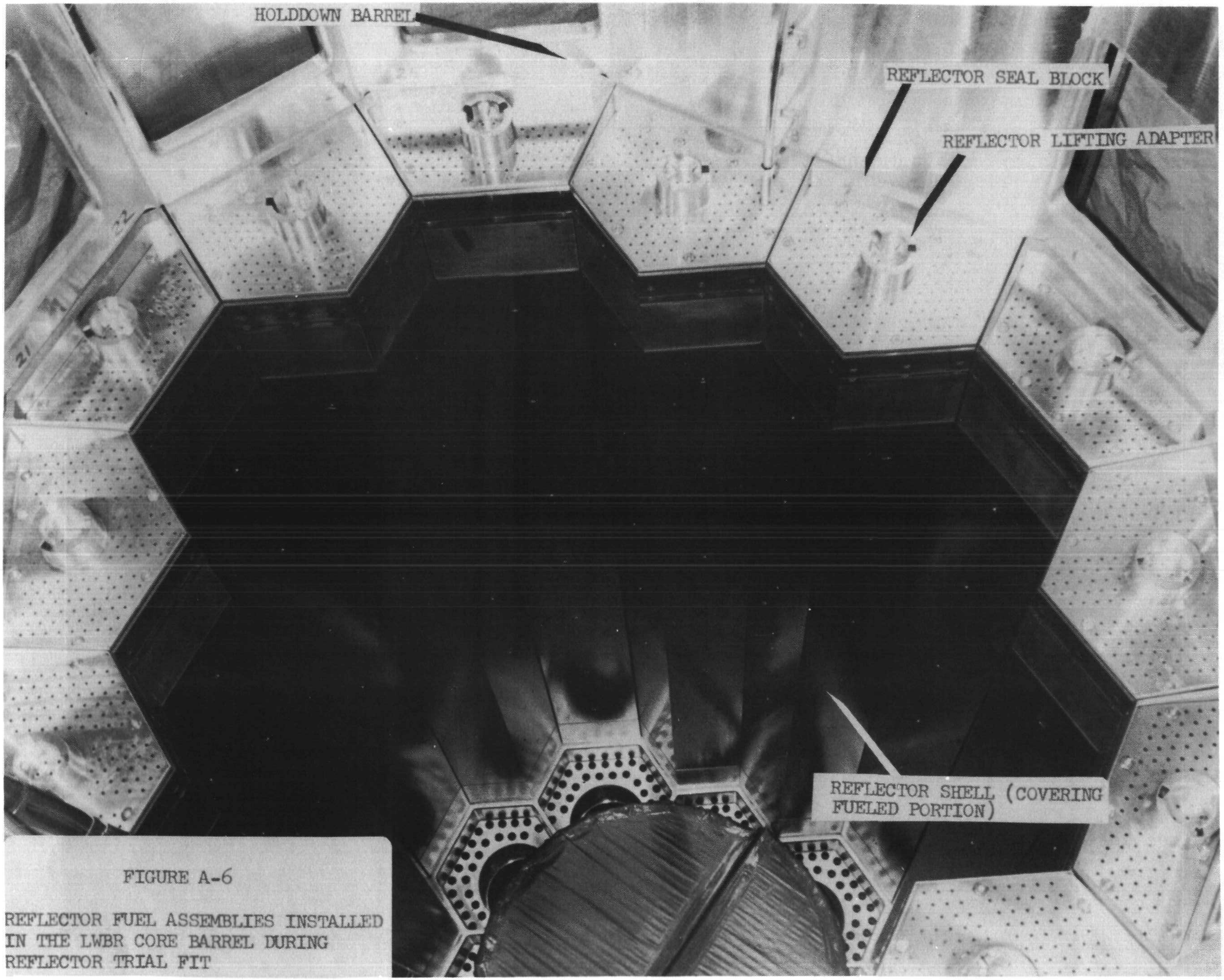


FIGURE A-6

REFLECTOR FUEL ASSEMBLIES INSTALLED IN THE LWBR CORE BARREL DURING REFLECTOR TRIAL FIT

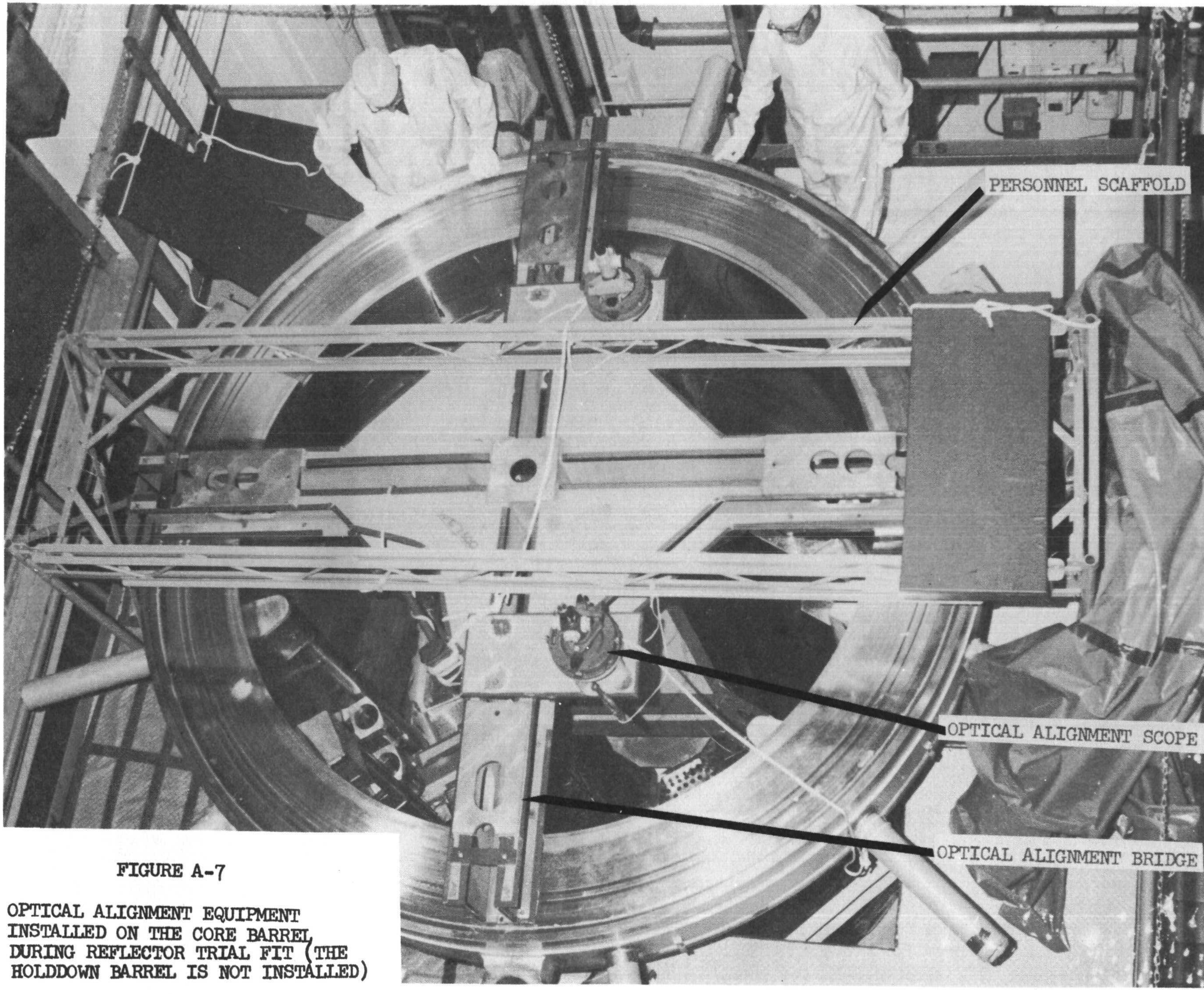


FIGURE A-7

OPTICAL ALIGNMENT EQUIPMENT INSTALLED ON THE CORE BARREL DURING REFLECTOR TRIAL FIT (THE HOLDDOWN BARREL IS NOT INSTALLED)

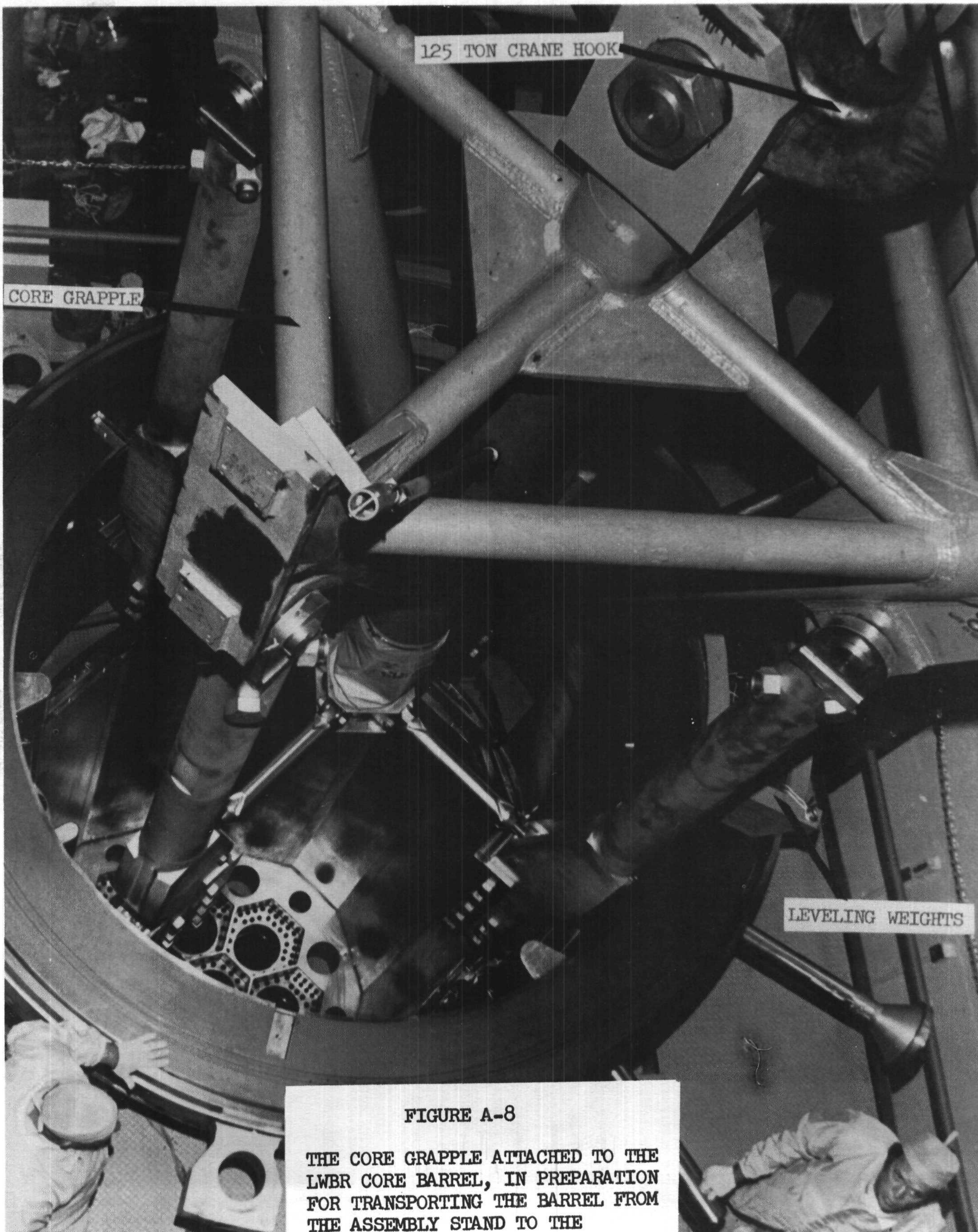


FIGURE A-8

THE CORE GRAPPLE ATTACHED TO THE LWBR CORE BARREL, IN PREPARATION FOR TRANSPORTING THE BARREL FROM THE ASSEMBLY STAND TO THE REACTOR VESSEL

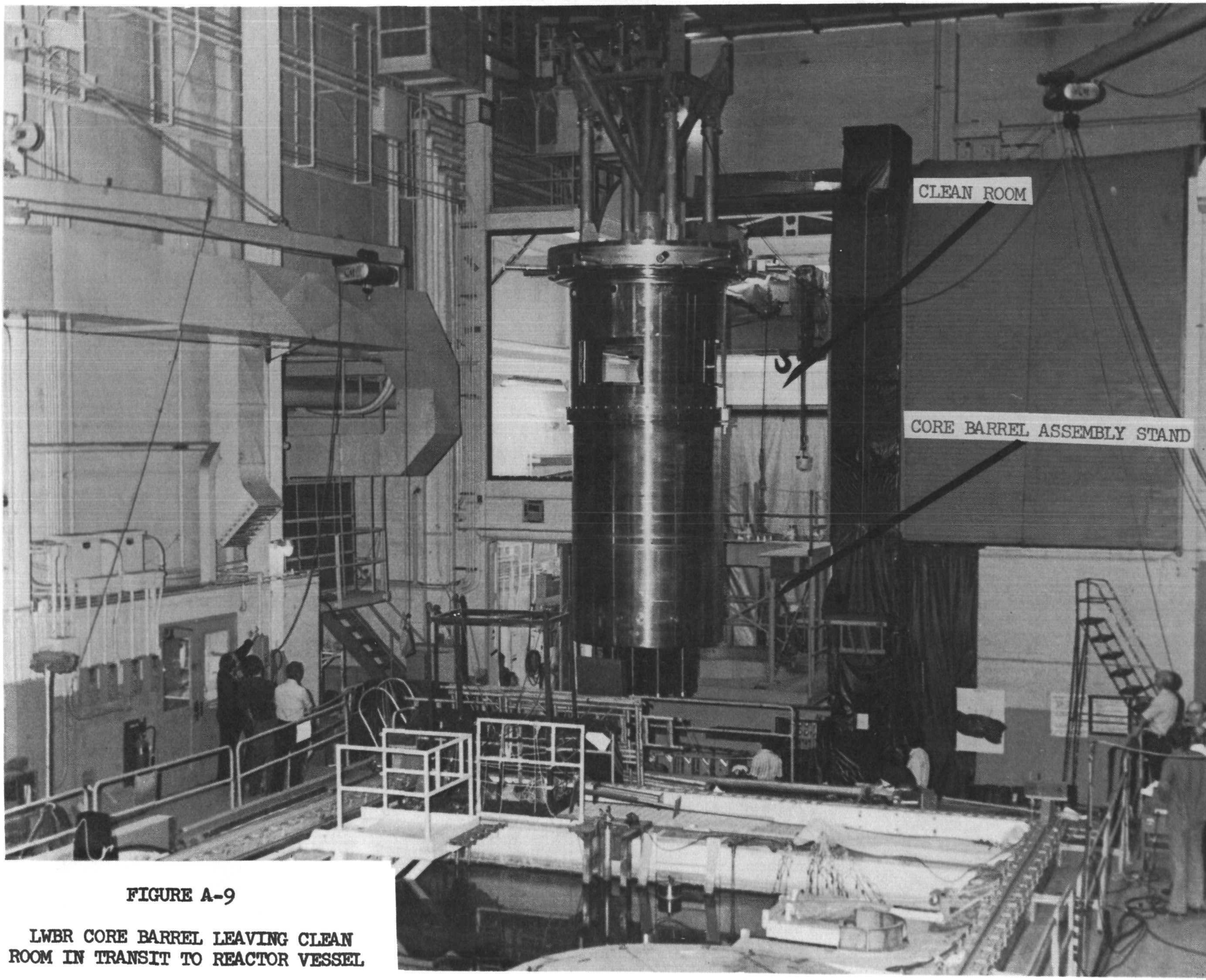


FIGURE A-9

LWBR CORE BARREL LEAVING CLEAN ROOM IN TRANSIT TO REACTOR VESSEL

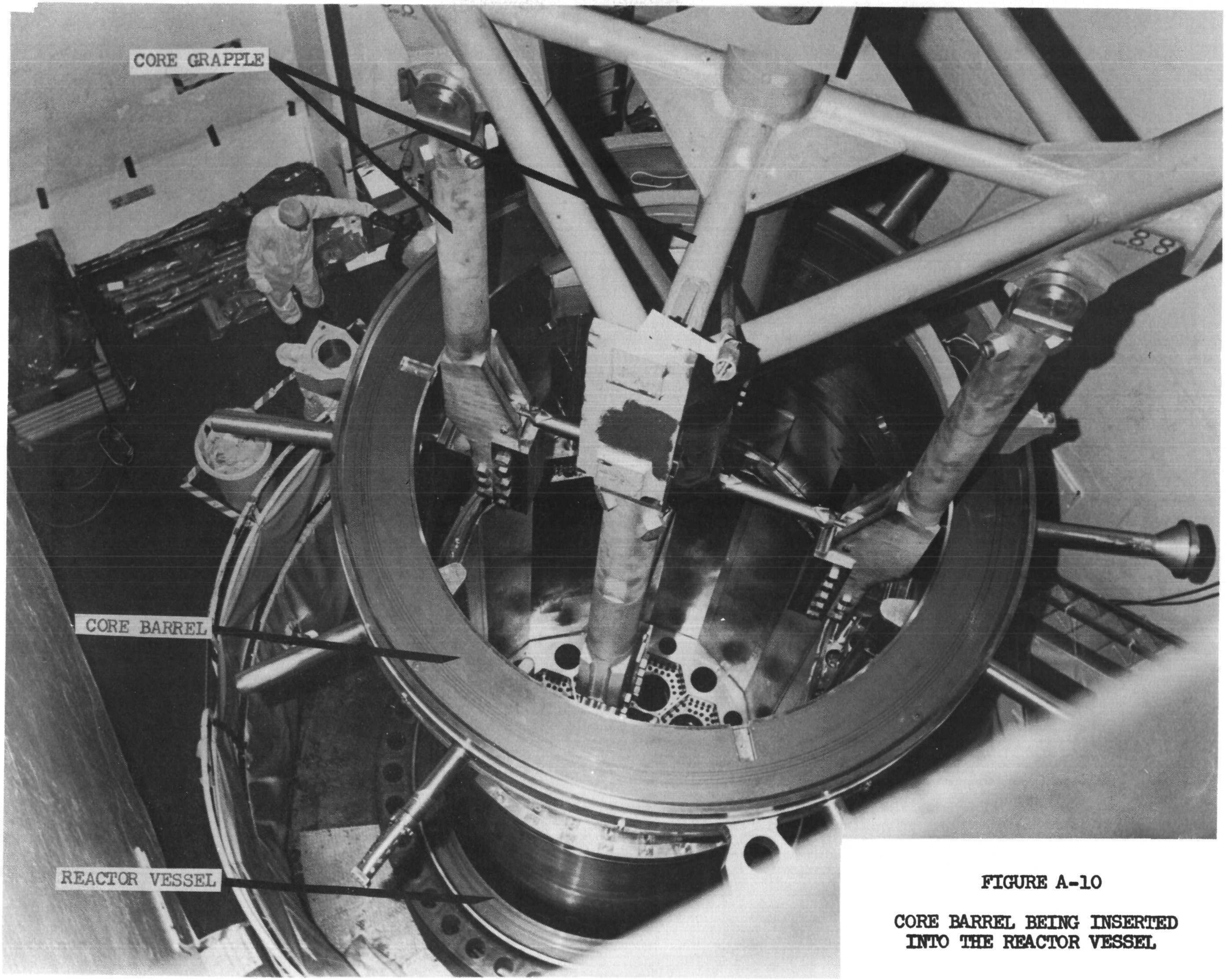


FIGURE A-10

CORE BARREL BEING INSERTED INTO THE REACTOR VESSEL

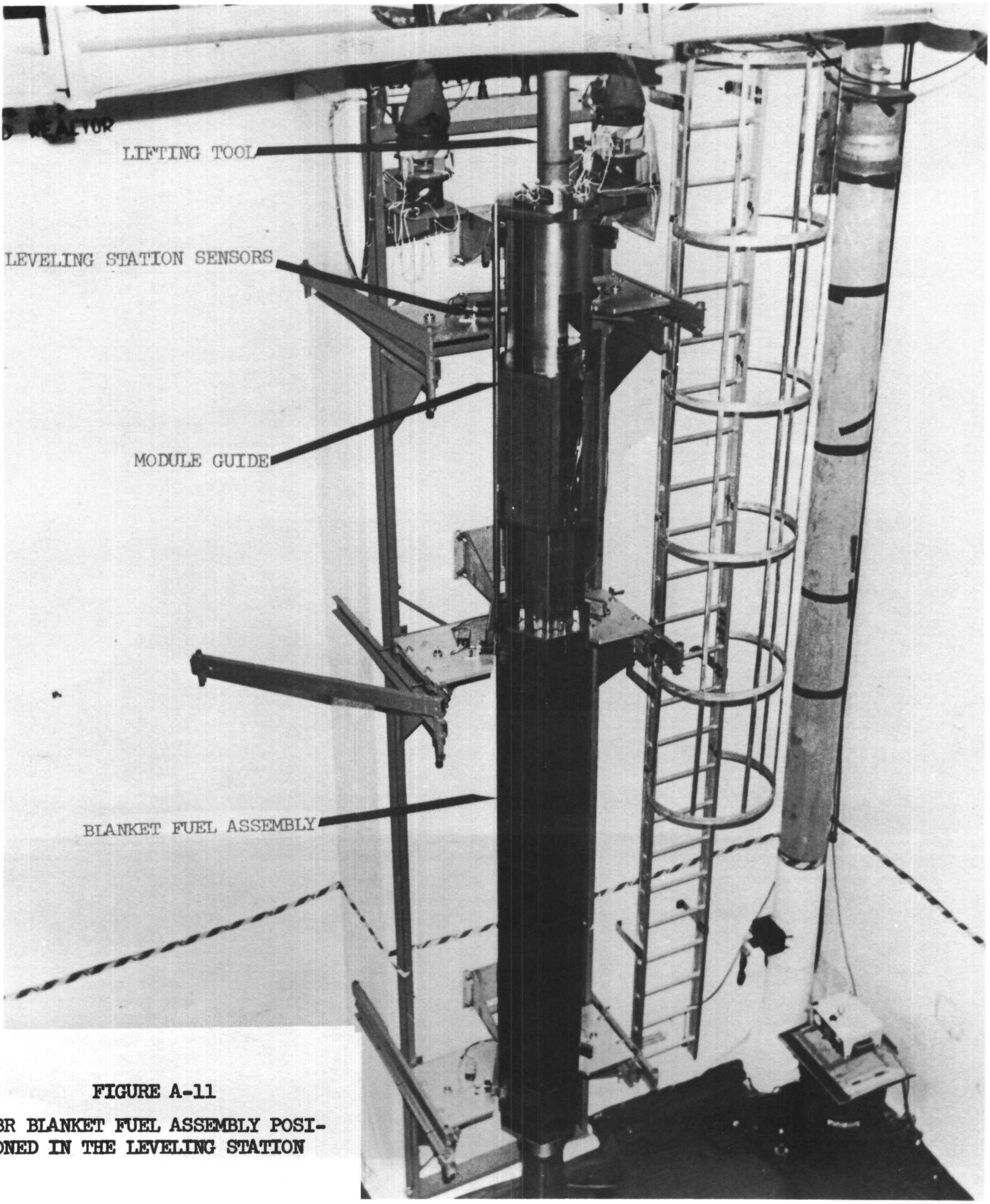


FIGURE A-11

LWBR BLANKET FUEL ASSEMBLY POSITIONED IN THE LEVELING STATION

FIGURE A-12

INSTALLING THE FIRST BLANKET FUEL ASSEMBLY INTO THE REACTOR VESSEL

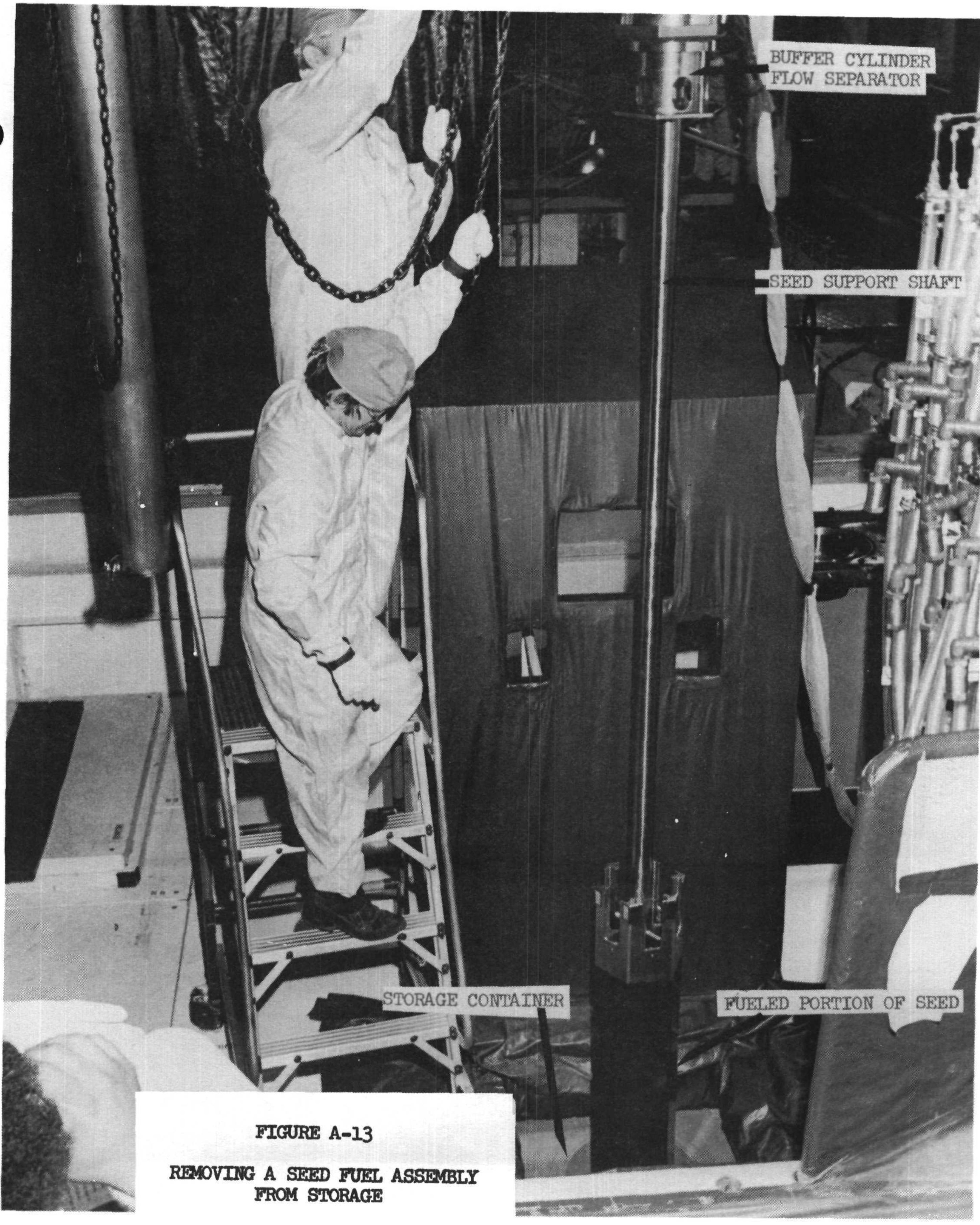


FIGURE A-13

REMOVING A SEED FUEL ASSEMBLY FROM STORAGE

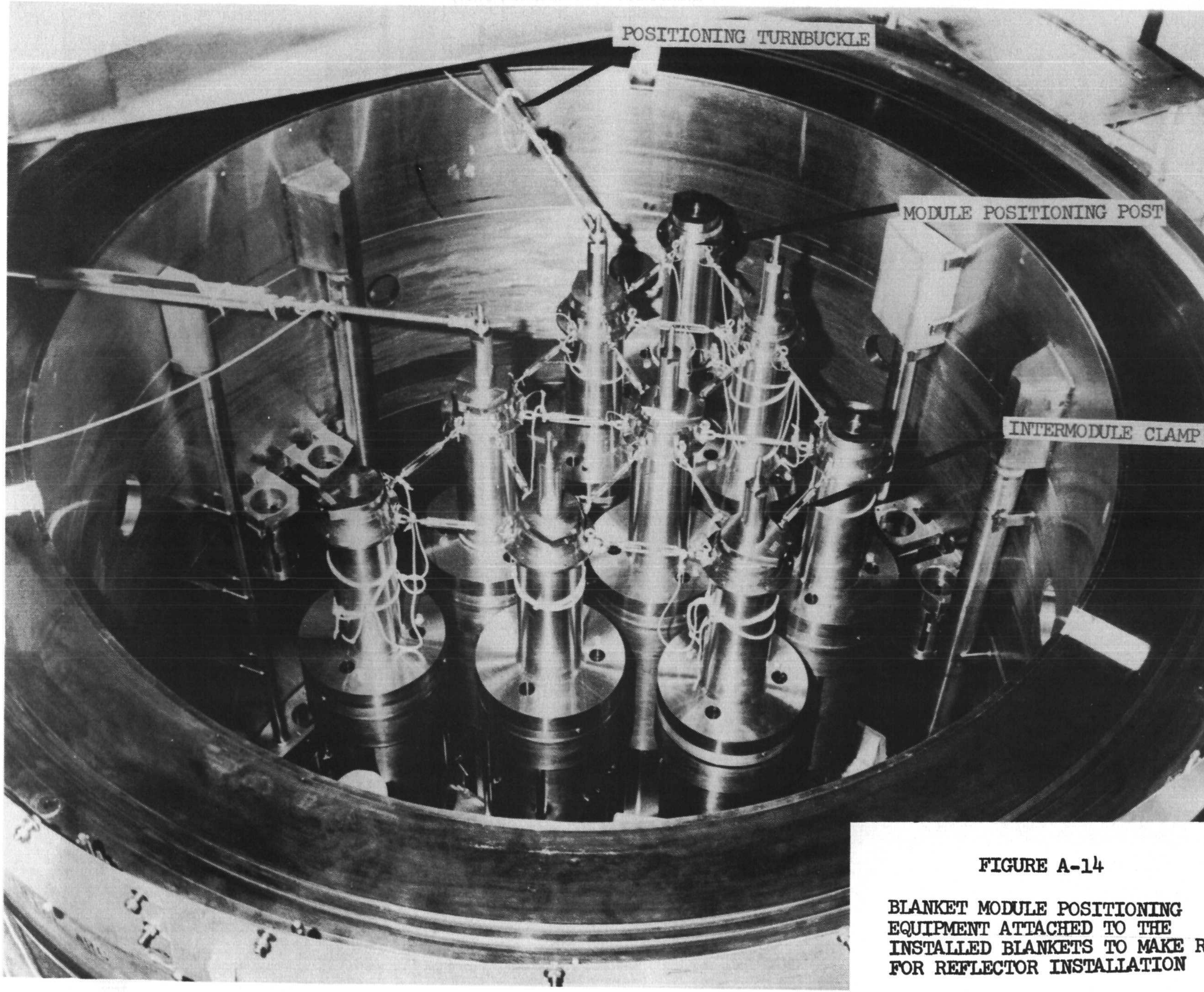


FIGURE A-14

BLANKET MODULE POSITIONING EQUIPMENT ATTACHED TO THE INSTALLED BLANKETS TO MAKE ROOM FOR REFLECTOR INSTALLATION

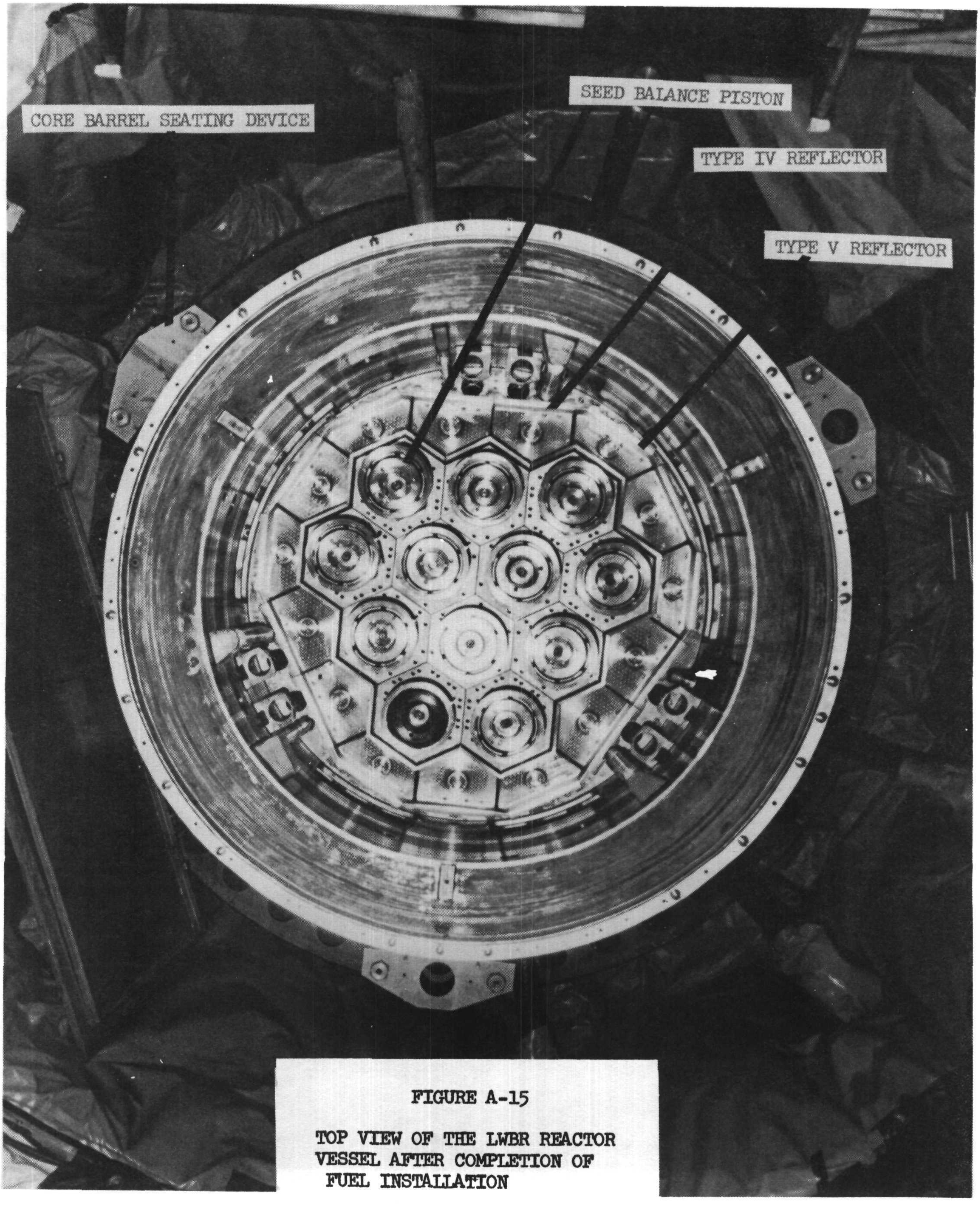


FIGURE A-15

TOP VIEW OF THE LWBR REACTOR VESSEL AFTER COMPLETION OF FUEL INSTALLATION

FIGURE A-16

THE HOLDDOWN BARREL INSTALLED IN THE LWBR REACTOR

(PERSONNEL ARE CHECKING THE FLUX THIMBLE GUIDE PATH FOR THE ONE INSTRUMENTED REFLECTOR FUEL ASSEMBLY)

FIGURE A-17

TOP VIEW OF THE REACTOR VESSEL FOLLOWING HOLDDOWN BARREL INSTALLATION

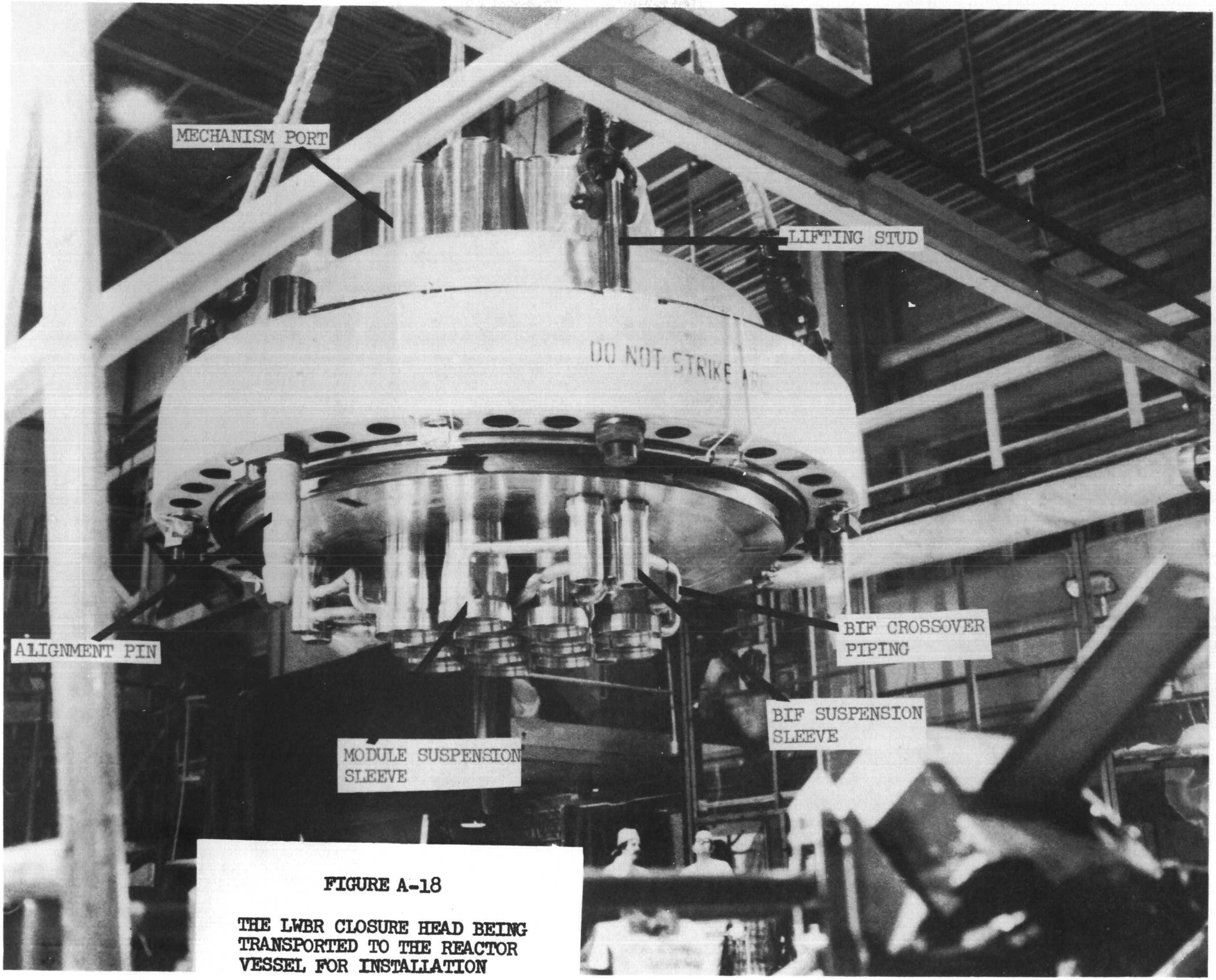


FIGURE A-18

THE LWBR CLOSURE HEAD BEING TRANSPORTED TO THE REACTOR VESSEL FOR INSTALLATION

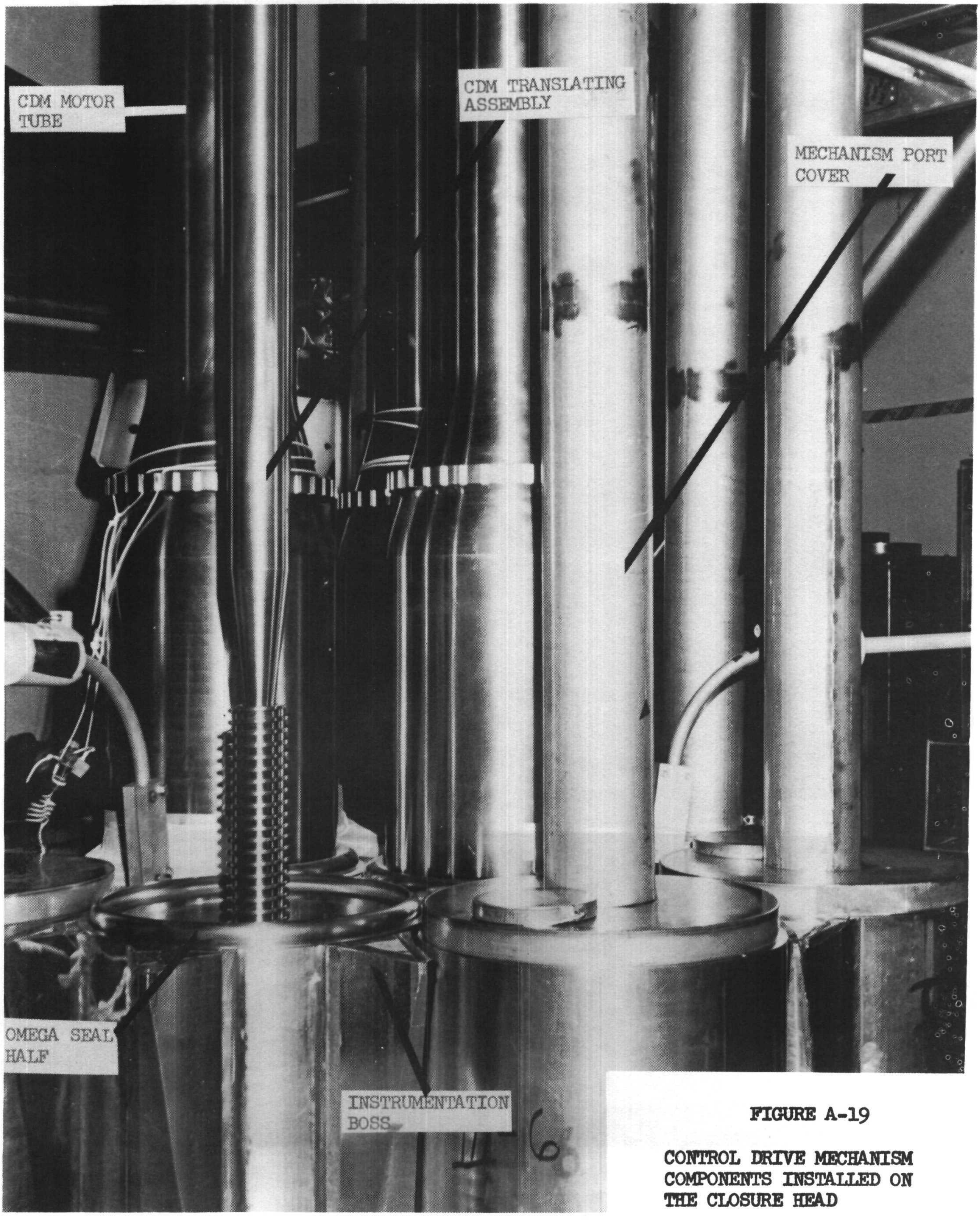


FIGURE A-19

CONTROL DRIVE MECHANISM COMPONENTS INSTALLED ON THE CLOSURE HEAD

FIGURE A-20

INSTALLING A CONTROL DRIVE
MECHANISM MOTOR TUBE

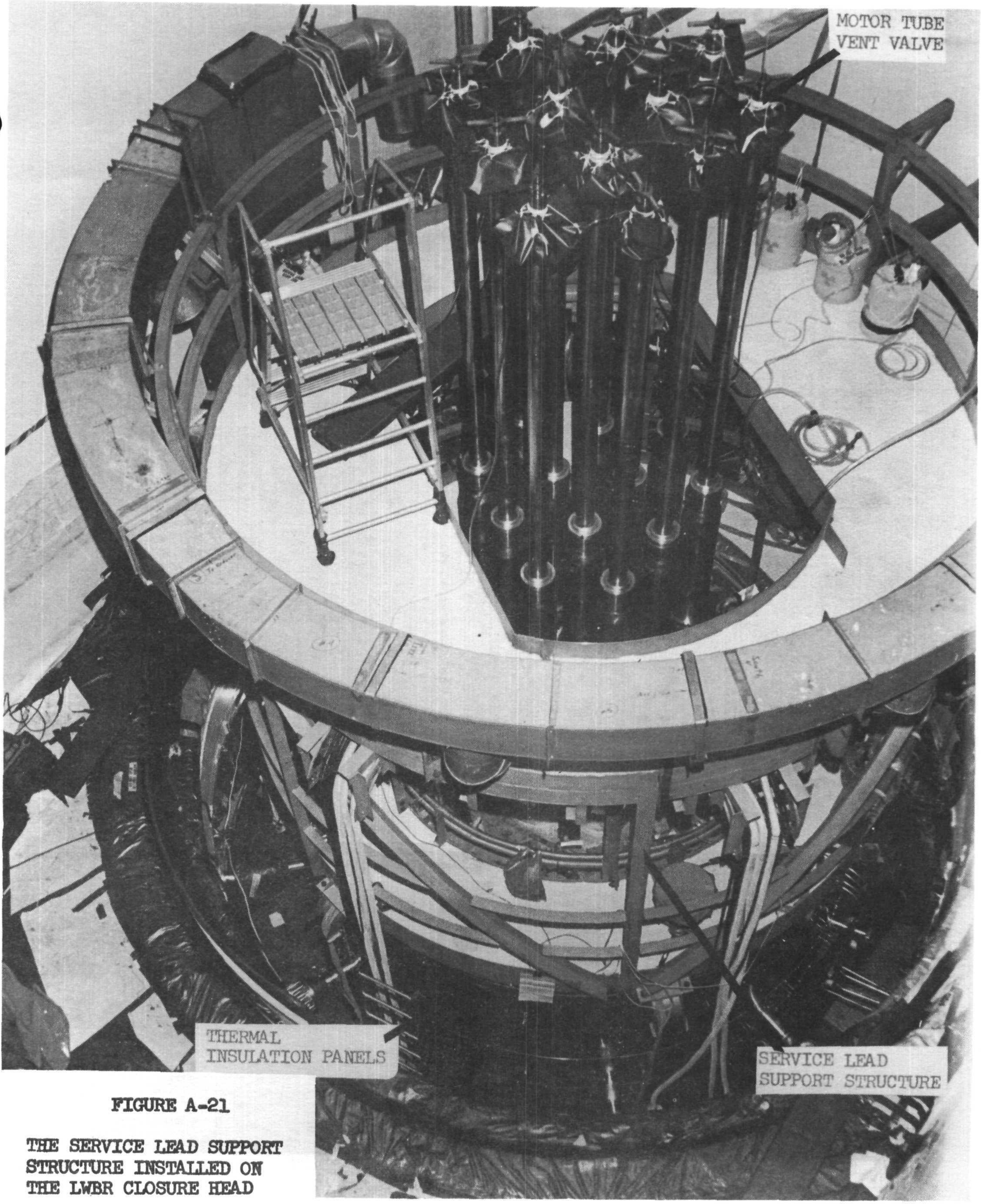


FIGURE A-21

THE SERVICE LEAD SUPPORT STRUCTURE INSTALLED ON THE LWBR CLOSURE HEAD

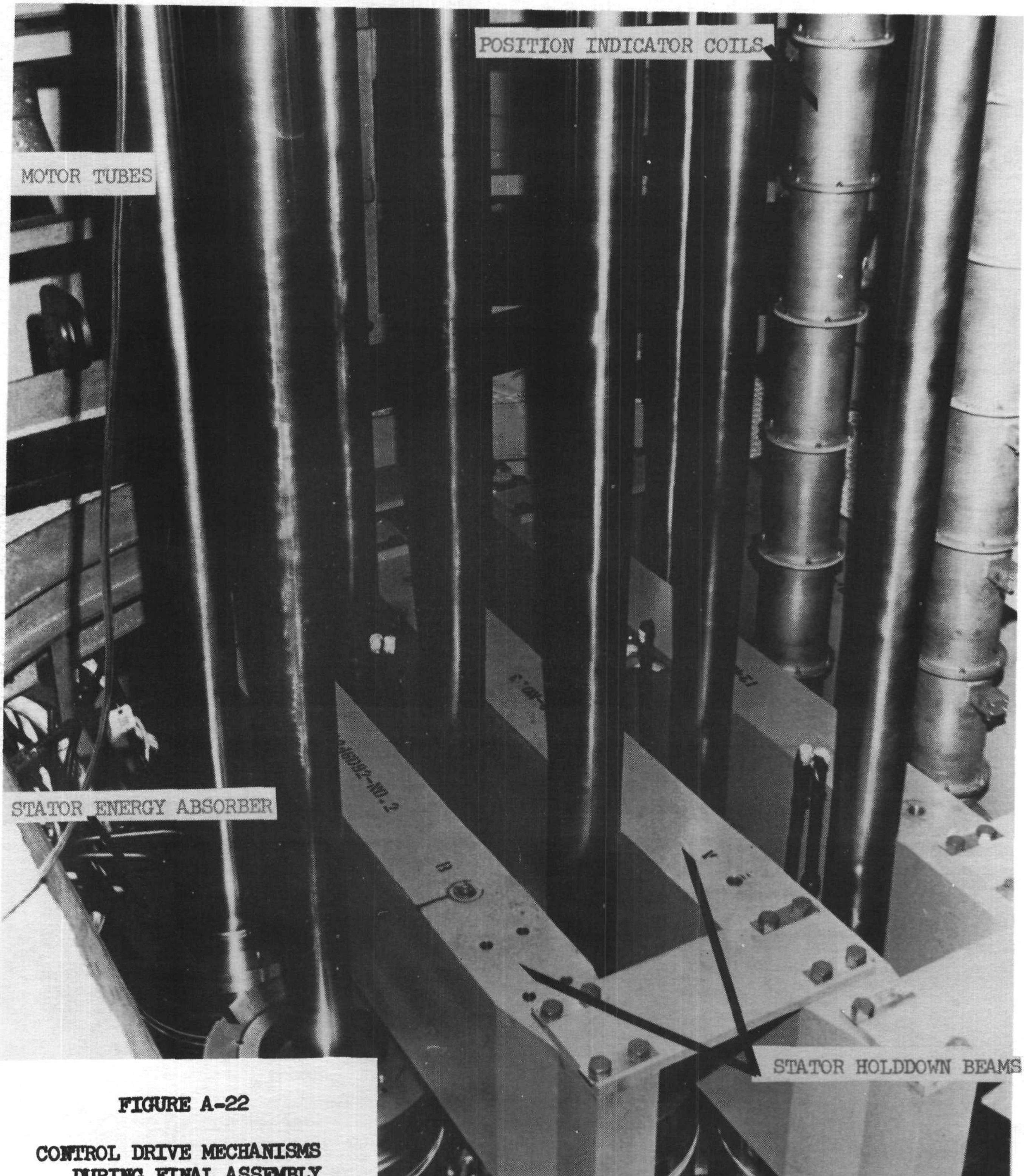


FIGURE A-22

CONTROL DRIVE MECHANISMS DURING FINAL ASSEMBLY

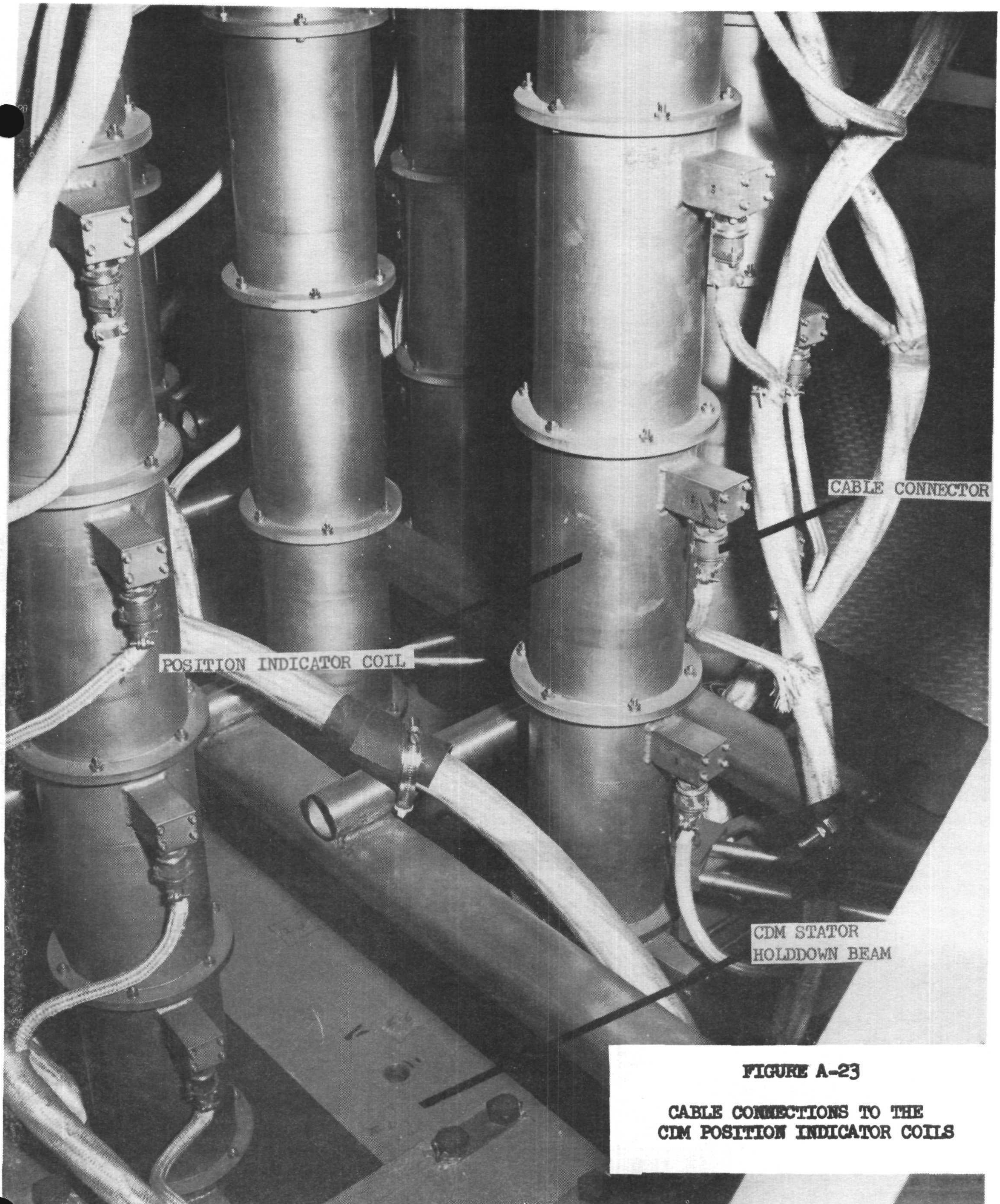


FIGURE A-23

CABLE CONNECTIONS TO THE CDM POSITION INDICATOR COILS

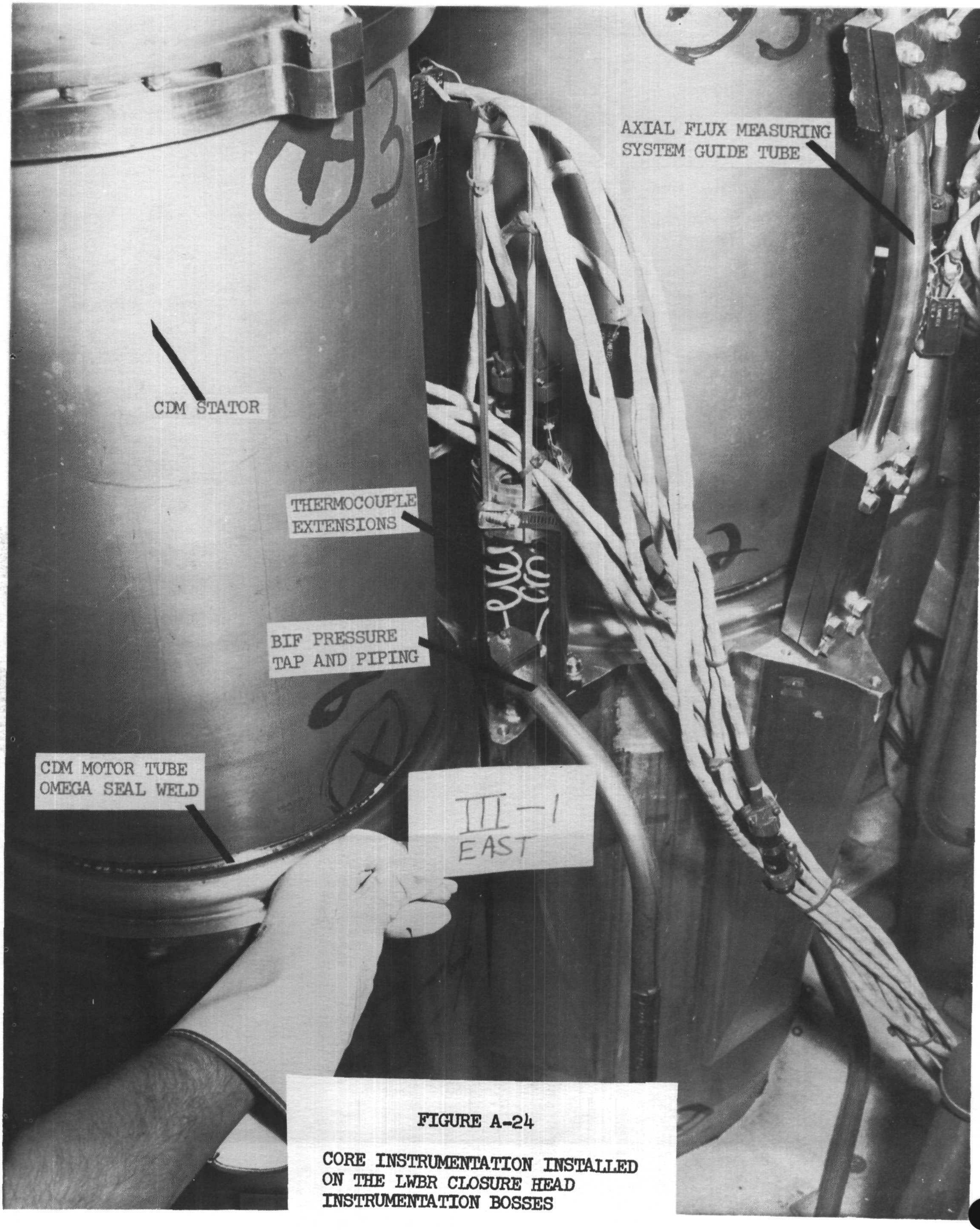


FIGURE A-24

CORE INSTRUMENTATION INSTALLED ON THE LWBR CLOSURE HEAD INSTRUMENTATION BOSSES

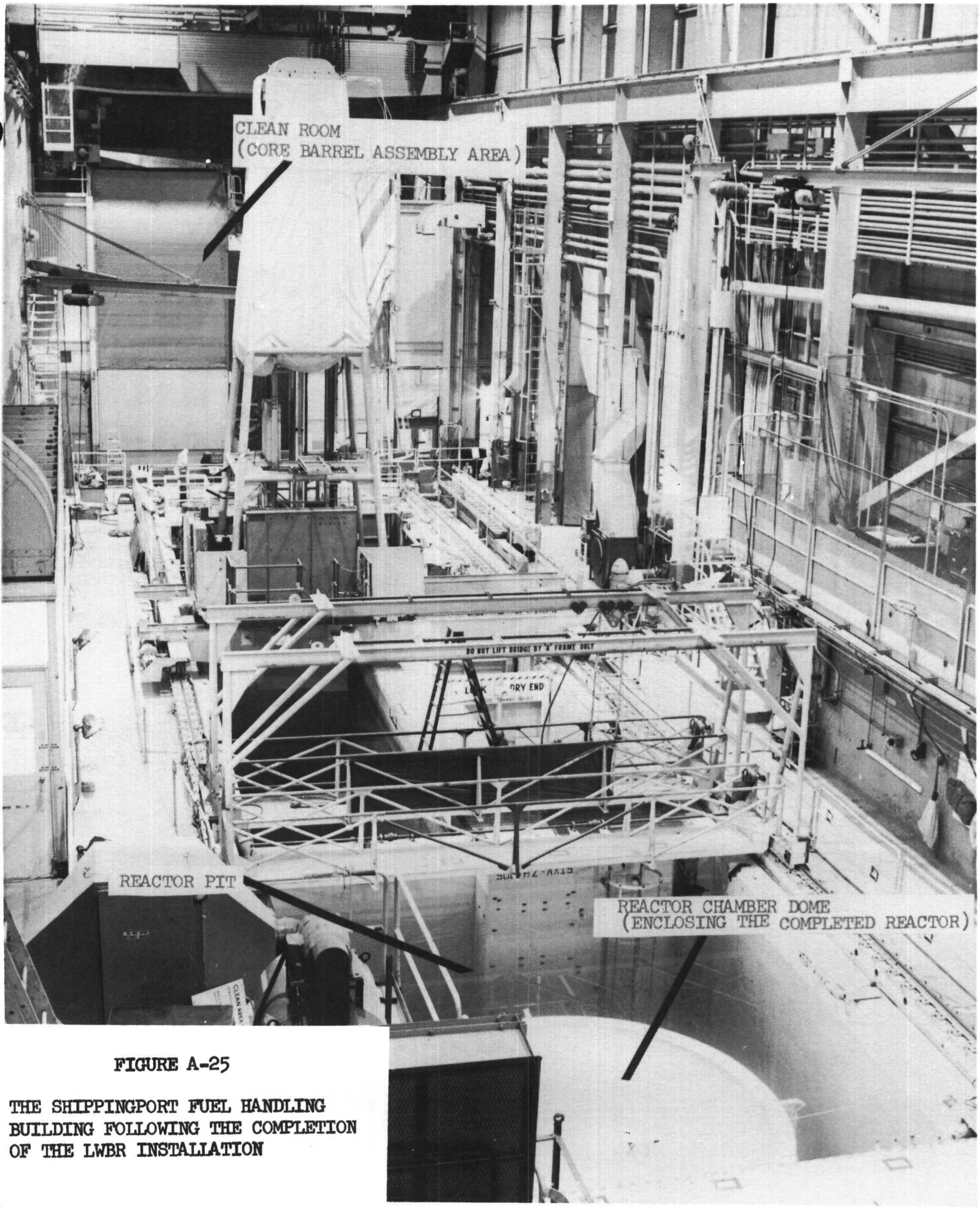


FIGURE A-25

THE SHIPPINGPORT FUEL HANDLING BUILDING FOLLOWING THE COMPLETION OF THE LWBR INSTALLATION

APPENDIX B

PRECONDITIONING AND FILTERING OF THE LWBR REACTOR PRIMARY SYSTEM AND INSPECTION RESULTS

APPENDIX B

PRECONDITIONING AND FILTERING OF THE LWBR REACTOR PRIMARY SYSTEM AND INSPECTION RESULTS

I. INTRODUCTION

The Shippingport reactor vessel and four reactor coolant loops, Figure B-1, were preconditioned and filtered under hot, pressurized conditions prior to installation of the LWBR core. The primary purpose of this preconditioning was to minimize deposition of plant corrosion products (crud) on the LWBR core and to minimize the chance of loose foreign material becoming trapped in small LWBR core clearances.

II. BACKGROUND

A. Decision to Precondition and Filter

The corrosion of reactor plant materials made of iron and nickel alloys releases oxide corrosion products (crud) into the coolant. Crud is transported by the circulating coolant and may deposit in the core fuel region. Crud reduces cooling system flow due to increased fluid friction and restricted flow areas. It can also impede heat transfer from the fuel rods to the coolant.

Information from a commercial nuclear power plant identified that a significant cooling system flow reduction occurred shortly after plant startup. Preconditioning had not been performed on this plant. Previous Shippingport experience showed that significant cooling system flow reductions occurred after PWR-2 operations commenced. (PWR-2 was the reactor core installed in the Shippingport Plant prior to LWBR.) The plant modification prior to initial PWR-2 operation resulted in a major portion of the reactor coolant system surface area being new (all four steam generators and the core were replaced). The core crud buildup experienced by the PWR-2 core was attributed to conditioning of new coolant system surfaces and to ammonia reactor coolant chemistry operations in the pH range of 9.8 to 10.2. Upon altering the pH range to 10.1 to 10.3, flow conditions stabilized with some increase in PWR-2 coolant flows being observed. During the PWR-2 to LWBR core conversion two of the four reactor coolant loop ("1A" and "1D" loop) steam generators (see Figure B-1) were replaced. This replacement represented approximately 25 percent (23,300 ft^2 area out of 93,500 ft^2 total area) of the non-Zircaloy surface area of the

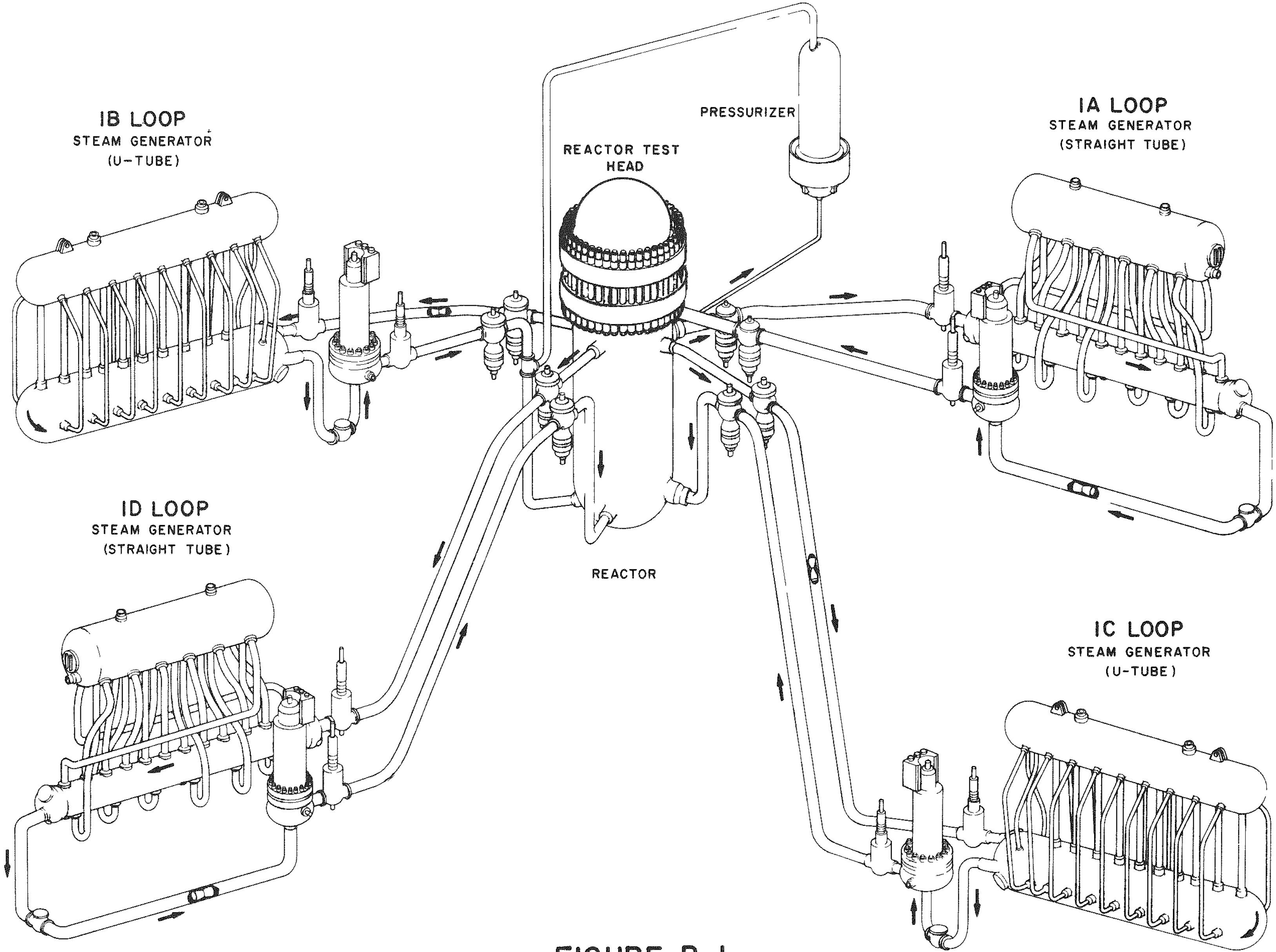


FIGURE B-I
SHIPPINGPORT PLANT DURING PRECONDITIONG

reactor coolant system, which again presented a possibility for introduction of crud and foreign material into the reactor coolant system, warranting preconditioning and filtration.

B. Preconditioning Theory

Preconditioning is performed to minimize the amount of circulating oxide corrosion products (crud) in the reactor coolant available for deposition on the core. Such deposition can adversely affect core thermal-hydraulic and fuel element performance. Crud resulting from corrosion and wear of reactor plant materials may be retained on metal surfaces or released to reactor coolant as mobile crud. The corrosion release rate is at its highest during initial exposure of metal surfaces to the hot reactor coolant (preconditioning) and decreases with time of exposure as a protective oxide film is formed. Therefore, crud deposition with potential activation during subsequent critical operation is minimized. Activation of the crud occurs when the circulating or deposited crud is exposed to high levels of ionizing radiation in the core during critical operations. High temperature operations cause corrosion products formed at ambient temperatures (which may consist of very small particles and may be difficult to filter) to agglomerate, thus allowing effective crud removal by filtering and purification systems. The primary purposes of the LWBR preconditioning and filtering were to minimize deposition of crud on the LWBR core (preconditioning) and to minimize the chance of loose particles becoming trapped in small clearances in the LWBR core (filtering). The expected results of preconditioning were (1) less crud deposition on the LWBR core, resulting in higher flow maintained in the core, (2) reduced after-shutdown radiation levels after critical operation, (3) reduced reactor coolant crud levels during critical operations, and (4) reduced propensity for accelerated fuel-element cladding corrosion and diminished cladding mechanical properties.

C. Methods of Preconditioning Considered

Two methods of preconditioning were considered. Both methods required closure of the reactor vessel with a hydrostatic test head but differed in the amount of plant restoration required and the mode of filtration. The first method required restoration and operation of only the 1A and 1D reactor coolant loops (loops with new heat exchangers) after installation of loop filters capable of removing particles 0.030 inch or larger in size and simulating the nominal LWBR core pressure drop. (See Figure B-1.) The second method required complete restoration and operation of all four reactor coolant loops after installation of a modified version of an existing reactor vessel filter. The reactor vessel filter would simultaneously filter reactor coolant flow from all four loops, simulate LWBR core pressure drop and remove particles 0.002 inch or larger in size. It was decided to perform preconditioning and filtering using the reactor vessel filter at hot four-loop reactor coolant full flow conditions for at least ten days (240 hours). This method provided additional assurance that deposition of crud on the LWBR core would be minimized and that any foreign materials in the reactor coolant loops would be detected and removed prior to installation of the LWBR core.

It should be noted that original planning for startup of the Shippingport plant following installation of the LWBR core included plant and core preconditioning in parallel with reactor coolant 1A and 1D loop filtering operations after installation of the LWBR core in the reactor vessel. However, based on the potential for reduced reactor coolant flow as discussed in Paragraphs II.A and II.B, the decision was made to precondition and filter the Shippingport plant prior to LWBR core installation.

III. IMPLEMENTATION OF THE PRECONDITIONING PROGRAM

A. Introduction

Preparations for PWR plant preconditioning were initiated after the PWR-2 core and core barrel had been removed and the steam generators in coolant loops 1A and 1D had been replaced. Preconditioning required installation of the filter in the reactor vessel, and watertight closure of the reactor vessel with the hydrostatic test head as shown on Figure B-2. The four reactor coolant loops were completed and isolated from other plant systems to allow plant pressurization, heatup and reactor coolant pump operation for preconditioning.

B. Reactor Vessel Filter

The reactor vessel filter shown on Figure B-3 is a modified version of the reactor vessel filter used for Shippingport plant filtering as part of initial construction in 1957. New upper and lower adapters were added to the original design filter to allow sealing and interfacing of the filter with the vessel thermal shield and hydrostatic test head (see Figure B-2). The reactor vessel filter is designed such that particles and agglomerated crud passing into the reactor vessel with the reactor coolant flow are either carried up through the filter central cone by the coolant and are trapped by one of forty filter cartridges, or, depending upon their mass, settle out to the bottom of the reactor

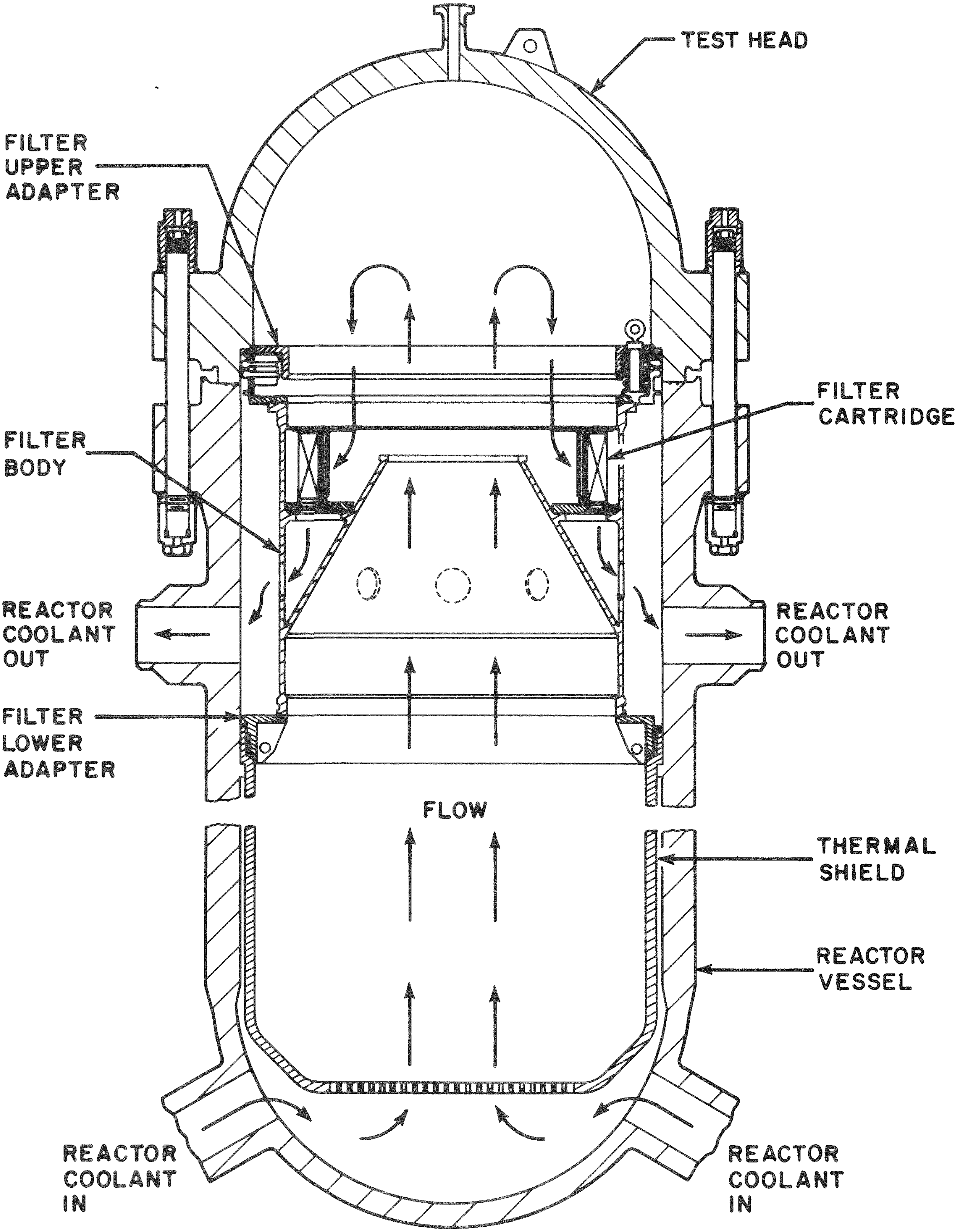


FIGURE B2
FILTER ARRANGEMENT IN
SHIPPINGPORT REACTOR VESSEL

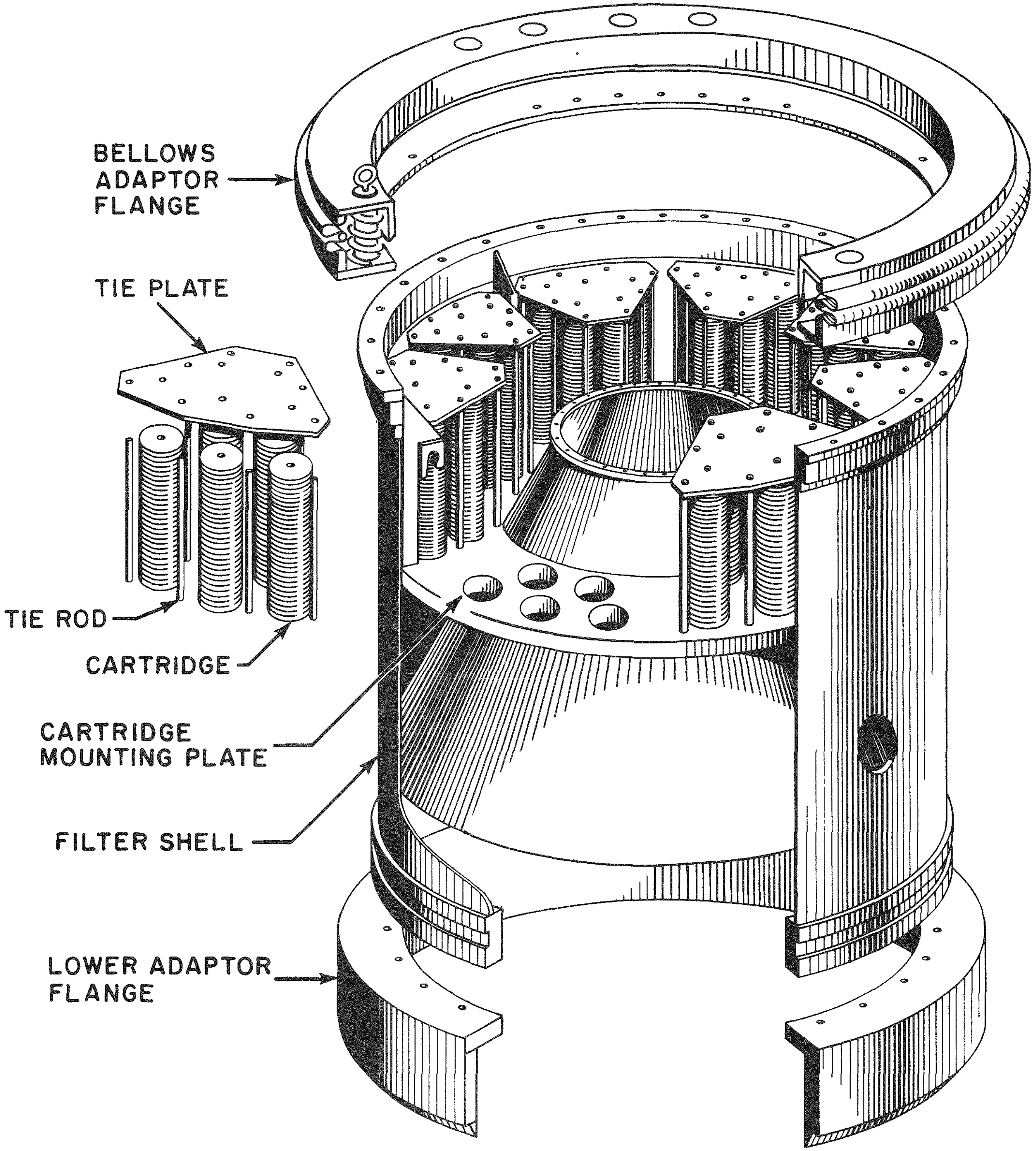


FIGURE B-3 REACTOR VESSEL FILTER

vessel. Particles and crud trapped on the filter cartridges are removed from the system when the filter is removed, while particles on the bottom of the vessel are removed by hydrovacuuming following filter removal.

Leakage past the lower end of the filter is prevented by a metal-to-metal seal between the filter lower adapter and vessel thermal shield. Leakage past the upper end of the filter is prevented by a metal-to-metal seal between the filter upper adapter bellows and the vessel test head. The filter is supported inside the reactor vessel by the lower adapter which seats on the top of the thermal shield. Forty coil springs and the bellows in the upper adapter are compressed by the hydrostatic test head and hold the filter firmly in place while also allowing differential thermal expansion of the filter with respect to the reactor vessel.

The actual filtration of the coolant flow takes place at the forty filter cartridges, which are an all-metal edge-type filter cartridge. Thirty-two of the cartridges will retain all particles whose two smallest dimensions are greater than 0.005 inch while the remaining eight will retain all particles whose two smallest dimensions are greater than 0.002 inch. Since the filter is a recirculating system, a very high percentage of all particles 0.002 inch and larger are removed. The cartridge, Figure B-4, consists of a series of major and minor metal discs (0.025 inch thick) keyed to, and supported by, a center spindle. Closure plates at either end of the spindle keep the discs tightly compressed. The degree of filtration is determined by the difference in diameter between the ID of the outer rim of the major disc and the OD of the outer rim of the minor disc. Dirt and crud particles of a size such that the two smallest dimensions are larger than the nominal difference in radii (either 0.002 or 0.005 inch) are trapped on the OD of the minor discs. Dirt and crud particles of a size such that the two smallest dimensions are larger than 0.025 inch are trapped on the OD of the major discs. Filtered water passes axially down the inside of the major and minor discs, and is discharged through the cartridge into a plenum below the cartridge mounting plate. The water discharges from this plenum through twelve filter outlet ports into the area of the reactor vessel outlet nozzles as shown on Figure B-2.

The reactor vessel filter is also designed to approximate the pressure drop through the reactor vessel that would be experienced if the core were installed. The filter provides a calculated pressure drop of 69 psi at 527 F and a coolant flow rate of 28.55×10^6 lbs/hr versus a calculated LWBR core pressure drop of 58 psi under four loop flow.

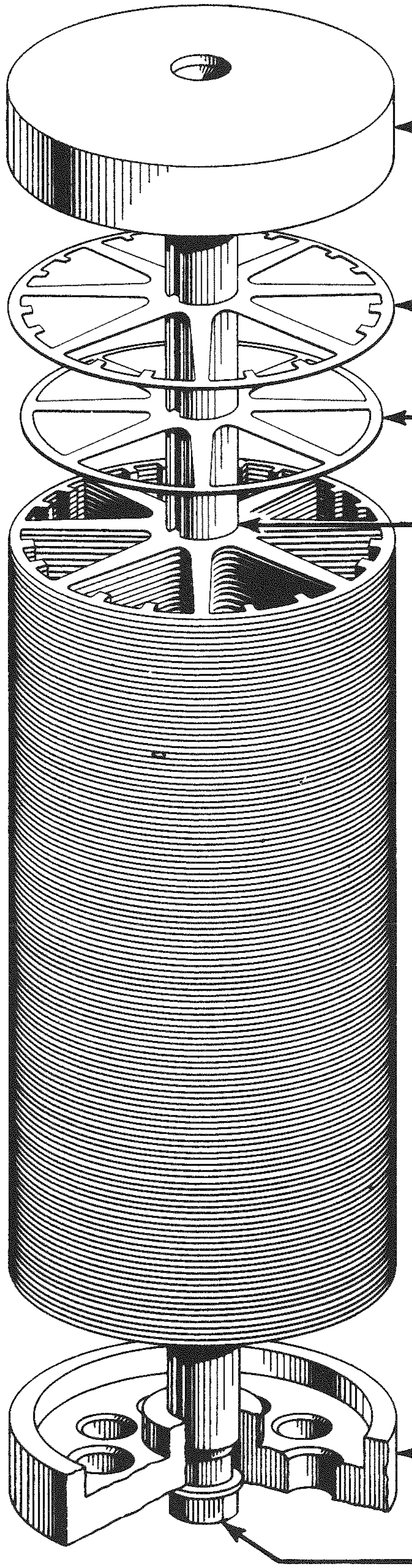


FIGURE B-4 FILTER CARTRIDGE 5.7 INCH DIAMETER

The all-metal cartridges, made from machined components, were used to minimize the risk of filter media migration into the reactor plant piping.

C. Hydrostatic Test Head

A hemispherical hydrostatic test head, Figure B-5, was used as the reactor vessel closure during preconditioning operations. The test head weighs 118,680 pounds and was held in place on the reactor vessel by 42 closure studs. The 6-inch diameter closure studs were elongated 0.096 inch producing a total test head preload of 42,000,000 pounds. This preload resisted a head pressure load of 22,000,000 pounds produced by plant operation at 2000 psi during preconditioning. A water-tight seal was formed between the test head and reactor vessel by two large diameter (116.30 and 118.80 inch diameter) stainless steel O-rings of 3/8 inch cross-section. The O-rings were preinstalled into two close-tolerance O-ring grooves in the reactor vessel flange prior to test head installation. A problem with the use of these O-rings is discussed in Appendix J.

IV. PLANT PRECONDITIONING

A. Plant Conditions

1. Coolant Chemistry

The pre-core preconditioning and plant filtering were performed prior to the LWBR core installation with the reactor vessel filter and PWR test head installed. After the loops and vessel were filled with water, the reactor coolant chemistry was established and maintained as follows:

a. pH 10.10 to 10.30 with NH_4OH additions
b. Conductivity consistent with pH
c. Oxygen less than 0.14 ppm
d. Hydrazine 1.0 to 1.5 ppm greater than oxygen concentration until oxygen is less than 0.14 ppm
e. Fluoride less than 0.1 ppm
f. Chloride less than 0.1 ppm
g. Total gas less than 125 cc/kg (80 cc/kg prior to operations at T_{ave} greater than 200F)

2. Preconditioning Requirements

After the coolant was verified to be within the required specifications, the plant was heated by operating the reactor coolant pumps. A total of at least 240 hours of preconditioning time for the 1A and 1D loops (loops with new

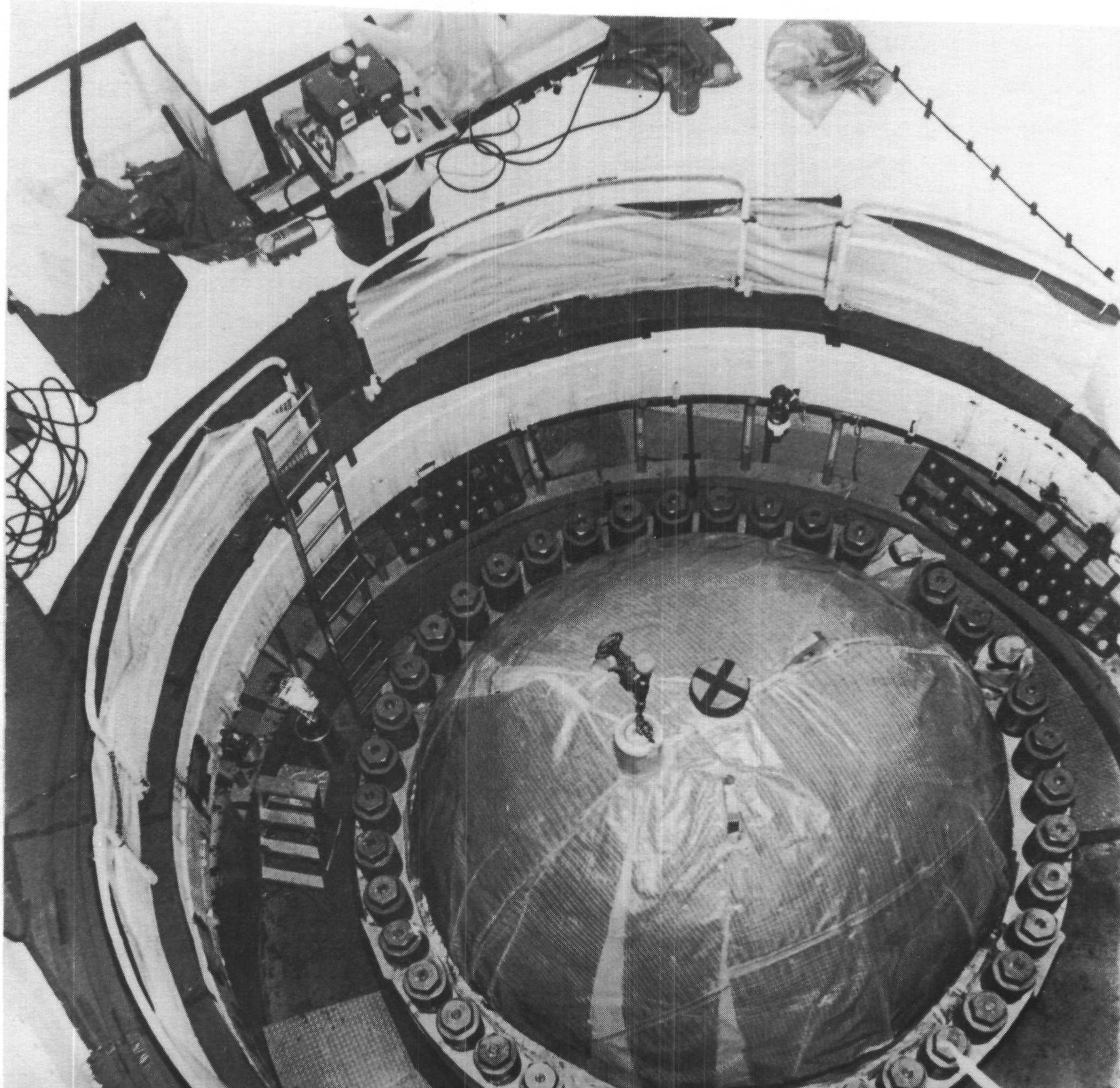


FIGURE B-5

TEST HEAD ON THE REACTOR VESSEL

heat exchangers) with the reactor coolant system at a temperature greater than 481 F (normal operating range is 481 to 531 F) was obtained as follows:

a. One hour of operation with the 1A loop reactor coolant pump on fast speed was equivalent to one hour of preconditioning time for the 1A loop, and one hour with the 1D pump on fast speed was equivalent to one hour of preconditioning time for the 1D loop.

b. Two hours of operation with the 1A loop reactor coolant pump on slow speed were equivalent to one hour of preconditioning time for the 1A loop, and two hours of operation with the 1D pump on slow speed were equivalent to one hour of preconditioning time for the 1D loop.

3. Filtering Requirements

The reactor coolant system was filtered, using the reactor vessel filter, concurrently with pre-core preconditioning. Fast speed pump operations were required as follows with plant temperature between 481 F and 531 F:

a. Each reactor coolant loop pump operating individually for two hours at a time.

b. The 1A and 1D pumps operating simultaneously for two hours.

c. The 1B and 1C pumps operating simultaneously for two hours.

d. All four pumps operating simultaneously for two hours.

During cooldown from the preconditioning, the following reactor coolant loop fast speed pump operations were conducted for "cold" filtering:

a. Each pump operating individually for one hour at a time at T_{ave} between 413 F and 435 F. The 1B and 1C pumps were also operated simultaneously on fast speed for one hour at a plant temperature between 413 F and 435 F.

b. One hour of operation with all four pumps on line simultaneously at a plant temperature between 413 F and 435 F.

c. The 1A, 1B and 1D pumps operating individually for one hour at a plant temperature equal to or less than 250 F.

During the preconditioning period each reactor coolant loop pump on line was stopped and started at least once every 24 hours to loosen crud deposits. Various reactor coolant analyses were required at least once a day. Crud concentration and activity analyses were required after a crud-burst causing event. If crud levels were greater than 100 ppb, specific clean-up operations were required to minimize deposition of crud on plant surfaces.

B. Preconditioning Results

A total of 587 and 602 preconditioning hours were logged for the 1A and 1D main coolant loops, respectively. Preconditioning was conducted between April 2, 1976 and May 5, 1976. The logged preconditioning hours exceeded the 240 hour minimum requirement.

During preconditioning the filter resistance to main coolant flow increased approximately 32 percent from the beginning to end of the preconditioning effort. This resistance resulted in a 7 percent reduction in system flow and a 14 percent increase in filter pressure differential (i.e., from an initial 70 psi to a final 79.9 psi). The reactor coolant loop flows obtained during filtering operation were approximately 10 percent greater than those predicted for LWBR core operation. Therefore, adequate filtering flow rates were obtained.

Crud levels were periodically monitored during preconditioning and filtering. Generally, a decreasing trend was noted in crud concentration and crud activity levels. For example, during the first five days of preconditioning, crud levels averaged about 90 ppb and crud activity levels averaged about 3.4×10^{-4} μCi/ml. During the final five days of preconditioning when loop filtering was being conducted, the crud levels averaged about 20 ppb, and the crud activity levels averaged about 3.8×10^{-5} μCi/ml. Thus preconditioning was effective in reducing plant crud and crud activity levels.

Crud activity during preconditioning comes from "old" crud remaining in the system from previous critical operations.

V. POST PRECONDITIONING CLEANUP AND INSPECTION

A. Post Preconditioning Filter Inspection

The reactor vessel filter cartridges and external surfaces were visually inspected during removal of the filter from the reactor vessel. The results of the inspection were as follows:

1. The reactor vessel filter and all 40 filter cartridges were found free of any indication of structural damage or bypass of reactor coolant flow.
2. No gross buildup of particulate matter or debris was observed on or in the area of the filter cartridges, indicating that cleanliness controls implemented during defueling and plant modification work had kept the primary system clean.

3. New filter cartridges and surfaces of the reactor vessel filter which had not previously been exposed to hot reactor coolant were covered with a tightly adherent copper-colored film, whereas surfaces which had seen previous exposure to hot primary coolant were gray in color. The copper color was interpreted as typifying short term stainless steel exposure to hot reactor coolant and constituting a normal condition in the chain of color transitions from initial bright metallic to fully conditioned gray.
4. No broken pieces of primary system parts (locking tabs, bolts, nuts, etc.) were observed.
5. Maximum radiation levels measured during inspection of the filter were 180 mrem/hr one foot above the filter and 450 mrem/hr one foot from the filter side wall. These radiation levels correspond to an estimated curie content of 0.8 curies.

B. Hydrovacuuming of the Reactor Vessel

After removal of the reactor vessel filter, the reactor vessel and thermal shield were hydrovacuumed to remove any foreign material which was too dense to have been removed during the preconditioning and filtering operation and had settled to the bottom of the reactor vessel. A hydrovacuum operates on the same principles as a household vacuum cleaner except water instead of air is used as the soil/debris transport medium. Water and debris, drawn from the bottom of the reactor vessel by a manually positioned tubular suction lance, are passed through a strainer and filter cartridges by the hydrovacuum pump. The water, filtered of debris, is recirculated to the reactor vessel. A performance test conducted with the hydrovacuum unit verified that the unit was capable of retrieving debris up to the size and weight of a 1/4 inch nut.

Access to the bottom of the reactor vessel was achieved by passing the hydrovacuum lance through each of the 523 flow holes in the bottom of the thermal shield and rotating the lance about each hole to maximize the area vacuumed. Debris captured during hydrovacuuming were minimal. The largest consisted of a 3/8 x 3/8 inch piece of pressure sensitive tape and a 1/2 x 1/8 x 1/32 inch paint chip.

C. Post Hydrovacuuming Vessel Cleanliness Inspection

To ensure reactor vessel cleanliness the bottom of the vessel was inspected using an underwater TV camera and video monitor. The TV camera inspection, which was performed through 24 random thermal shield flow baffle holes, showed no evidence of foreign particles. The inspection provided a clear magnified view of the bottom of the reactor vessel as evidenced by clearly defined images of a vessel machining alignment hole located at the center of the vessel dished bottom. Based on the TV camera inspection the reactor vessel was considered clean and free of foreign material.

APPENDIX C

ALIGNMENT OF THE CORE BARREL COMPONENTS USING OPTICAL ALIGNMENT SCOPES

I. INTRODUCTION

The design of the LWBR core barrel required that the three major components (the bottom plate, the lower core barrel, and the upper core barrel seal ring assembly) be aligned during final assembly. This orientation was necessary to ensure that the correct clearances between the fuel assemblies would be available in the finished, assembled core barrel. To obtain the required precise measurements of component alignment, optical alignment methods combining vertical alignment scopes and associated equipment were used. Optical methods were selected because of their capability to measure accurately over relatively long distances, where mechanical measuring equipment becomes unmanageable, inaccurate, and in many cases, unobtainable. Optical alignment of the upper and lower core barrels and the bottom plate was used at various stages of assembly and was an important aid in forecasting any problems resulting from misalignment of the components prior to final and permanent assembly. Refer to Figure 4 for illustration of the LWBR core components.

The alignment techniques used are those commonly employed for aligning field-erected, large, reciprocating or rotating machinery such as pipe line compressors or hydroturbines. No new alignment procedures needed to be developed.

II. EQUIPMENT DESCRIPTION

The optical alignment procedure was based on the use of one or more lines of sight using alignment telescopes.

An alignment telescope consists of a tube which has a reticle of cross hairs near the operator's eyepiece, and an objective lens on the opposite end. A movable lens, called a focusing lens, is placed between the objective lens and the reticle. By moving the focusing lens, the target in front of the alignment telescope can be focused on the reticle. This forms an inverted image on the reticle. The eyepiece erects and magnifies the inverted image and the reticle pattern together so that the observer sees the reticle pattern cross lines on the target at the point where the line of sight strikes the target. Targets are used which contain paired cross hairs enabling precise location of the target. The targets are placed in machined holes precisely located in the bottom plate or in brackets attached to the upper or lower core barrels. Figure C-1 shows a paired line target on which sets of lines are used, depending upon the length of sight used. The telescopic sights were equipped with spirit levels which were used to accurately determine the direction of gravity, the reference direction. In optical alignment, the word VERTICAL means, "in the direction of gravity", and the word HORIZONTAL means, "perpendicular to the direction of gravity". To align the core barrels to the bottom plate an alignment telescope was mounted into a plumb aligner bracket which was supported and centered in either the upper or lower core barrel, depending on which core barrel was being aligned. See Figure C-2 for a schematic view of the alignment scope in the plumb aligner bracket.

This method of using the alignment telescope gave accuracies of one part in 200,000. For example, if the target is placed at a distance of 200 inches from the alignment telescope, the distance and the direction will be in error by less than 0.001 inch. Optical micrometers are integral parts of the optical telescope. An optical micrometer displaces a line of sight parallel to itself. The extent of the movement is read to 0.001 inch.

It should be noted that the following precautions had to be taken with the optical alignment telescopes:

a. Vibration could make the use of alignment telescopes impossible. Accordingly strong, massive stands were used for the telescopes, and personnel movement on the stands was controlled.
b. High levels of illumination were required at the targets. However, the lights could not be close to the line of sight because of significant distortion of the line of sight resulting from the heat generated by the lights. High intensity spot lights operating at least five feet from the line of sight gave acceptable results.
c. All welding and brazing had to be completed before optical alignment was begun.

III. OPTICAL INSPECTION OF THE ALIGNMENT OF THE LOWER CORE BARREL TO THE BOTTOM PLATE

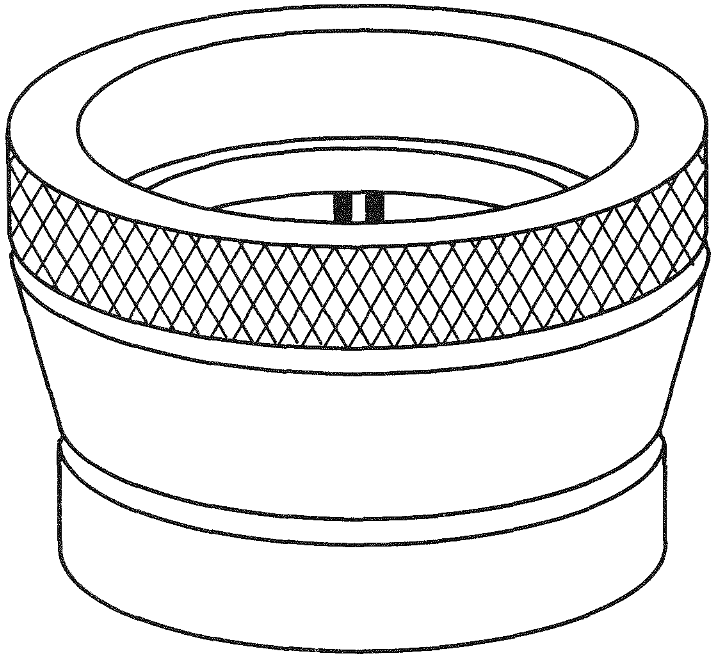
To understand the theory of the methods used for aligning the lower core barrel to the bottom plate, a description of the fabrication methods of these components is required.

During the fabrication and machining of the lower core barrel and bottom plate a set of axis lines was established, which in turn became the index from which all features of the components were located and machined. In addition, target holes for locating sighting targets (see Figure C-1) were machined into the bottom plate adjacent and in-line with the alignment holes. An additional target hole was also machined into the center of the bottom plate and was used as an additional reference for the optical alignment. The bottom plate was final machined first and as a separate unit from the lower core barrel. Final machining means the index holes and target holes were machined in sequence to assure they would be reasonably aligned and in a true line. Because of certain inherent machining inaccuracies, it was known that perfect alignment between the index holes and target holes was nearly impossible to attain. To discern the relationship between the target holes and the index holes, highly accurate mechanical inspection equipment was used to measure the relationship. The deviations from a true line were measured, located, and later factored into the final alignment measurements and calculations.

After completion of the machining and measuring of the bottom plate, the lower core barrel was to be machined using the same reference axis lines. Therefore it was necessary to transfer those lines from the bottom plate to the lower core barrel. The lower core barrel was placed on the bottom plate and the index hole locations (axis line references) were transferred by machine tool to the lower core barrel flange. The lower core barrel was final machined with some degree of assurance that the axis lines between the two units would be near coincidence. The lower core barrel was fitted to the bottom plate and aligned using the index holes as reference, and the two pieces were match-drilled to obtain the same alignment at final assembly.

Upon receipt and assembly of the lower core barrel to the bottom plate at Shippingport, the alignment was rechecked to ensure its correctness before installing the interference fit pins that secure the two components together. A description of this alignment check follows.

Prior to the optical inspection of the lower core barrel and bottom plate subassembly, the lower core barrel was leveled to within 0.001 in/ft or better. A highly accurate straight edge which was flat and straight within 0.0002 in/ft and a precision spirit level with a capability of measuring 0.0005 in/ft was used. The straight edge was first placed on the lower core barrel flange on the W-Y axis and the core barrel was leveled to within 0.001 in/ft or better. The straight edge was then placed on the X-Z axis and



TOP VIEW

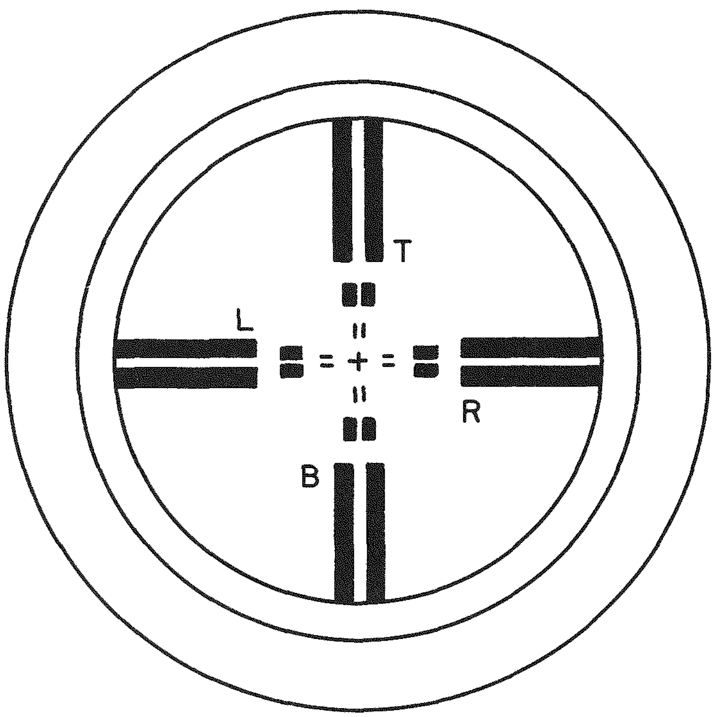


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FIGURE C-1
PAIRED LINE OPTICAL GLASS TARGET

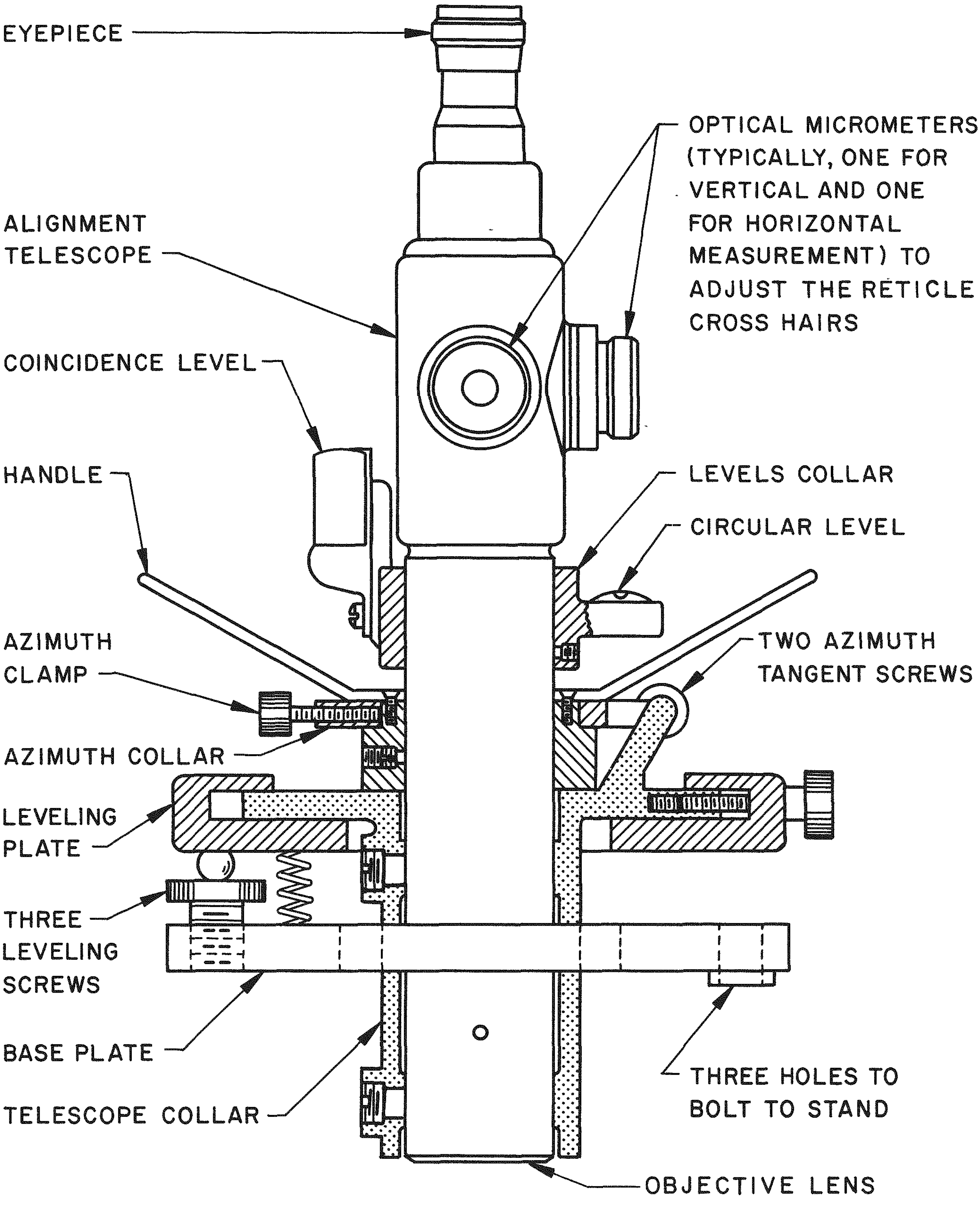

FIGURE C-2
SCHEMATIC OF THE ALIGNMENT SCOPE IN THE PLUMB ALIGNER BRACKET

the barrel again leveled to 0.001 in/ft or better. The leveling operations were repeated until the levelness of the core barrel flange could not be improved.

The core barrel bottom plate was not mutually parallel with the lower core barrel; it was therefore necessary to measure the bottom plate levelness. A straight edge and precision level, as previously described, was used. However, actual level measurements were required and were obtained as follows. Two equally sized precision blocks were placed on the bottom plate top surface at the W-Y axis. The straight edge was then placed on the blocks with the precision level on the straight edge top surface. Using precision shims, the straight edge was adjusted until level. The shim thickness was measured and recorded. This measurement consequently determined the levelness of the bottom plate. The same procedure was repeated on the X-Z axis. The levelness dimension of the bottom plate was needed to calculate the total amount of deflection of the axis lines.

Optical glass targets (Figure C-1) were inserted into the bottom plate target holes and were oriented in the same direction. An optical bridge assembly (Figure C-3) was placed on the lower core barrel flange and located by means of precision pins into the core barrel axis holes.

The optical bridge is a sturdy "X" shaped structure on which the optical telescopes were mounted to make the alignment measurements. The bridge was equipped with bearing pads which rested on the core barrel flange at the four axis points and were precision machined in the same plane within 0.001 TIR. Four axis holes and four optical target holes were precision machined in the bridge and their locations in respect to one another were accurately measured and recorded. The dimensional deviation was then factored into the final alignment measurements as were the deviations of the target holes in the bottom plate.

Four open targets (targets without glass) were inserted into the optical bridge and were oriented in the same direction as the glass targets in the bottom plate. Open targets, which are targets with nylon cross hairs, were used in this position because the glass target markings and the light bending qualities make it impossible to focus "through" the glass onto an objective target.

An optical telescope/plumb aligner bracket assembly was attached to a spacer spool and mounted on the optical bridge. (See Figure C-3.) The telescope was then adjusted and accurately leveled through a 360 degree arc by observing the previously mentioned spirit levels. The slang used for this

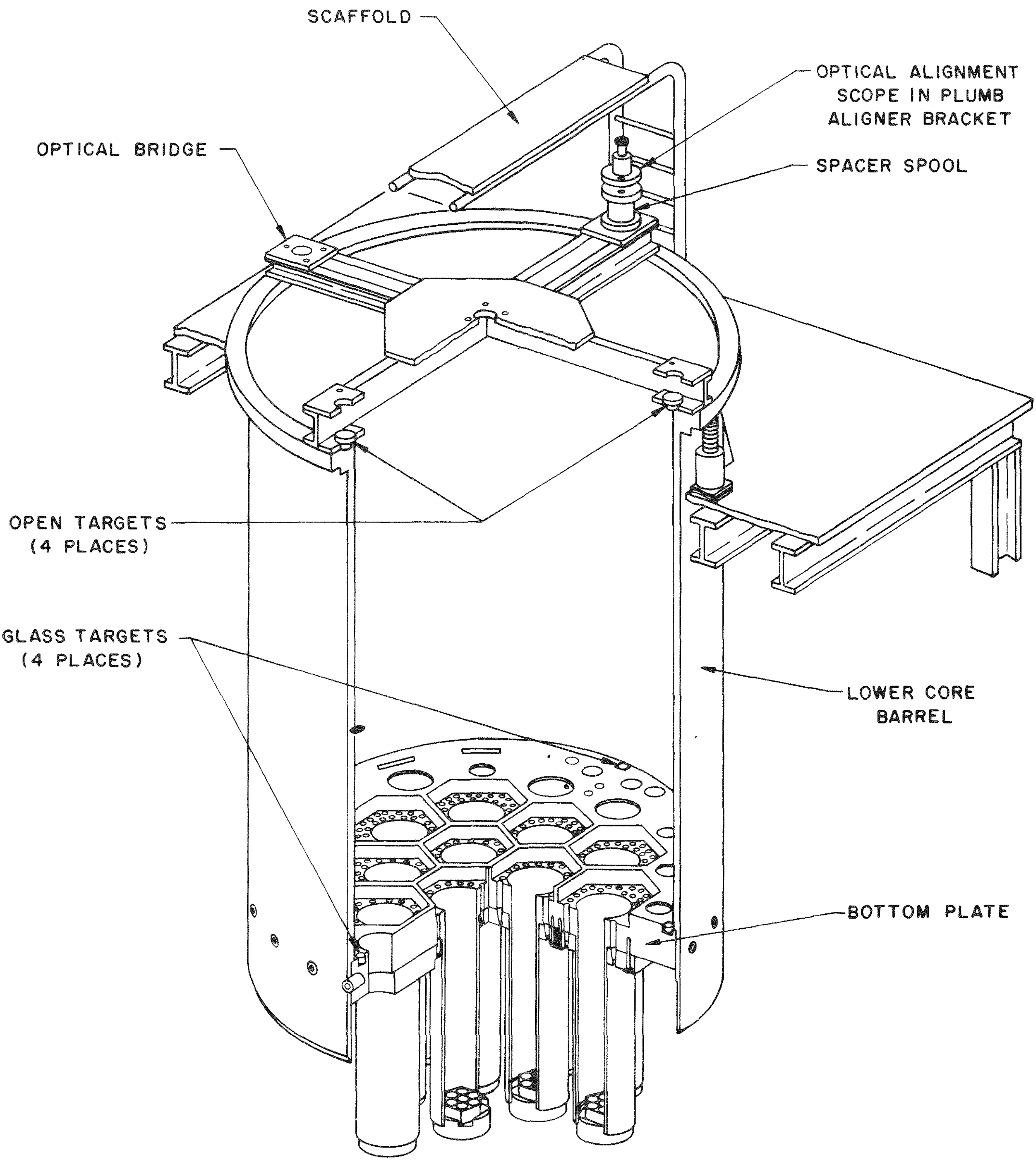

FIGURE C-3

OPTICAL ALIGNMENT EQUIPMENT MOUNTED ON THE LOWER CORE BARREL particular operation is "making the telescope level to the world." Once this levelness was attained, the telescope was focused on the bottom plate target at any axis and "zeroed in." The effect of this was to superimpose the "built in" telescope reticle cross lines onto the target cross lines. This operation was the straight-line reference between the telescope and the objective target and was essentially a zero dimension.

The telescope was then focused on the target immediately below the telescope (known as the top target) and the reticle cross lines were superimposed on the target cross hairs. The amount of displacement between the upper and lower target was measured by using the telescope micrometers. It was noted which top target quadrant the telescope cross hairs displaced as well as the distance they were displaced. The total misalignment was then calculated using the measured displacement and the known axis pin to target hole machining misalignment in the bottom plate, lower core barrel and the optical bridge.

IV. ROTATIONAL AND LATERAL ALIGNMENT OF THE UPPER CORE BARREL TO THE LOWER CORE BARREL/BOTTOM PLATE ASSEMBLY

The alignment procedure for the rotational and lateral alignment of the upper core barrel to the lower core barrel/bottom plate assembly was similar to the previously described alignment of the lower core barrel to the bottom plate, except that two matched inspection plates were used and a leveling of the upper barrel was not required. The optical alignment inspection was used to align the upper barrel to an optimum position in relation to the lower barrel/bottom plate assembly.

During the manufacturing of the upper core barrel the vendor had to meet the following requirements:

1. The upper and lower core barrel flanges were to be parallel to each other.
2. The seal ring surface had to be equally parallel to the top and bottom core barrel support flange seating surfaces.

These requirements were necessary so that when the upper core barrel was seated on the lower barrel top flange, the tilt of the lower barrel assembly was reflected or continued through the upper barrel top flange and seal ring.

The upper core barrel alignment pin holes were rough machined small so that when the best alignment of the upper core barrel to the lower barrel was attained, there was sufficient metal stock to allow reaming of the alignment pin holes to match the alignment pin holes in the lower core barrel. To attain the best alignment between the upper and lower core barrel assemblies, two match machined inspection plates were manufactured for this portion of the optical alignment. The inspection plates were machined with five axis target holes, one each at the W, X, Y, Z axis points near the periphery, and one on the center line. These axis holes were in the same relative location as the target holes in the bottom plate. Again, as described previously, because of inherent inaccuracies of machining tools, it was impossible to machine a series of holes to exactly duplicate the size and locations. Therefore the deviations of the target holes from a true location were measured and recorded for use in determining the alignment of the core barrels.

The alignment was then accomplished as follows. The upper core barrel was placed on the lower core barrel assembly with the axis lines aligned as closely as possible. This was accomplished by guiding the upper core barrel onto the lower barrel using the rough machined alignment pin holes and pins. After the units were seated together, the pins were removed to allow movement (rotational and lateral) of the core barrel. One inspection plate was installed on the seal ring at the bottom of the upper core barrel. The plate was rotationally aligned with the upper core barrel using close fitting pins installed in matched alignment holes in the alignment plate and the upper core barrel seal ring. The second of the matched inspection plates was placed on the top surface of the upper core barrel flange and aligned in much the same way as the first plate. At this time a scaffold for the telescope sight operator was installed. This scaffold prevented added weight on the inspection plate which would distort the plate and introduce inaccuracies into the final alignment.

Open targets were placed in the two inspection plates and oriented in the same direction as those targets in the bottom plate. An optical telescope/plumb aligner bracket was placed on a spacer spool (needed for close focusing) and positioned over a target in the top inspection plate. The telescope assembly was not clamped into position until a rough alignment of the telescope was completed.

The telescope was leveled using the bull's eye rough leveling spirit level, and focused on the target nearest the scope, located in the alignment plate resting on the upper core barrel flange. The scope was rotated through 360 degrees and adjusted to be coincident with the target. At this time the scope was not necessarily level, but coincidence with the target was a requirement. The scope was then focused on the second target, located in the alignment plate resting on the seal ring, to determine the relative position of the scope/top target versus the second target. The scope assembly was then moved until coincidence existed between the scope and the two targets. At this time the scope assembly was clamped into position on the top plate. The line of sight of the scope was then parallel to the center line of the upper core barrel. The scope was then focused on the bottom plate glass target and the displacement was measured. The same procedure was performed for the remaining axis line targets. Based on the results, the distance the upper core barrel was to be rotated and moved laterally to attain alignment was determined. With special jacking equipment, the core barrel was moved. The alignment inspection was repeated, the upper core barrel again moved, and the procedure was repeated until the best alignment was achieved. The alignment pin holes were machined with portable equipment until the required fit was achieved. Then the barrels were bolted together and the alignment was complete.

V. SUMMARY

The upper and lower core barrels, and the bottom plate were accurately aligned using telescopic sights and targets. Levelness and machining accuracy of the three components was precisely measured and factored into the evaluation of the inspection data. The equipment used was able to detect a 0.0015-inch rotational orientation error of the lower core barrel with the bottom plate.

The techniques used were similar to those used to align large, site erected machines such as pipe line compressors or hydraulic turbines. No new alignment checking techniques were required. After alignment the upper and lower core barrels and the bottom plate were pinned together to prevent shifting during reactor operations.

APPENDIX D

BRAZING FLOW INSTRUMENTATION TUBING USING INDUCTION BRAZING EQUIPMENT

I. INTRODUCTION

The LWBR core has flow measuring venturis in the bottom plate of the core barrel for each of the twelve fuel module locations. The pressure taps from these venturis are led upward inside the barrel in two separate groups and through the primary system pressure boundary in two instrumentation nozzles. Each group has four spare pressure tubes; therefore, each group consists of sixteen pressure tubes. Due to the size of the core barrel, it was manufactured and shipped in three parts or components. These three components are the bottom plate, the lower barrel, and the upper barrel/support flange. Each of these components includes a portion of each instrumentation tube; therefore, it was necessary to join each of the tubes at two places when the three components were assembled at the installation site. The brazed joints were in the vertical run of the pressure tubes. The functional requirements for these brazes are that the joints must be pressure-tight and remain tight for the life of the LWBR core, and it must be possible to make the joints at the assembly/installation site within the space restrictions imposed by the core barrel design. During the design it was determined that "field" induction brazed joints could meet these requirements. Figure D-1 shows the installed configuration.

II. DESIGN DESCRIPTION

The pressure tubes are 0.232-inch outside diameter and have an 0.041-inch wall thickness. The braze sleeves joining the tubing ends are 0.235-inch inside diameter and have a nominal wall thickness of 0.050-inch. There were two different dimensions between tube ends in each group at each joint location which required two different lengths of braze sleeves, 1.26 inches and 2.90 inches. The outer row of tubes have the larger end-to-end spacing, 2.00 inches, which provides access for brazing the inner row of tubes which are next to the core barrel wall. The end-to-end spacing on the inner row of tubes is 0.36 inch, which is just sufficient to allow installation of a braze sleeve.

The braze sleeves are made from Inconel Alloy 600. The pressure tubes in the barrel bottom plate and the upper barrel/support flange are also made from Inconel Alloy 600, and the pressure tubes in the lower core barrel are made from

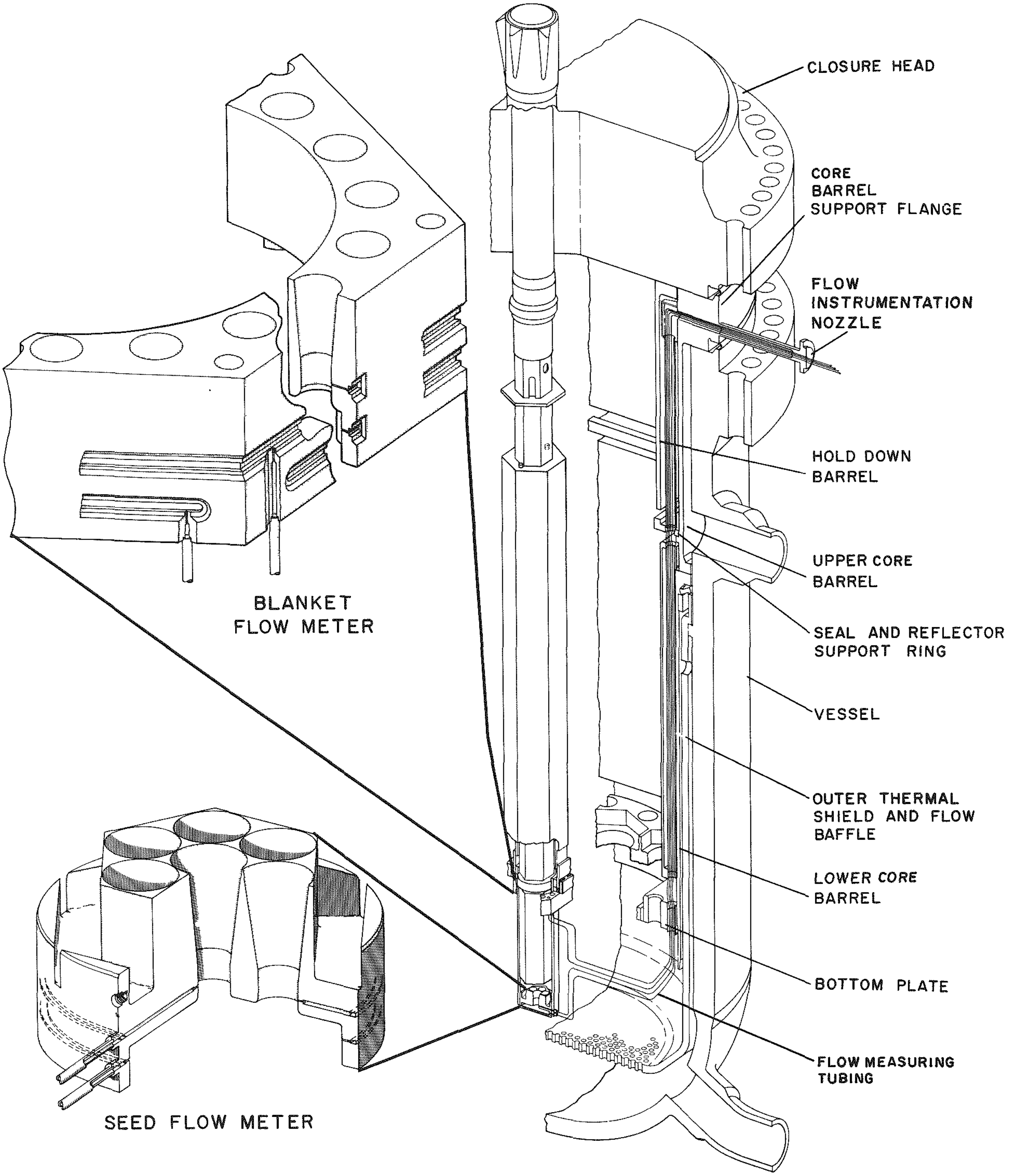

Figure D-1. Flow Instrumentation

AISI-304 stainless steel. Therefore, each brazed joint joins one Inconel Alloy 600 tube to one AISI-304 stainless steel tube through an Inconel Alloy 600 braze sleeve. The brazed joint configuration and dimensions are shown on Figure D-2.

Each of the braze sleeves has a 0.03-inch radius circumferential groove on the inside surface at each end of the sleeve. This groove holds the preplaced brazing alloy. The brazing alloy was in powdered form and in accordance with American Welding Society (AWS) specification NBi-7 which contains 11 to 15 percent chromium, 9 to 11 percent phosphorus, and the remainder nickel. The powdered brazing alloy was mixed with an acrylic binder and placed in the grooves of the brazing sleeves. After curing of the binder, a sleeve was installed over a pair of tube ends and then brazed using induction brazing equipment which provided purge gas and brazing heat. The melting point of the alloy is 1630 F; therefore, all parts of the surface to be brazed were heated to above 1630 F. The purge gas was high purity argon. The two brazed joints for a braze sleeve (one joint at each end) were brazed individually and each required a setup and heating cycle.

Following brazing, each joint was inspected and leak tested. The leak test pressure was 100 psi and was applied to the outside of the brazed joint.

III. EQUIPMENT DESCRIPTION

The equipment used for brazing the flow instrumentation tube joints was an induction brazing system. As shown on Figure D-3, the major components of this system are a power supply unit, remote RF output unit, remote control cable and control pendant, water cooled power output cable, and brazing tool. The power supply unit contains the high voltage transformer and rectifier, the cooling water circulating pump and reservoir, and the electrical controls. The remote RF output unit, which can be located up to 150 feet from the power supply, consists of the radio frequency power source, radio frequency ammeter, power level and brazing time controls, purge gas controls, and two purge gas flow meters. The remote control cable and pendant attaches to the remote RF output unit and provides flexibility for remote operation of the system in restricted working area. The water cooled power cable is 10 feet long and delivers the RF brazing power from the remote RF output unit to a brazing tool on the work. The brazing tool, shown in Figure D-4, and brazing tool adapter apply the RF power to heat the tubing joint being brazed.

The induction brazing system was designed specifically for brazing tubing connections in the range 3/16 through 3/4 inch diameter. All components

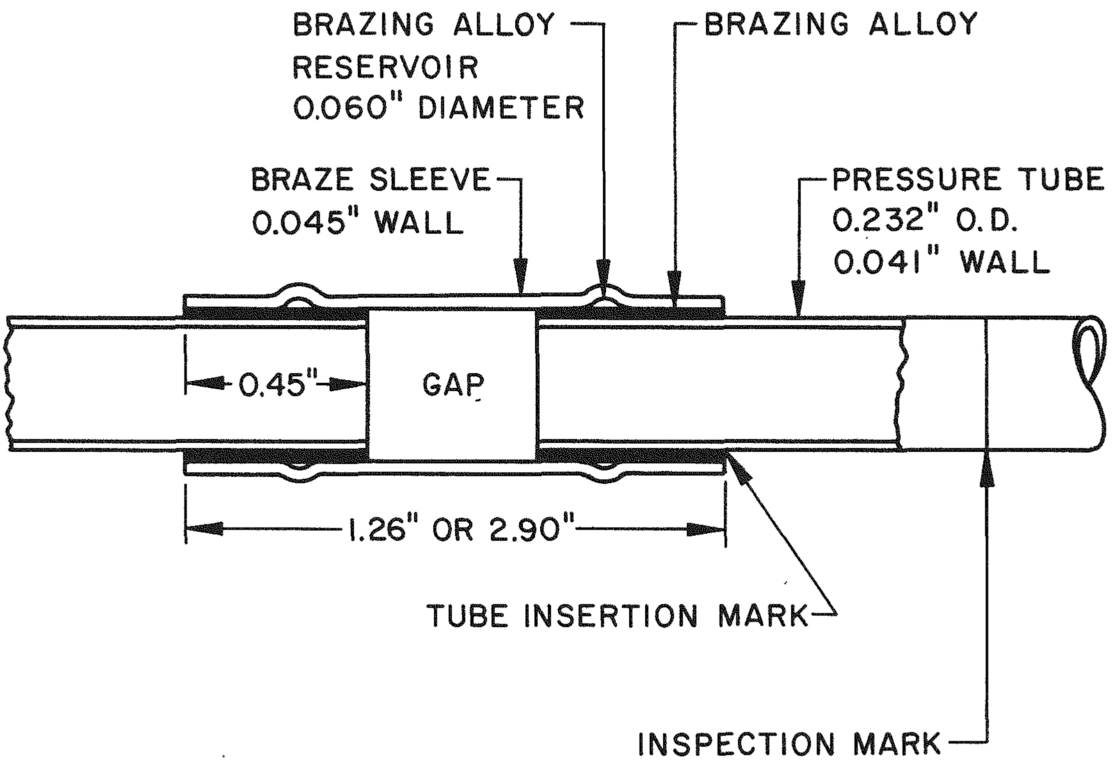

FIGURE D-2
BRAZED JOINT DESIGN

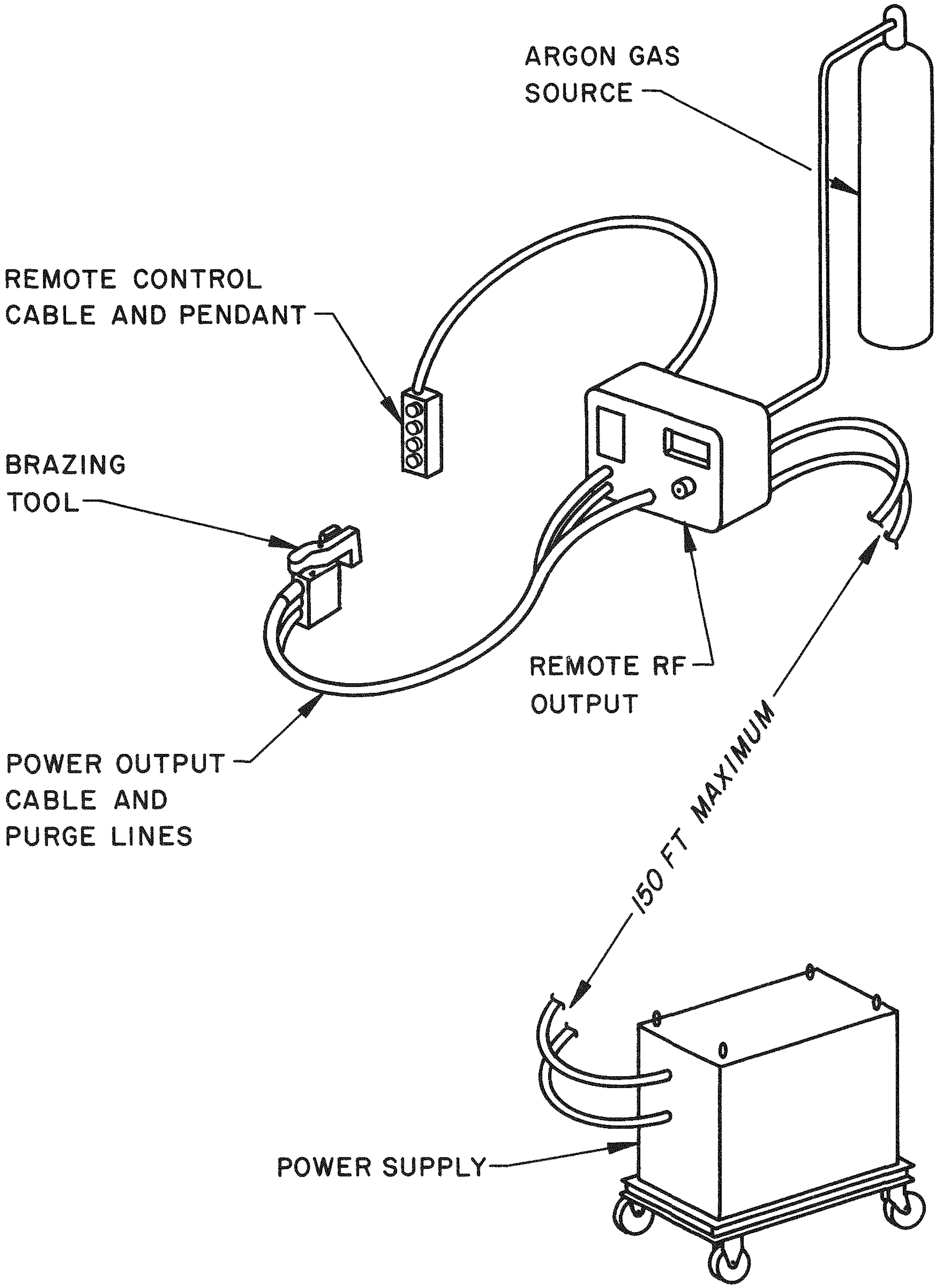

FIGURE D-3
INDUCTION BRAZING SYSTEM COMPONENTS

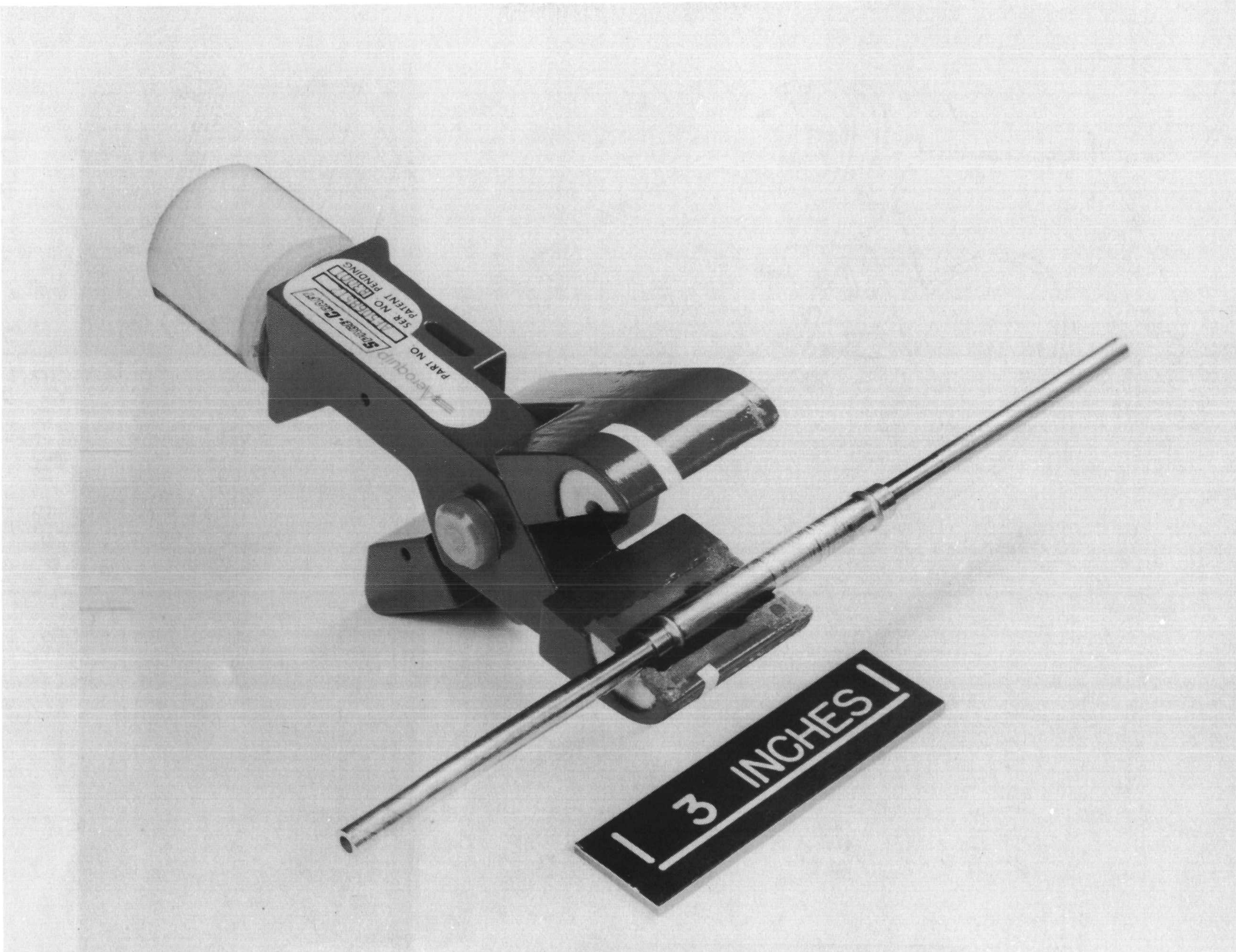

FIGURE D-4
BRAZE SLEEVE AND TUBING IN THE
BRAZING TOOL

accommodate the full range of tubing sizes except the brazing tool. The brazing tools must be the correct size for the tubing being brazed. Since the 0.232-inch diameter tubing is not standard, the supplier of the equipment made minor modifications to the nearest standard size tool designs (0.25 inch) to adapt them to the LWBR instrumentation tubing and braze sleeve design. The two different lengths of braze sleeves required two slightly different brazing tools.

IV. BRAZING PROCEDURE DEVELOPMENT AND QUALIFICATION

The supplier of the brazing equipment provided procedures for setting up and operating the equipment and the basic procedure for brazing. The equipment supplier's development work did not include the brazer alloy or the dimensions and material combinations of the LWBR instrumentation tubing; therefore, it was necessary to develop operating parameters for the LWBR application of this equipment.

A small amount of development work was performed at the supplier's facility using the supplier's equipment to prove the feasibility of the system for performing the instrumentation tube brazes. As part of this work, the vendor assembled instrumented mockups for use in the Bettis development effort.

After delivery of the equipment to Bettis, a development program was initiated to establish operating parameters and to qualify a brazing procedure. This program utilized tube and sleeve mockups having the same dimensions, material combinations, and braze alloy as the LWBR core barrel design. A small amount of work was also performed using alternate design sleeves having a larger volume of preplaced braze alloy; however, the larger reservoir was found to be unnecessary.

A description of the operating parameters required to be developed to prepare a brazing procedure follows:

A. Power Level Setting

This setting determined the level of the radio frequency power and was indicated on the radio frequency output ammeter. The setting was made on a 0 to 100 precision potentiometer and radio frequency current was read on the 0 to 300 ampere meter. The effect of power level varied slightly depending upon the brazing tool used; therefore, it was necessary to develop this parameter for each brazing tool to be used.

B. Power-On Time

The power-on time must be sufficient to permit the work to reach brazing temperature and allow the braze alloy to flow. It is closely related to the power level setting and is also dependent upon the brazing tool used.

C. Tool Purge Gas Flow Rate

The brazing tool introduces purge gas to the cavity around the work to prevent oxidation during the brazing operation. Since this flow rate is related to the design of the tool and size of the components being brazed, only one value was required.

D. Tube Purge Gas Flow Rate

The brazing system requires purge gas flow through the inside of the tube and sleeve to prevent oxidation during the brazing operation. This flow rate is related to the size of the tubing components; therefore, only one value was required.

E. Pre-Brazing Gas Purge Time

To assure that only purge gas was present in the cavity in the tool and the inside of the tube, it was necessary to provide a purging flow for a period of time before applying heat. This time is related to the length of the tubing upstream of the braze location, the flow rate, and the design of the brazing tool. Two different pre-brazing purge times were used because of the different lengths of tubing involved for the upper and lower brazed joint locations.

F. Post-Brazing Gas Purge Time

The gas purge is required following the heating cycle to prevent oxidation while the work is cooling. The purge gas also cools the work. This time is related to the flow rate and the size of the tubing components; therefore, only one time was required.

The first part of the development program consisted of establishing tentative parameters for the Bettis brazing equipment with each brazing tool to be used. This was done using the instrumented mockups and a temperature recorder. These tentative parameters were based on approximately 1900 degrees power cut off temperatures at approximately 60 seconds power-on time.

Following establishment of tentative parameters, a procedure was prepared and each tool was used to braze mockups which were visually and metallurgically examined. The parameters were adjusted until one of each type tool produced five consecutive acceptable brazed mockups that passed leak test and met the acceptance criteria shown in Table D-I. (Each mockup consists of two brazed joints as shown on Figure D-2.) This qualified both the equipment and the procedure. Following qualification of the procedure, additional brazing tools were qualified. Table D-II shows the operating parameters developed for the eight brazing tools used for the LWBR flow instrumentation brazing program. Each operator was qualified by brazing four consecutive mockups, two of each type, which were required to meet the requirements of Table D-I. The criteria for acceptance of production brazed joints, a visual examination followed by a pressure/leak test, were developed during checkout and qualification of the brazing procedure.

V. TESTING AND INSPECTION OF PRODUCTION BRAZED JOINTS

The acceptance criteria for the production brazed joints consisted of a visual inspection and a pressure test.

A. Visual Inspection

The production brazed joints were visually inspected, before being pressure tested, in accordance with the visual inspection criteria listed in Table D-III.

B. Pressure Test

The LWBR core design requirements specify that the instrumentation tube brazed joints were to be pressure tested at 100 psi. The design of the barrel bottom plate is such that there is no convenient access to the inlet ends of the flow instrumentation tubes so that they can be closed for pressure testing. Therefore, a method was devised to apply the test pressure to the outside surface of the brazed joint. The method used flexible test tees made from an elastomer material. A section through a tee is shown on Figure D-5. Each tee enclosed one brazed joint for pressure test; therefore, two were required for testing each brazed sleeve. These tees were installed and pushed back from the brazing zone before installing and brazing the sleeve. After the sleeve was brazed and inspected, the tees were moved into test position on the brazed sleeve, then worm gear drive hose clamps were installed to make a leak-tight seal on each side of the brazed joint. The pressure test consisted of applying 100 psi gas pressure (nitrogen) to the brazed joint, then isolating the test tee from the gas supply and holding the pressure for 10 minutes. The acceptance criterion was a pressure drop of 3 psi or less during the 10 minute period. After the test was finished, the hose clamps were removed, the test tee was split with a sharp knife, and then removed from the work.

TABLE D-I. QUALIFICATION CRITERIA FOR BRAZED JOINTS

1. Exterior fillet for 80 percent of the circumference with no single interruption more than 10 percent of the circumference.

2. Base metal penetration not to exceed 20 percent of the tube wall thickness; i.e., penetration not to exceed 0.008 inch.

3. Base metal erosion not to exceed 10 percent of the tube wall thickness; i.e., erosion not to exceed 0.004 inch.

4. No more than 40 percent voids permitted within the nominal capillary length.

5. Total sound bond length equal to 6T minimum, where T is the thickness of the thinnest member. Braze bond length and fillet length on both sides of the reservoir could be added together to determine total sound bond length.

6. The sound bond length was required to be free of any cracks or porosity.

7. No leaks were permitted in a pressure test at 100 psi for 10 minutes. Maximum allowable pressure drop during the 10 minute test was 3 psi.

TABLE D-II. BRAZING PARAMETERS

Power Level Setting and Power-On Time

Tool Serial No.	Tool Type	Power Setting	RF Amperes	Power-On Time (sec)
R3001	Short Sleeve	89.0	248 ± 2	60
R3002	Short Sleeve	91.2	254 ± 2	60
3165	Short Sleeve	88.0	251 ± 2	60
7661	Short Sleeve	91.0	261 ± 2	60
R3007	Long Sleeve	90.2	252 ± 2	60
R3008	Long Sleeve	92.4	258 ± 2	60
2657	Long Sleeve	89.5	256 ± 2	60
7662	Long Sleeve	95.0	273 ± 2	60

Tool Purge Gas Flow Rate - 15 cu ft per hour

Tube Purge Gas Flow Rate - 15 cu ft per hour

Pre-Brazing Gas Purge Time - Bottom Plate to Lower Core Barrel - 60 seconds

Lower Core Barrel to Upper Core Barrel - 90 seconds

Post-Brazing Gas Purge Time - 120 seconds

TABLE D-III. VISUAL INSPECTION CRITERIA FOR PRODUCTION BRAZED JOINTS

1. Surface oxide discoloration of the base metal was considered normal and acceptable. The presence of dark gray, black, or non-adhering loose scale in the immediate area of the braze (within 0.06 inch of the fillet) indicated excessive contamination and required engineering evaluation. This condition required a check of the purging system to assure purging was in accordance with the procedure requirements.

2. The centering of the sleeve on the tubing was inspected by measuring the dimensions from the ends of the braze sleeve to a reference mark on the tube. This dimension was required to be 0.500 ± 0.09 inch. If the dimension was not within the specified limit, it required engineering evaluation.

3. The entire heated area was inspected for melting of the tubing or sleeve. The only melting acceptable was a maximum of 0.062 inch on the corner of the end of the sleeve. A condition exceeding the specified limit required engineering evaluation.

4. The external junction of tube to sleeve was inspected for visible alloy flow. The acceptance requirement was that alloy must be visible around 80 percent of the circumference or periphery and no single interruption could exceed 10 percent of the circumference. Any joint not meeting this requirement was rejected.

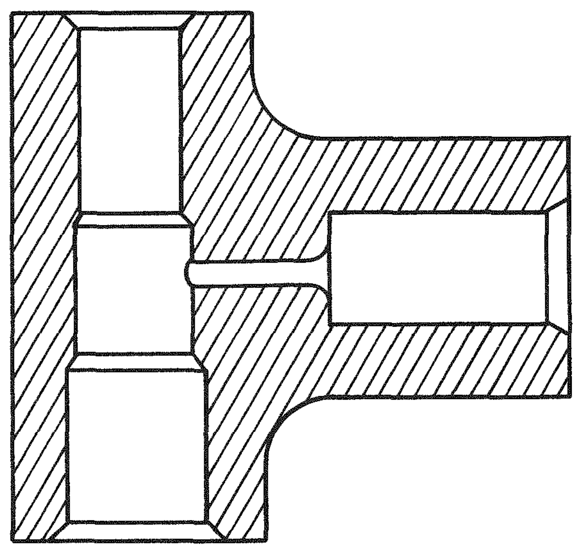

FIGURE D-5
PRESSURE TEST TEE

VI. SUMMARY

The brazing development program resulted in an adequate procedure and in adequate brazed joints. However, this program was expensive in terms of the amount of effort and equipment required to make the 64 tubing connections. It is recommended that in future instrumentation tube designs, mechanical connections are seriously considered and brazed connections specified only if mechanical connections are found to be inadequate.

APPENDIX E

SHIPMENT OF THE LWBR FUEL AND REFLECTOR ASSEMBLIES

I. INTRODUCTION

The LWBR blanket and seed fuel assemblies, and the reflector assemblies were built at the Bettis Atomic Power Laboratory. To ship these assemblies approximately 55 miles to the Shippingport Atomic Power Station (SAPS) special highway transport vehicles were used as shown on Figures E-1 and E-2. These vehicles incorporated air-cushioned suspensions, and elastic mounts for the assembly supports, to reduce accelerations resulting from highway irregularities and starting/stopping of the vehicles. These vehicles had a capacity of one assembly each shipment, so that 39 shipments were required.

II. GENERAL COMMENTS

The fuel and reflector assemblies were first placed in strongbacks, the assembly/strongback assemblies then installed in the shipping containers, and the containers shipped to SAPS. The containers were moved into the Fuel Handling Building where the assembly/strongback assemblies were removed, uprighted in the case of the seed and blanket assemblies, and placed in upright fixtures in the assembly storage facilities. The assemblies were then removed from the strongbacks and either placed in storage, or installed in the reactor.

The method of handling and shipping the module assemblies, and the design of the shipping containers, was partially dictated by the Allowable Dynamic Acceleration Limits (ADAL). The ADAL may be considered dynamic transport load limits, established to ensure that no local yielding would occur in any fuel or reflector assembly and that no fuel or reflector pellet separation would occur during shipment from Bettis to SAPS. Table E-I lists the ADAL, calculated maximum dynamic accelerations prior to shipment and the margin of calculated dynamic accelerations compared to the ADAL, for all axes of acceleration. No calculated dynamic accelerations or margins are given for the seed assemblies because the ADAL for the seed assemblies are much higher than for the other assemblies.

Accelerations were measured and recorded continuously during all module shipments. With two exceptions the ADAL for all modules was not exceeded during the shipments. Details of these discrepant accelerations and the resolutions of the problems are found in Appendix J.

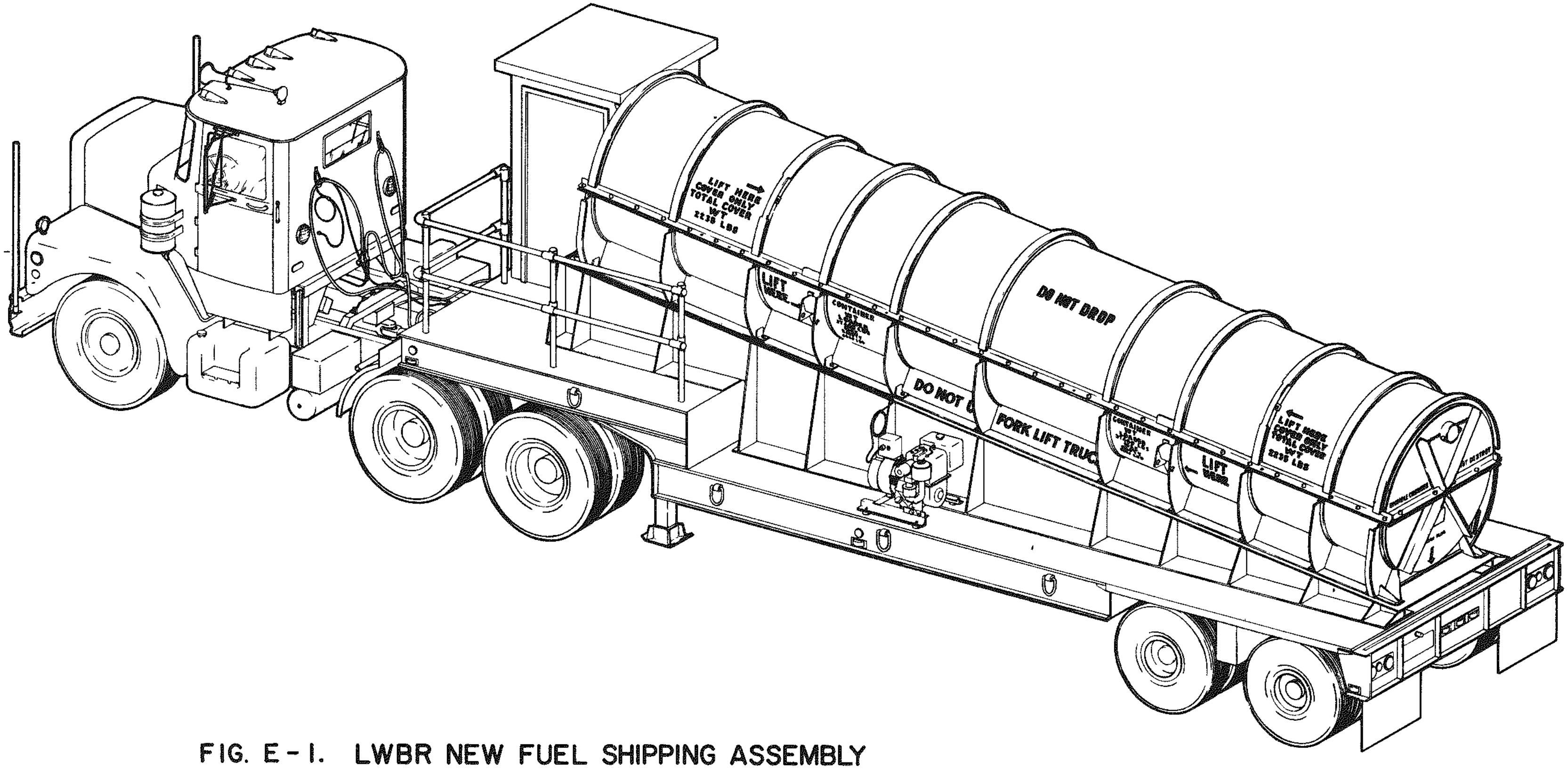

FIG. E-1. LWBR NEW FUEL SHIPPING ASSEMBLY

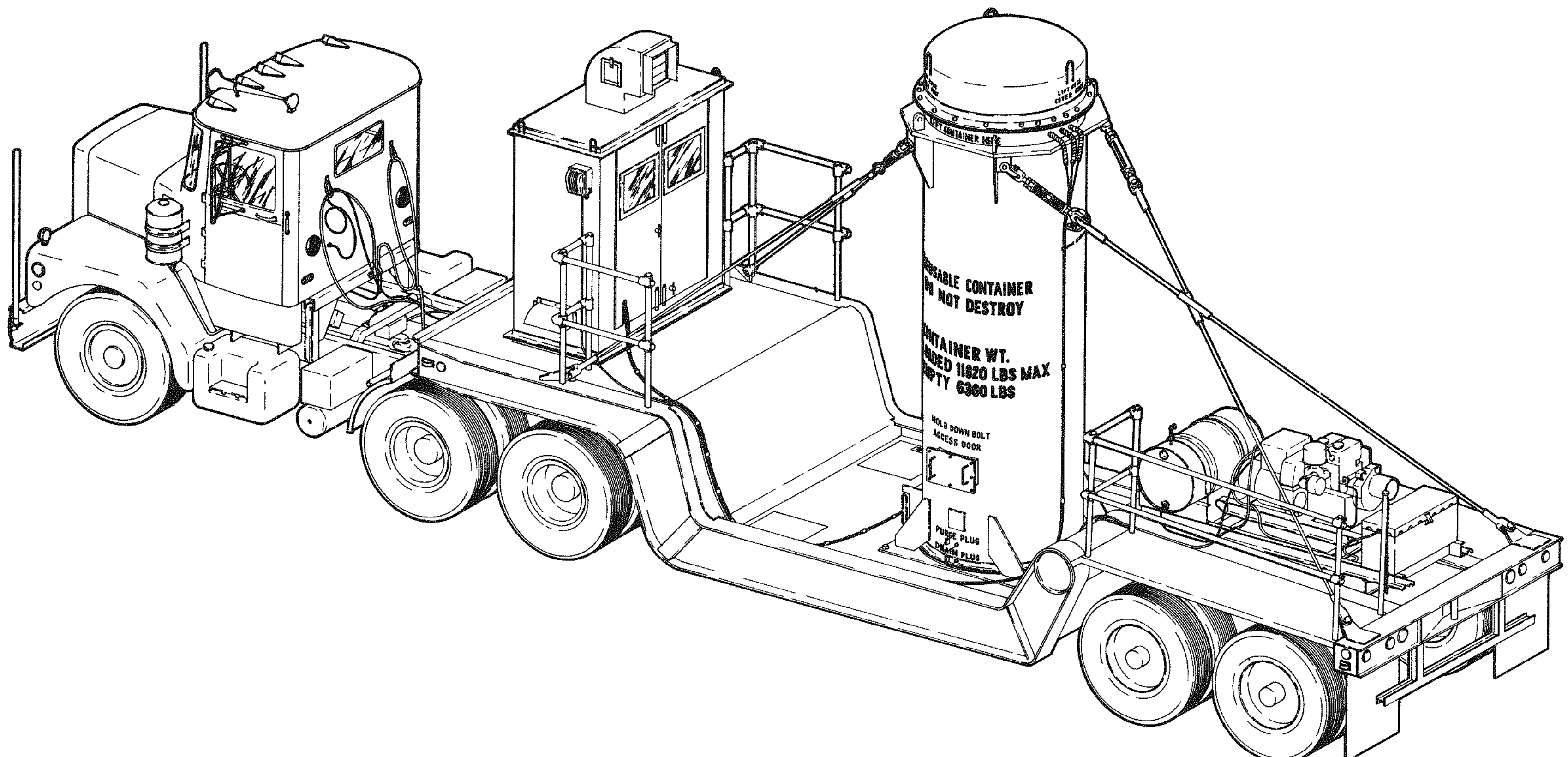

FIG. E-2 LWBR REFLECTOR SHIPPING ASSEMBLY

TABLE E-I. SHIPPING ACCELERATION PARAMETERS

Direction of (ADAL) at Acceleration Theoretical

Assembly Type	(1) Direction of Application	(2) (ADAL) at Critical Component	(3) Calculated Dynamic Acceleration	(4) Theoretical Margin
Reflector	Vertical	2.00	0.46	4.34
	Lateral	0.84	0.70	1.20
	Longitudinal	0.84	0.57	1.47
Blanket	Vertical	0.87	0.43	2.02
	Lateral	1.58	0.76	2.08
	Longitudinal	2.00	0.72	2.78
Seed	Vertical	2.43	---	---
	Lateral	3.32	---	---
	Longitudinal	3.00	---	---

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(1) Vertical - perpendicular to the plane of the road surface.
Lateral - perpendicular to the direction of truck motion and parallel to the plane of the road surface.
Longitudinal - parallel to the direction of truck motion.

(2) The ADAL at critical components correspond to and are consistent with the ADAL at the support structure (strongback).

(3) Accelerations calculated using data resulting from a REM-3 (test assembly) reflector Bettis to Shippingport and return test shipment.

(4) Margin is the ADAL divided by the calculated dynamic acceleration.

To keep the accelerations within the ADAL during highway transport, speeds were restricted to a maximum of 20 mph, and the route was carefully selected to avoid known road hazards. Escort vehicles were used ahead of and behind the trucks to preclude collisions as a result of the slow speeds. No limited access highways were used, because of the 40 mph minimum permitted speed requirement on these highways. The 55 mile trip from Bettis to SAPS took about 7 hours travel time. During transport the on-board tape recorders (for recording voice comments and the 3-axis accelerations) were powered by on-board gasoline powered generators.

III. SHIPMENT OF THE SEED MODULES

The seed modules were shipped in the strongbacks (Figure E-3), which were placed in the new fuel shipping assembly (Figure E-1) for transport. Figure E-5 shows the strongback in the shipping container. The shipping container is sloped to the rear, as shown on Figure E-1, because it was necessary to keep all fuel pellets at the lower end of the fuel rods, and in contact with each other within each rod, for proper performance of the core. If the fuel rods had been horizontal during shipment, longitudinal accelerations could have caused the pellets to separate, deflecting the springs in the top of the rods, and possibly jamming in the separated position as a result of chipping of the pellets.

The strongback assembly (Figure E-3) incorporated elastic shear mounts to reduce accelerations on the strongback housing. Three-axis accelerometers were mounted to the strongbacks with leads passing out through the shipping container to the on-board recorders. Three-axis accelerometers were also mounted to the trailer bed. The trunnions were used to support the strongback when rotating the strongback/fuel assembly between vertical and horizontal orientations. Rotation was limited to prevent the top of the modules from ever being lower than the bottom to preclude the possibility of pellet separation.

IV. SHIPMENT OF THE BLANKET MODULES

The blanket modules were shipped in strongbacks (Figure E-4), inside the new fuel shipping assembly (Figures E-1 and E-5). Comments above for the shipment of the seed modules also apply to the shipment of the blanket modules. In addition, the strongback-grid interface (Figure E-6) used a poured-in-place room temperature vulcanizing silicon rubber inside a polyethylene tube to provide full support for the lower half of each blanket grid. A mandrel was used inside the blanket guide tube to preclude collapse of the guide tube in the event of a

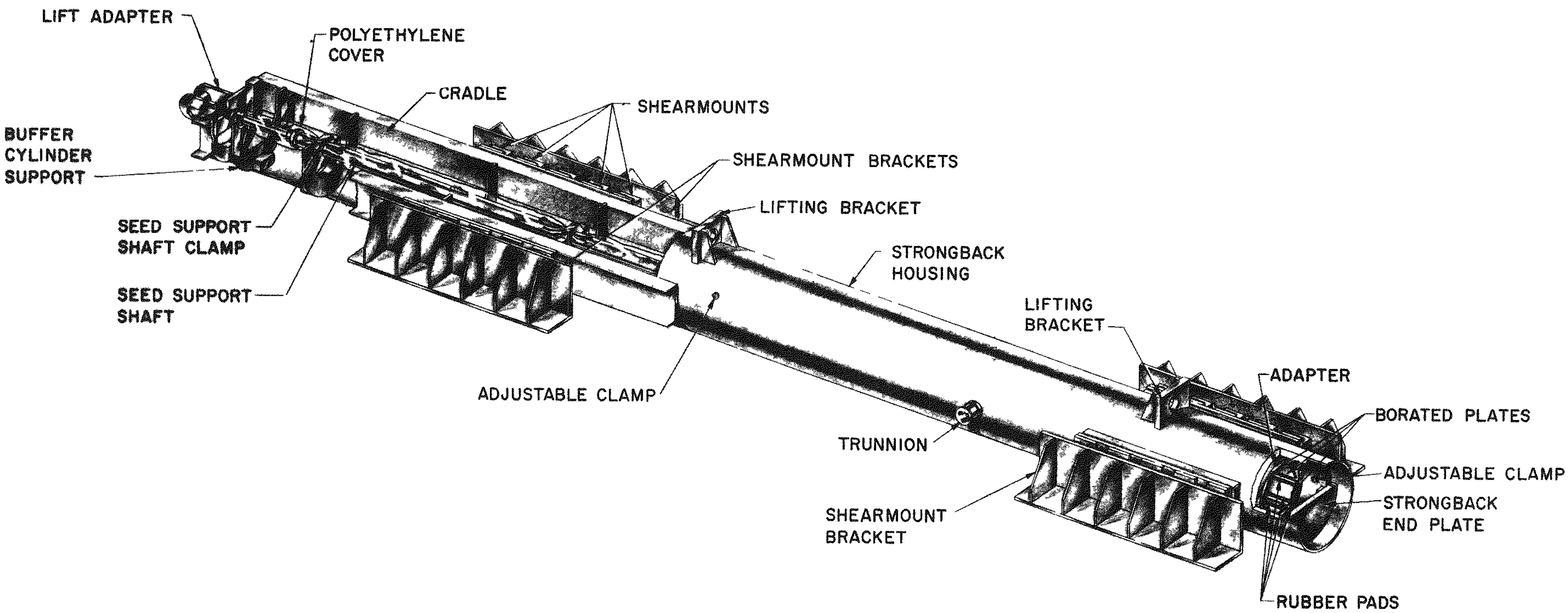


FIG. E-3 LWBR MOVABLE FUEL STRONGBACK ASS'Y

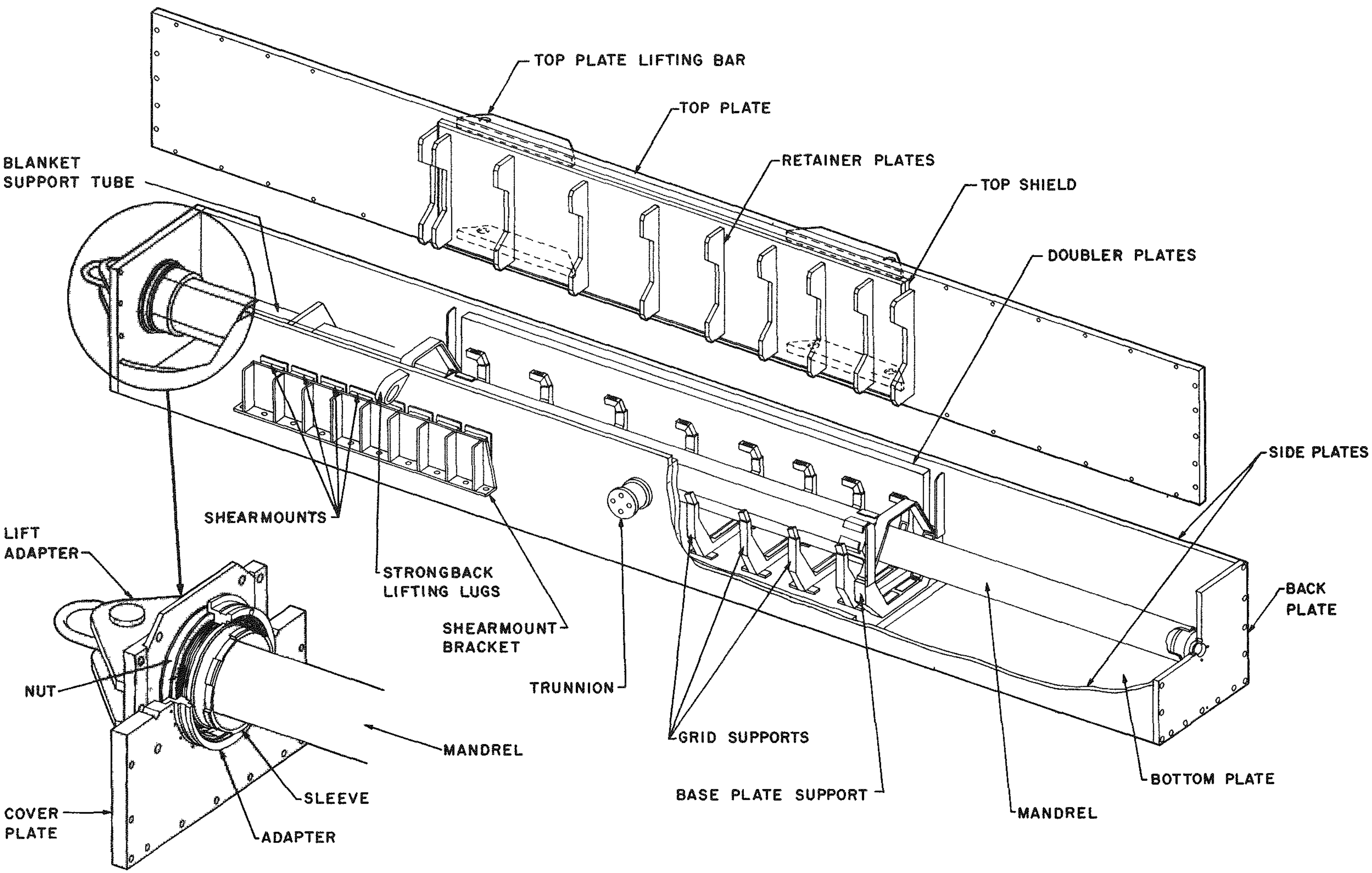


FIG. E-4 LWBR STATIONARY FUEL STRONGBACK ASS'Y

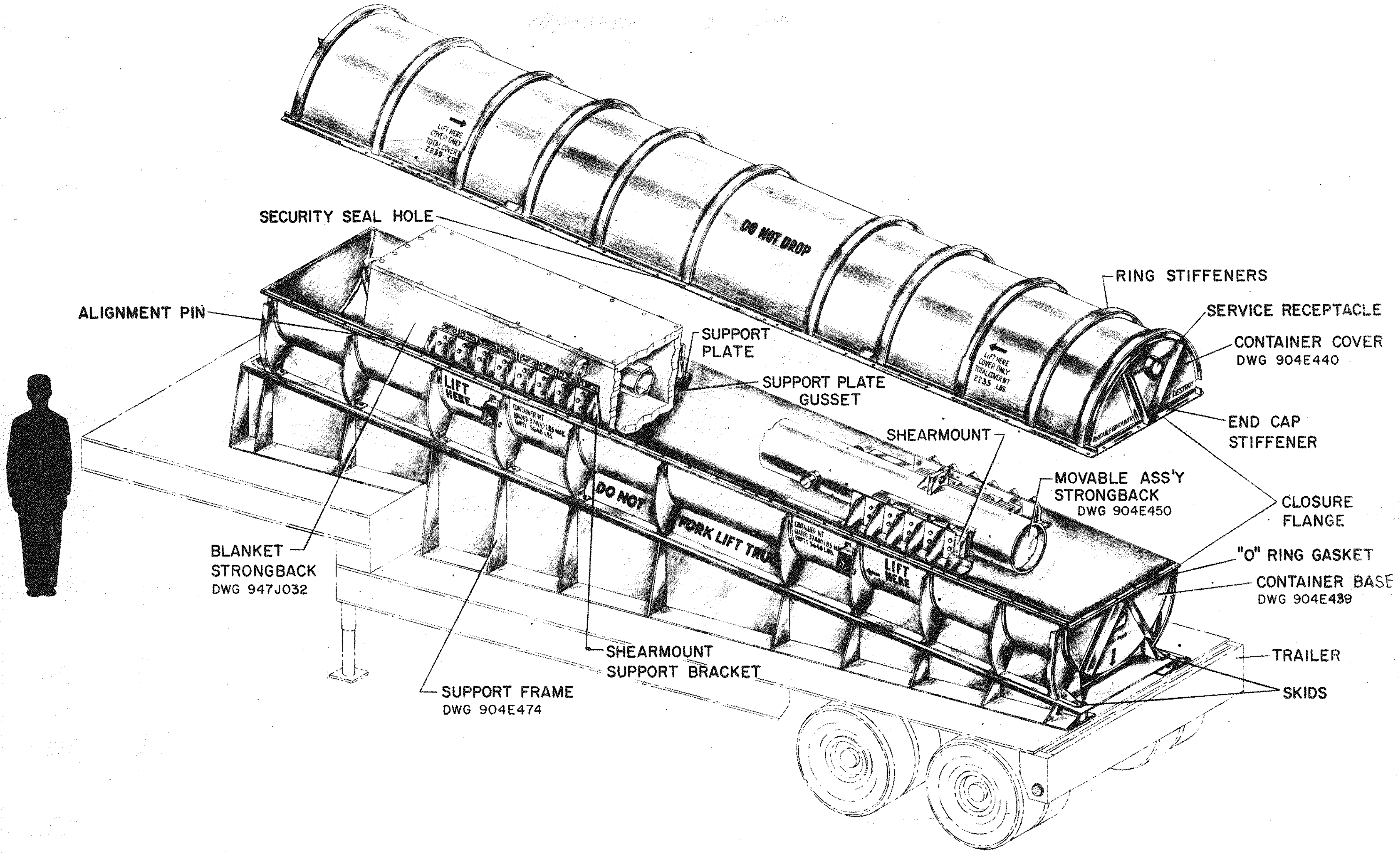
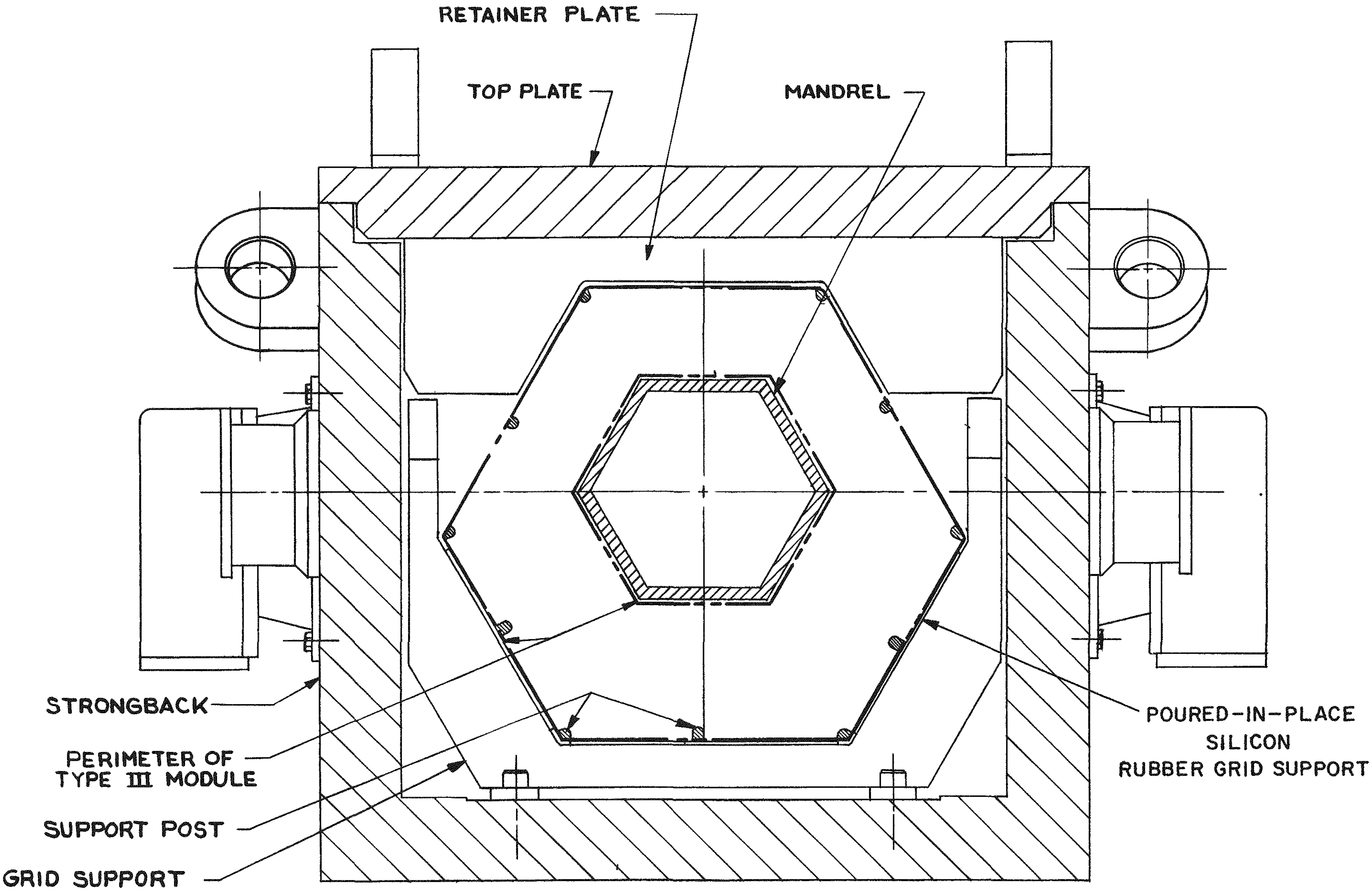


FIG. E-5 LWBR NEW FUEL SHIPPING CONTAINER



BLANKET GRID/STRONGBACK INTERFACE
FIG. E-6

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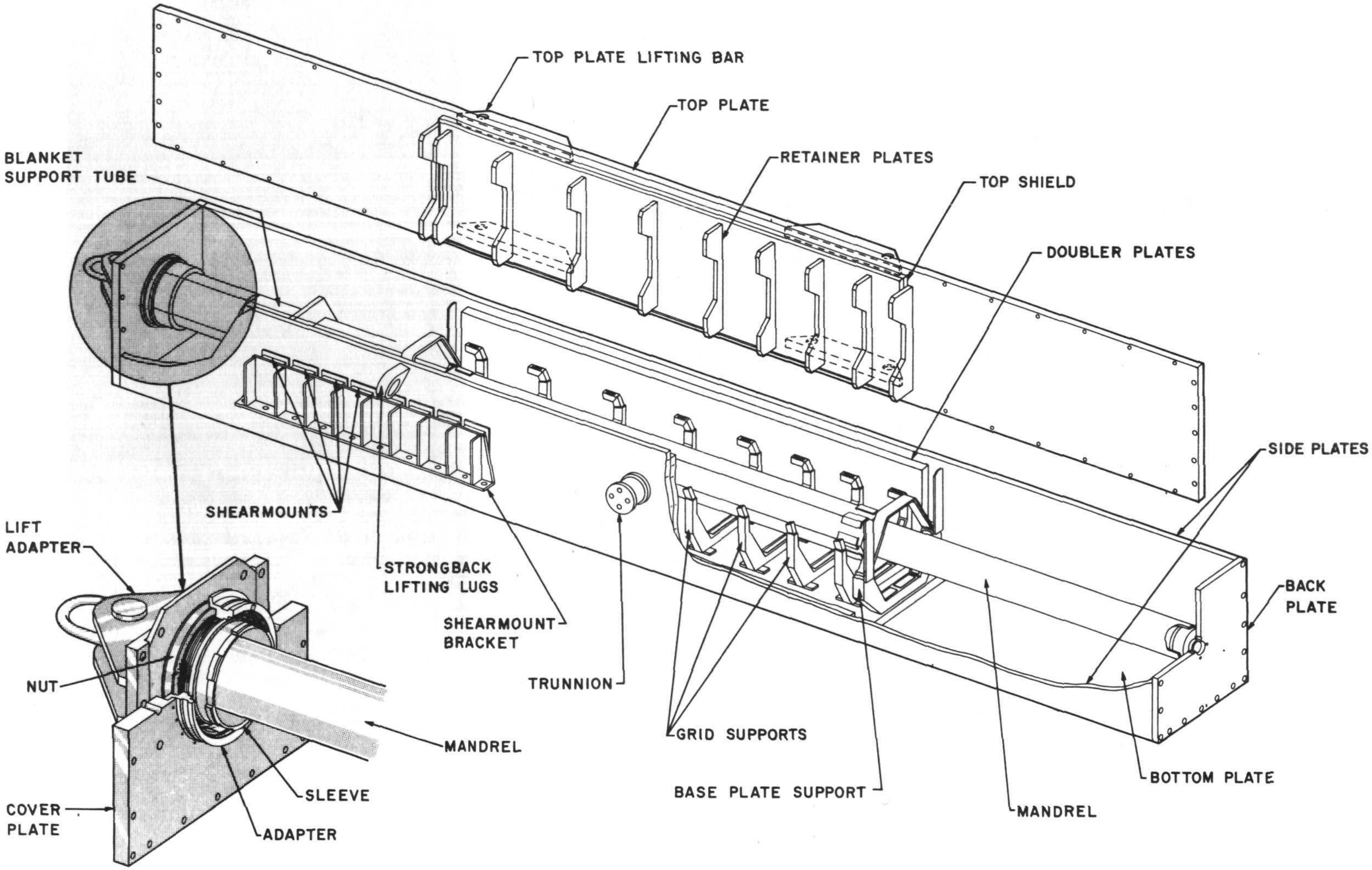


FIG. E-4 LWBR STATIONARY FUEL STRONGBACK ASS'Y

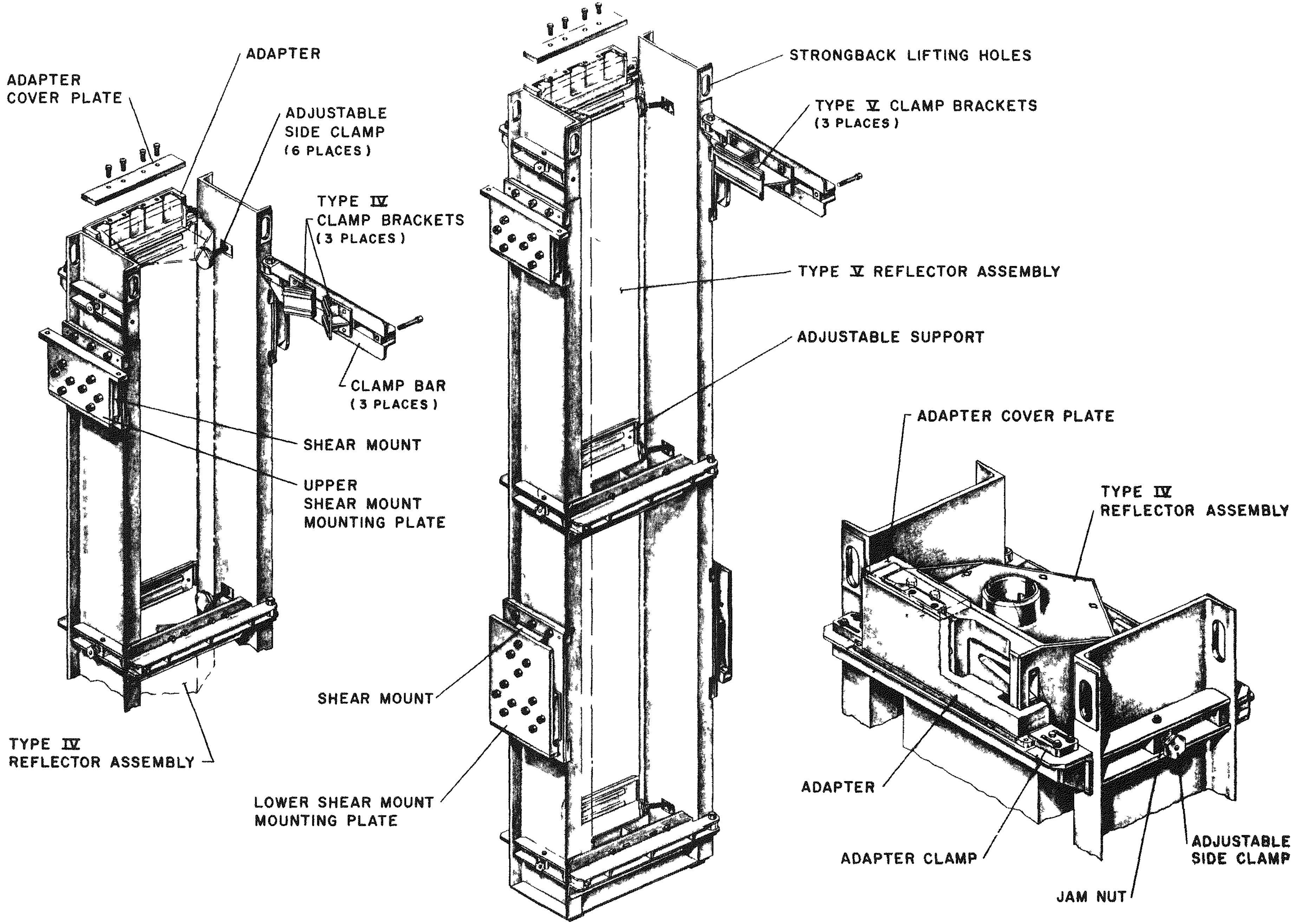


FIGURE E-8 LWBR REFLECTOR STRONGBACK ASS'Y major accident and to prevent an inadvertent criticality resulting from rearrangement of the blanket rods in the presence of a moderator such as water.

V. SHIPMENT OF THE REFLECTOR MODULES

The reflector modules were shipped in the vertical orientation, as shown on Figure E-2, because of the limited ability of the reflector modules to resist side loading (see lateral and longitudinal ADAL for the reflectors in Table I). The height of the resultant shipping assembly was about 15 ft., 3 in., causing some problems with overhead wires and structures during transport. To alert the crew during transport, the lead vehicle carried two 15 ft. 3-in. high poles to provide early notice of low obstacles. By raising the wires as required, and avoiding low underpasses, the shipments were made without difficulty.

VI. SUMMARY

The LWBR seed and blanket fuel modules and the reflector modules were shipped from Bettis to SAPS (a distance of about 55 miles) without damage. Air-suspension vehicles, shock absorbers, slow speeds, and careful selection of routes were all used to keep accelerations on all modules within acceptable limits.

APPENDIX F

INSTALLATION OF THE LWBR BLANKET AND REFLECTOR MODULES
USING DISPLACEMENT TRANSDUCERS AND MODULE GUIDE PLATES

I. INTRODUCTION

In determining the method for installation of the LWBR Blanket and Reflector Module, the following conditions were considered:

1. The cross sections of the types II and III blanket fuel assemblies were not symmetrical about the vertical axis, requiring off-center lifting equipment to enable installation of these fuel assemblies in a vertical position. The three type I blanket fuel assemblies, which were the prototype central power station fuel assemblies, were symmetrical about the vertical axis. The reflector module lift points were all located above the center of gravity. However, all blanket and reflector modules were leveled to preclude the possibility of intermodule contact.
2. The fuel rods and grids of the blanket fuel assemblies are exposed, similar to commercial nuclear fuel assemblies, rather than being protected by a smooth sided shell as was the case with previous Shippingport fuel assembly designs. However, the LWBR blanket fuel assemblies are not as susceptible to damage during installation as conventional commercial fuel assemblies because of two features of the design:
   a. Each blanket fuel assembly has full length guide posts at each corner.
   b. Each grid is inset in relation to the corner guide posts approximately 0.005 inch.
3. Low level radiation fields are produced by the unirradiated LWBR fuel assemblies, making it undesirable for technicians to manually guide the fuel assemblies during installation.
4. Clearances between LWBR fuel module assemblies are somewhat smaller than in previous Shippingport core designs; however, intermodule clearances are somewhat larger than those provided in commercial nuclear plants.

These conditions made it prudent to provide installation equipment which would minimize the risk of contact between posts of adjacent modules.

An engineering evaluation of the core intermodule clearances showed that, for the blanket fuel modules and the reflector modules to be installed in the core without having contact of the blanket guide posts with adjacent modules, each module must be held within 0.014 inch of its assigned space envelope and maintained within 0.0024 inch/ft of vertical during its insertion. These requirements were met by using the following equipment:

1. A handling tool capable of adjusting the verticality of the modules by employing a fine threaded three legged turnbuckle arrangement.
2. A leveling station capable of determining the verticality of a module suspended from the handling tool.
3. A positioning device capable of finely positioning the module laterally during insertion.
4. A module guide system capable of controlling the module position during its insertion.
5. A module positioning system capable of maximizing available envelopes, for module installation into the barrel, by tilting previously installed modules away from the location being fueled.

The purpose of this appendix is to describe the design and operation of the above equipment.

II. LEVELING STATION

A. Leveling Station Sensors

The leveling station utilized commercially available eddy current displacement transducers in its operation. The eddy current displacement measuring system consisted of nine transducer systems with oscillator demodulators and sensors having a signal conditioner electronic synchronization option, and three dual power supply digital voltmeter readouts, with associated cables.

In operation, the displacement sensor is a non-contacting measurement transducer using the eddy-current technique. As the target surface (must be metal, preferably steel or stainless steel) moves toward the sensor, more eddy currents are created and the losses in the bridge circuit within the sensor increases. Target surface movement creates impedance variations which are transmitted to the oscillator demodulator where the signal is demodulated and linearized. The electrical output from the oscillator demodulator is then transmitted through cables to the power supply digital voltmeter. The voltmeter provides a digital voltage readout which can be directly correlated to target surface displacement from the sensor in thousandths of an inch.

B. Leveling Station

The LWBR blanket and reflector leveling station design provided the necessary features for properly leveling the blankets and reflectors prior to their installation in the LWBR core. The overall view of the LWBR blanket and reflector fuel assembly leveling station is shown in Figure F-1. The station consists of a carbon steel frame weldment; top, middle, and bottom plate assemblies which are leveled and optically aligned with each other; and the eddy current transducers. The middle and bottom plate assemblies were employed during reflector leveling operations, while the top and bottom plate assemblies were used during blanket leveling.

The fuel assemblies were prevented from touching the plate assemblies during leveling, to prevent an impact from misaligning the transducers, by three specially designed bumpers anchored to the concrete wall behind the leveling stand. Additionally, three protective gate assemblies were installed in the vicinity of the three plates, to protect them during other refueling operations, where access to the leveling stand was not needed.

C. Alternate Leveling Methods Considered

As noted in the introduction, the LWBR blanket and reflector fuel assemblies were within 0.0024 inch per foot of vertical during installation into the reactor vessel to minimize the possibility of blanket guidepost contact during installation. To attain this degree of verticality required that the surfaces of the fuel portion of the blanket module be vertical within 0.034 inch over the length between the seal block and the stub tube (approximately 146.50 inches). Various methods of measuring the verticality of the blanket module had been considered. Spirit levels were considered initially (bull's-eye type, machinist level, etc.) but the major disadvantage of a spirit level is that it measures over such a short distance. Also, the design of the blanket fuel assembly is such that it does not provide a convenient surface onto which a spirit level may be attached. The fact that the unirradiated fuel assemblies produced low levels of radioactivity made the leveling more difficult since it was desirable that technicians not work close to the assemblies for extended periods of time; hence, direct reading of spirit levels posed a problem. Because of the inherent problems with using spirit levels in this application, Bettis considered remote forms of level measurement. Although many forms of remote level measurement were available from industry, almost all of the devices required attachment to the object being leveled. Once attached to the object, most devices required

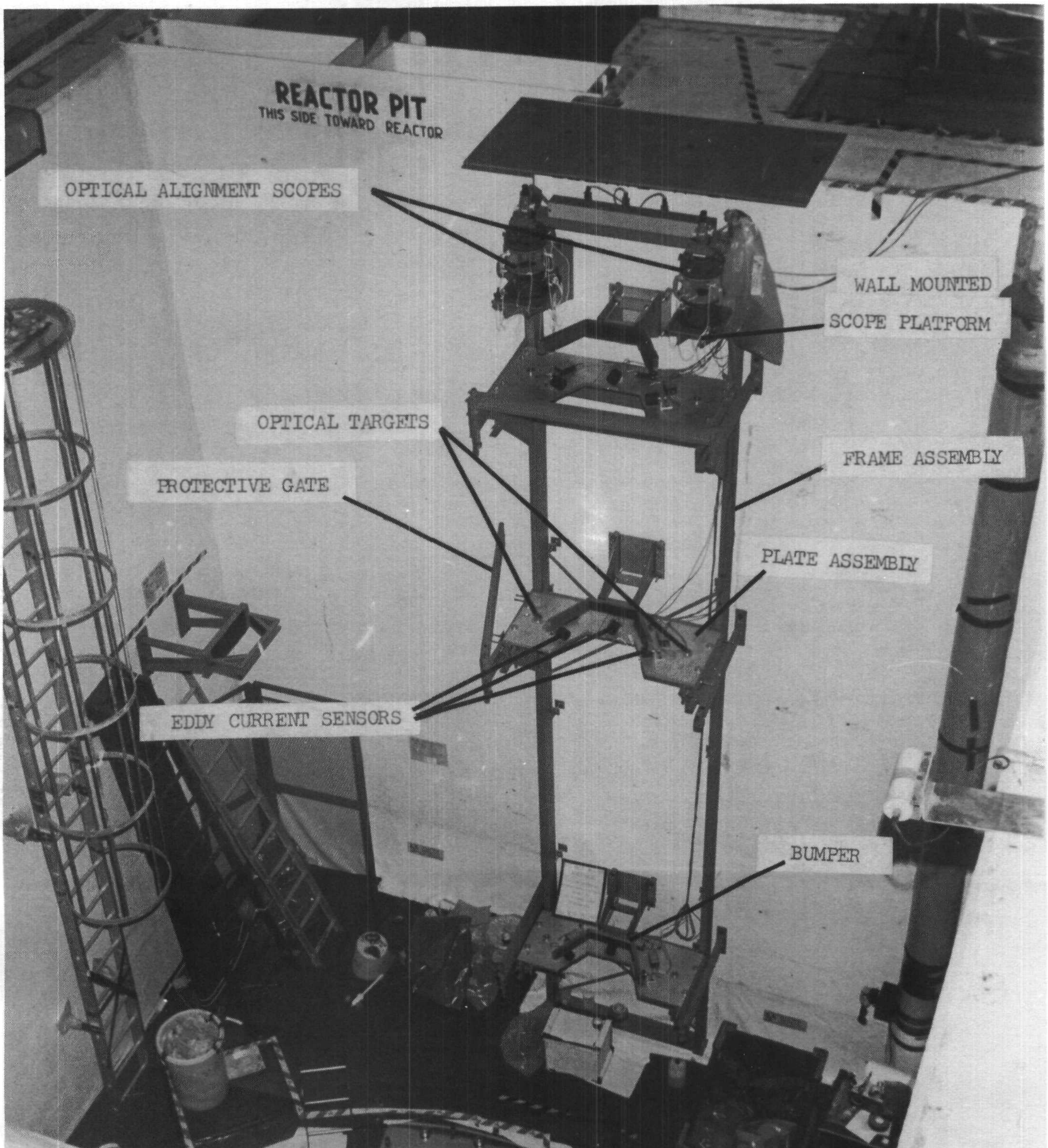


FIGURE F-1 - LEVELING STATION

some type of wire hookup. The remote level measuring devices were rejected because they were not compatible with previously designed fuel installation equipment.

D. Key Design Requirements

Design Requirements for the blanket fuel assembly leveling station were as follows:

1. The level measuring system had to be compatible with previously designed LWBR fuel installation equipment.
2. The method of leveling had to measure over a long distance, preferably over the length of the fuel portion of the blankets.
3. The preferred method of leveling was to be one which did not rely on devices attached to the module, thus eliminating hookup wires, sophisticated readout equipment, and operations involving removal of the device before the module was completely installed in the core barrel.
4. The method of leveling had to be such that radiation exposure to operating personnel was reduced to a minimum.
5. Simplicity of design and operations was considered to be extremely important.
6. The leveling system was to permit leveling of the fuel assemblies in the reactor pit as a final step prior to their installation into the reactor vessel.
7. The leveling station also had to be able to measure the verticality of the reflector assemblies.

E. Theory of Operation

The design of the LWBR blanket and reflector leveling station was based on the definition of slope of a line segment or flat surface. The slope of a line segment cannot be defined until a referenced datum is selected from which to measure. The average slope of the line segment over a specified distance may be measured by specifying three dimensions; namely, the distance between the two measuring points and the distance at each of the measuring points from the reference datum line to the line segment in question.

The blanket and reflector fuel assemblies were fabricated from components which share a common theoretical centerline. The LWBR blanket and reflector leveling stand was designed to: (1) serve as the selected reference datum, and (2) measure the slope of the theoretical blanket or reflector centerline via selected external surfaces of the blanket or reflector fuel assembly. As-built dimensions from the module centerline to the selected external surfaces of the module were factored into the design of the leveling operation. The external surfaces selected on the blanket assemblies were the pilot portion of the stub tube and the guide pad on the blanket module guide. These surfaces were chosen because they were (1) tightly dimensioned with respect to the theoretical blanket centerline, (2) fabricated from stainless steel, and (3) were far enough apart so that blanket verticality is measured over a large portion of the blanket length. The surfaces selected on the reflector assembly were the stub tube and the seal block and were chosen for the same reasons listed above.

The leveling stand served as the reference datum, which was a set of two intersecting and vertical-to-the-world imaginary planes. The design of the top, middle, and bottom plate assemblies was such that the position or location of the faces of the three eddy-current displacement transducers on the plate were referenced from the two optical target holes. Each plate was identical to the other plates. When the three plate assemblies were aligned optically, the faces of the eddy-current displacement transducers were all in one vertical plane and hence formed the necessary reference datum.

F. Equipment Design Description

The LWBR blanket and reflector leveling station consisted of one carbon steel frame weldment, three aluminum plate assemblies, and nine non-contacting eddy-current displacement transducers and associated hardware.

The leveling station frame was fabricated from stuctural steel channels and plate. The frame assembly consisted of two vertical legs, four horizontal spans, six plate supports, and stiffening gussets and diagonals. At the bottom of each of the two vertical legs of the frame, an integral jacking bolt and leveling pad was installed. These jacking bolts permitted the frame to be roughly leveled in the east-west direction at installation.

The frame was mounted against the south wall of the reactor pit on top of a 4-inch high curb and secured with commercial machine bolt anchors. The anchor system permitted leveling the frame in the north-south direction. At installation the frame was leveled so that a minimum amount of leveling adjustment to the plates would be required.

The frame assembly included six plate supports which provided the necessary support for the top, middle, and bottom plate assemblies. The plate supports provided the means to level, position (laterally and/or rotationally), and secure the leveling plate assemblies.

The three leveling plate assemblies were fabricated from cast aluminum tooling plate and provided the necessary surface on which to mount the eddy-current transducers. Each plate had two precisely located holes to serve as optical target holders. All important plate dimensions were referenced from these optical target holes. The three leveling plates were identical except for the method of leveling and securing them to the frame. The top plate was equipped with four jacking bolts, one in each corner, which were used to level the top plate assembly on the frame. Four cap screws secured the top plate to the frame once leveling was completed. The middle and bottom plates were leveled by adjusting four cap screws and ball caster assemblies as necessary. Once properly positioned the middle and bottom plates were secured to the frame using four cap screws, which passed through clearance holes in the plates and into hex nuts welded to the frame. The positioning adjustments on the middle and bottom plates provided for up to 1 inch of movement in any direction. The optical alignment scopes used in this alignment operation were mounted on reactor pit wall mounted platforms above the top plate (see Figures F-1 and F-2). The scopes remained mounted throughout the fuel installation operation and were used to periodically check and adjust plate alignment as necessary.

Three eddy-current sensors were mounted on each plate in a special bracket which permitted unilateral movement of the sensors only. The sensors were mounted on each plate so that their outer face was flush with a precisely located surface on the front edge of the plate, which was closely toleranced with respect to the optical target holder holes in the plate. With the eddy-current sensors mounted on the plates and the plates optically aligned, the leveling station was ready for use.

G. General Operation of Leveling Station

1. Blanket Leveling

The procedure for leveling each blanket fuel assembly began at the new fuel storage facility when the stationary fuel handling tool was attached to the blanket fuel assembly. The three turnbuckle assemblies on the lifting tool were adjusted to predetermined lengths which theoretically positioned the lift point directly over the center of gravity of the blanket module. The blanket module was then lifted out of the new fuel storage facility and into its specific type module guide. The blanket module was then transferred to the leveling stand and positioned within the leveling stand using the positioning equipment and read-outs from the eddy-current transducers on the stand. When positioned within the leveling stand, the readouts from the two sets of transducers (top and bottom

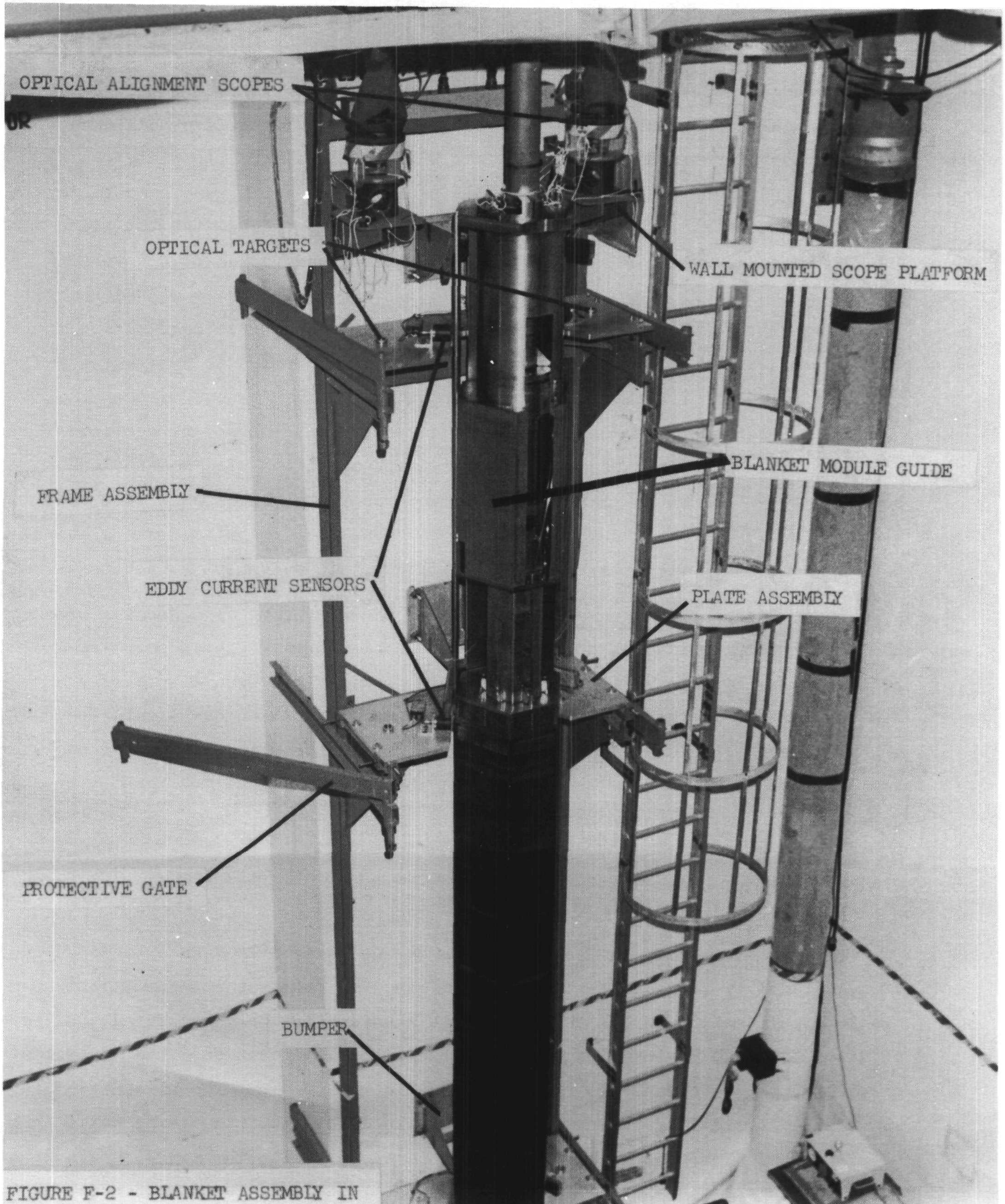


FIGURE F-2 - BLANKET ASSEMBLY IN LEVELING STATION plates) were used to determine the slope of two sides of the blanket module. If the slope of either side was not within 0.0024 inch per foot, turnbuckle adjustments on the handling tool were made.

After the necessary turnbuckle adjustments and readjustments were performed to obtain the desired degree of blanket verticality, the blanket module was transferred to the reactor vessel for installation.

2. Reflector Leveling

The procedure for leveling reflector fuel assemblies began at the reflector assembly storage location. The same lifting tool used for blanket module handling was used with the reflector installation tool to handle the reflector during installation. The three turnbuckle assemblies on the lifting tool were adjusted to predetermined lengths which theoretically positioned the lift point directly over the center of gravity of the reflector module. The reflector was then raised out of its storage location and transferred to the leveling station in the reactor pit. When positioned within the leveling stand, the readouts from two sets of transducers (middle and bottom plates) were used to determine the slope of two sides of the reflector module. If the slope of one or two sides was not within 0.0024 inch per foot, adjustment to the turnbuckles on the lifting tool was made. After the necessary turnbuckle adjustments and readjustments were performed to obtain the desired degree of reflector verticality, the reflector module was transferred to the reactor vessel for installation.

3. Functional Check

Each eddy-current sensor was functionally checked, and the vertical alignment was verified within 72 hours of the beginning of the installation procedure for each blanket and reflector assembly.

III. MODULE GUIDE SYSTEM

A. Need for Module Guide System

When the blanket modules were installed into the reactor vessel barrel, a minimum clearance of 0.014 inch existed at interfaces between the 12 LWBR blanket modules. This close clearance made it prudent to install blanket modules without having contact between posts in modules. Also, low level radiation fields were produced by unirradiated LWBR fuel modules, restricting manual guidance during installation. Therefore, the desirability of accurate and continuous remote guidance and alignment of each blanket module during insertion was identified. The blanket module guide system was evolved to prevent contact between adjacent blanket module posts during insertion. The fuel portion of the 12 LWBR seed modules and 15 reflector modules are smooth-sided shell assemblies and were not considered to present unique insertion problems. However, since the reflector modules interface with blanket modules in the reactor vessel core barrel, verification of adequate reflector insertion envelope was deemed desirable. The following paragraphs describe the module guide system developed and used for LWBR fuel module installation.

B. Description of Module Guide System Equipment

The LWBR fuel modules were successfully maintained within the desired insertion envelope through the use of a module guide system and by sequencing the modules to maximize intermodule clearances. The module guide system consisted of the following components:

1. Module Guide Plates

A base plate and inner guide plate shown on Figure F-4 were designed and fabricated. The 125-inch diameter base plate seats on the reactor vessel barrel flange and is accurately aligned by a dowel pin on each barrel axis. The base plate center penetration shown on Figure F-5 outlines an envelope approximately 1 inch larger than the external periphery of the nine outer blanket modules shown on the core pattern (Figure F-6). The 104-inch diameter inner guide plate bolts to the center of the base plate after doweling. The inner guide center penetration shown on Figure F-3 outlines an envelope approximately 1 inch larger than the external periphery of the three center blanket modules.

2. Module Guide Brackets

The module guide brackets dowel and bolt to the top surface of the base plate or inner guide plate and serve as alignment surfaces for insertion of blanket modules as shown on Figures F-3 and F-4. Either two or three guide brackets are used depending on blanket module type. The guide brackets have a raised rail along each edge on which the smooth corner posts located at each corner of the blanket module hex cross-section pilot during insertion as shown on Figures F-3 and F-5. The doweling and tolerances between the barrel flange, base plate, guide plate, and module guide brackets accurately locate the blanket module with respect to its installed envelope when the blanket corner posts are in light contact with the module guide brackets.

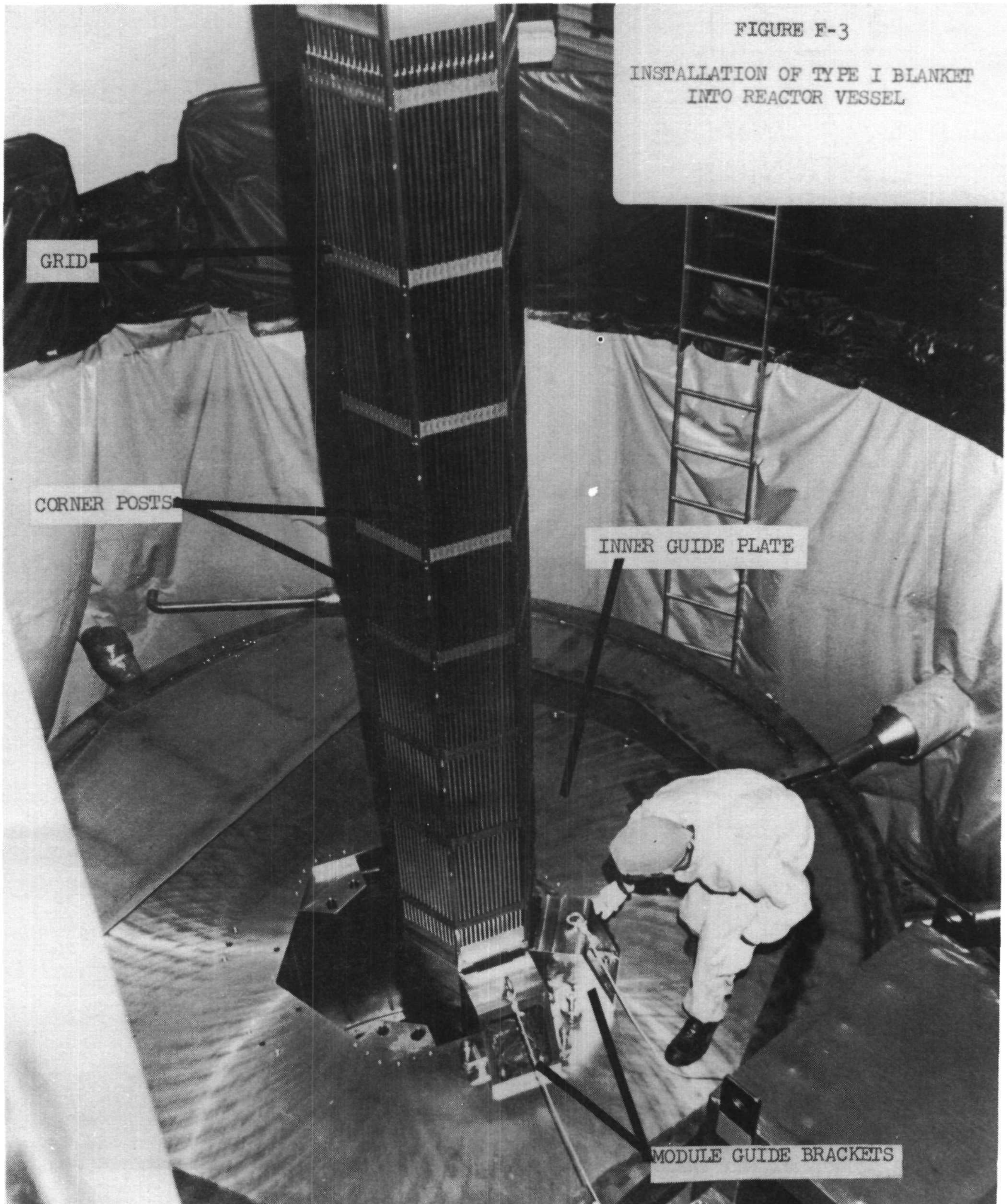
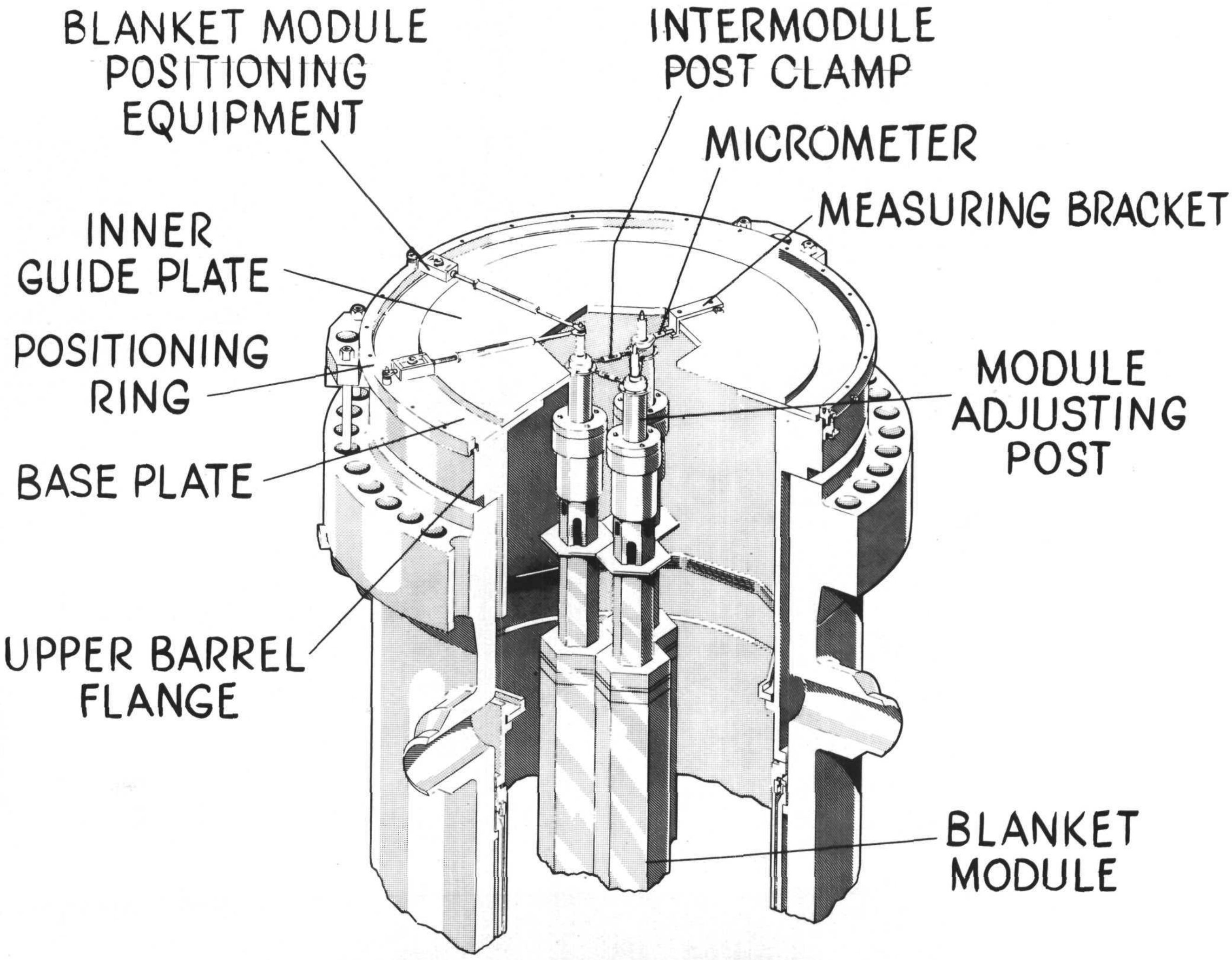


FIGURE F-3

INSTALLATION OF TYPE I BLANKET INTO REACTOR VESSEL



BLANKET MODULE
INSTALLATION

FIGURE F-4

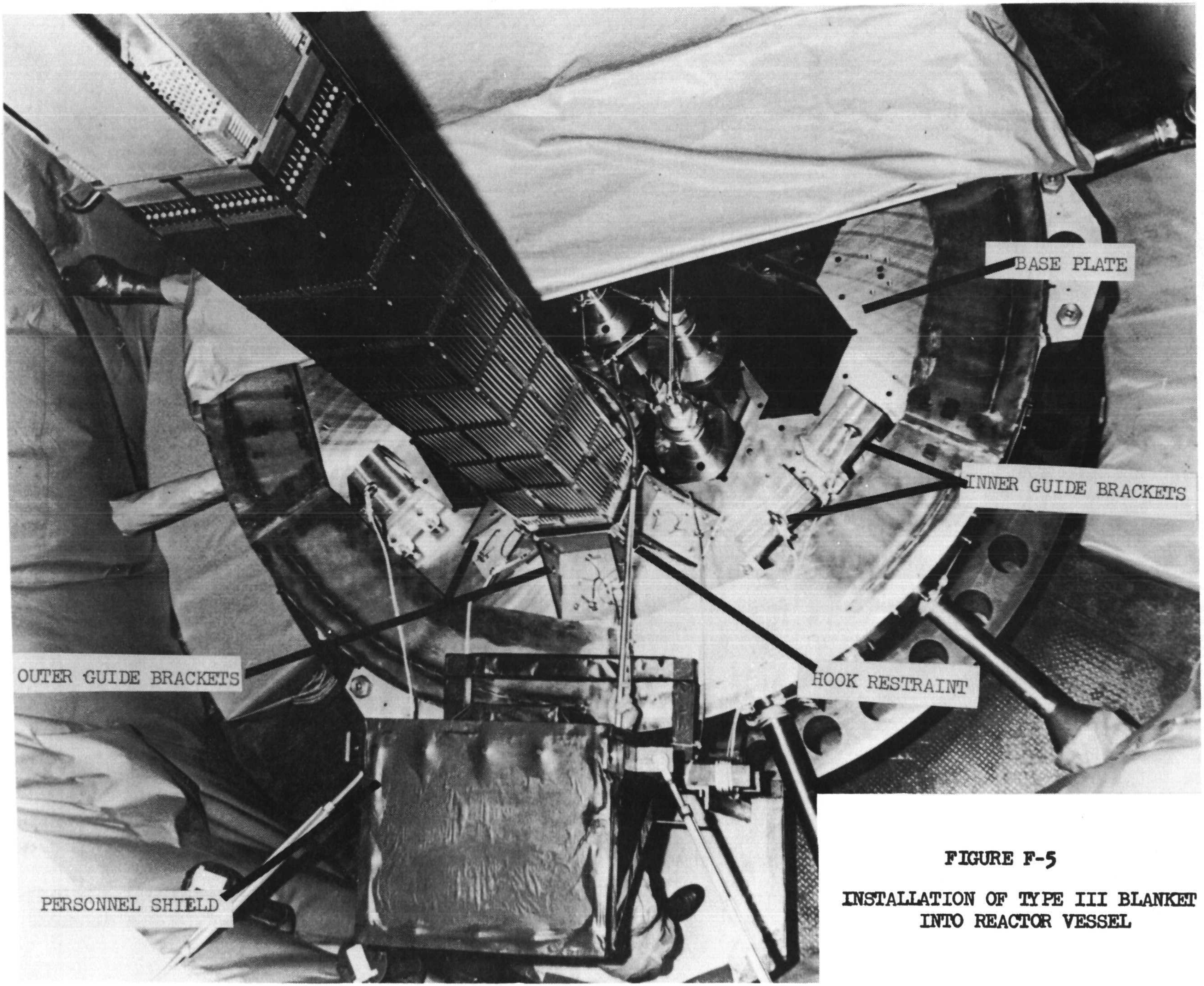


FIGURE F-5

INSTALLATION OF TYPE III BLANKET INTO REACTOR VESSEL

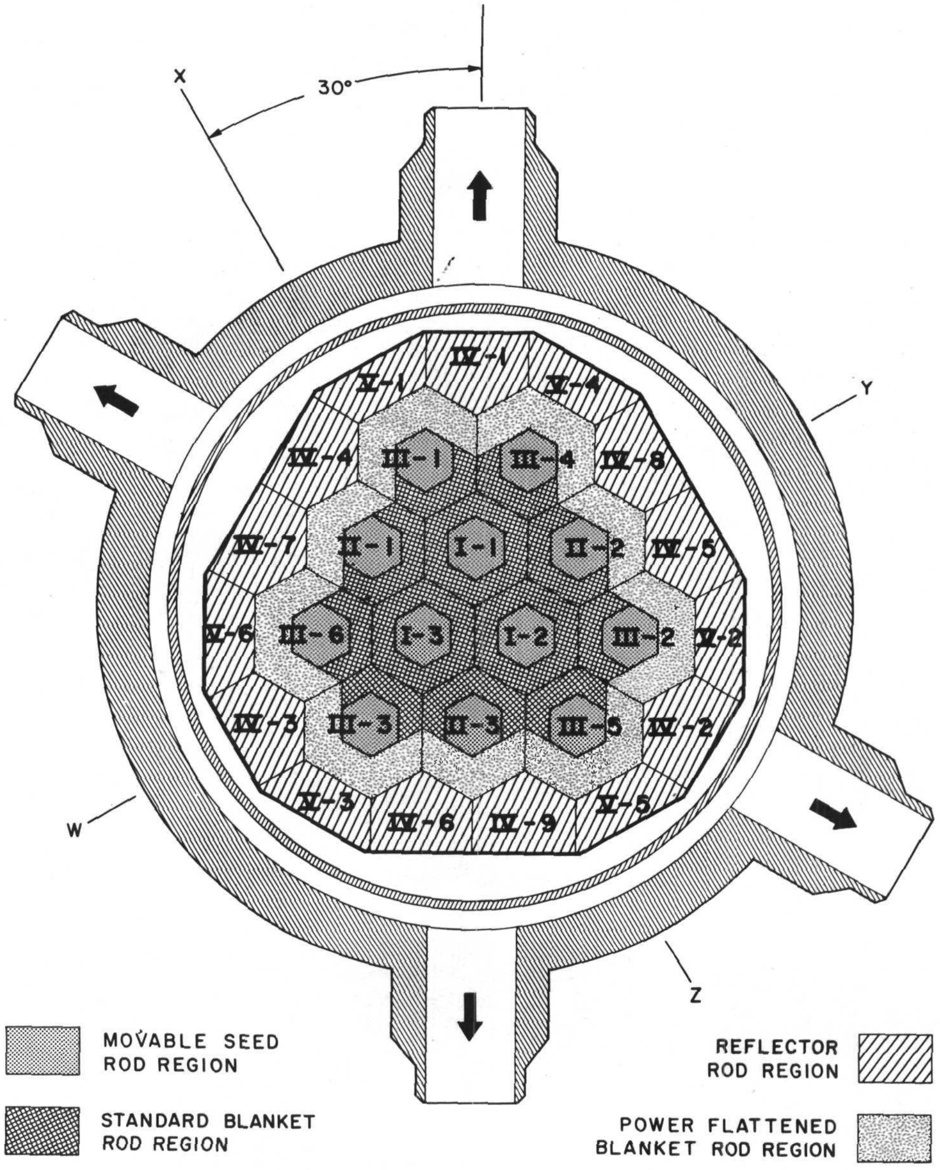


FIGURE F-6

**LWBR
CROSS SECTION
MODULE IDENTIFICATION**

3. Module Guides

The blanket module corner posts do not extend over an adequate length of the blanket to provide guidance of a blanket module for its full insertion distance into the reactor vessel barrel. Therefore, a temporary module guide was provided and installed over the upper end of each blanket module. The module guide provided a surface for the module guide brackets to pilot against. A module guide is shown installed over the upper end of a blanket module support tube on Figure F-2.

4. Blanket Module Positioning Equipment

An adequate space envelope was ensured within the barrel for the insertion of each blanket and reflector module by use of the blanket module positioning equipment shown on Figure F-4. A module adjusting post locks into the top of each blanket support tube. Intermodule post clamps (small turnbuckles), installed between adjacent module adjusting posts, and larger module positioning turnbuckles installed between the posts and a positioning ring installed on the barrel flange, serve to compact, expand, and reposition the installed blanket modules as necessary to maximize the envelope for installation of adjacent modules. Measuring brackets were provided which allowed the true position of each module to be determined, via micrometer measurements between the base plate/guide plate mounted measuring brackets and the module adjusting posts, to verify the existence of adequate clearance for installation of the next module.

C. Sequencing and Operation of Module Guide System

LWBR modules were installed starting at the center of the reactor vessel core barrel and working outwards. Blanket modules were installed in order by type followed by reflector modules. Seed modules were installed in blankets any time after installation of the blanket modules. The sequence of blanket module installation was of prime importance to module guide system operation. By inserting modules in the sequence, Type I first, Type II second, Type III third, and reflectors last (refer to Figure F-6), the blanket being inserted is free of close clearances in the radially outboard direction and never interfaces on more than three of six sides with previously installed blanket modules. The module guide system utilizes the radially outboard clearance area which will be occupied by reflector modules after blanket installation to maximize blanket clearances during insertion. Installation of a typical blanket proceeded as follows:

1. The blanket module positioning equipment was used to adjust the position of the top end of all installed blanket modules away from the desired envelope of the blanket to be inserted. Adjacent blankets were thereby positioned such that they did not encroach on the required insertion envelope. Existence of the required insertion envelope was verifed by measurement.
2. The module guide was installed on the blanket module and the blanket was then vertically aligned as previously discussed in the leveling station portion of this appendix.
3. Outer module guide brackets were then installed on the base plate or inner guide plate radially outboard of the insertion envelope of the blanket module to be installed. Two guide brackets were used for Type I and Type II blanket modules and three guide brackets for Type III blanket modules. The outer guide brackets positioned the blanket module 0.50 inch radially outboard of its nominal barrel position providing significant clearance with adjacent blankets. The blanket was piloted on the outer guide brackets as shown on Figure F-5. The blanket module corner posts were maintained in contact with the outer module guide bracket by a hook restraint. The hook restraint was manually operated from behind a personnel shield as shown on Figure F-5.
4. When the lower end of the blanket module approached the barrel bottom plate, module insertion was halted. The blanket module was then positioned radially inward using a precision module positioning device until it was within 0.18 inch of its nominal installed position and an approximate 0.20-inch clearance existed between it and an adjacent blanket. The outer module guide brackets were then replaced with a set of inner module guide brackets which positioned the blanket module 0.18 inch radially outboard of its nominal installed position.
5. Blanket module insertion was then continued. Although the blanket module was located 0.18 inch radially outboard of its nominal barrel position, the chamfers on the lower end of the blanket module guide tube and lead-ins on the barrel bottom plate penetrations were adequate to guide and pilot the blanket module guide tube extension into the bottom plate. When the pilot surfaces on the blanket module guide tube extension, the blanket stub tube, and the core barrel bottom plate

engaged, the minimum possible clearance with adjacent blanket modules was reduced to 0.014 inch; however, the blanket was held in its nominal position within 0.08 inch by the pilot surfaces, and the blanket rigging minimized the possibility of guide post contact.

6. After completion of the installation of about one-half of the blanket modules, the module positioning equipment was used to adjust the position of the installed blanket modules to ensure an adequate insertion envelope for the adjacent reflector modules. Each reflector envelope was then verified with a reflector cross-section gage, and about one-half of the reflector modules were then installed.
7. After the remaining blanket modules were installed, Step 6 was repeated to install the remaining reflector modules.

D. Alternate Methods of Module Installation Considered

Several possible alternative methods of guiding and aligning the LWBR fuel modules during insertion into the reactor vessel were developed and evaluated prior to selection of the method described in the preceding paragraphs. The alternative methods considered were as follows:

1. Original Concept

This concept consisted of a module guidance and alignment system utilizing a laser beam to position guides mounted above a cover plate supported on the barrel flange. The guide structure permitted accurately positioning the leveled blanket fuel module directly over its space envelope in the core. The positioning of the fuel module in the guides was accomplished by moving the crane in small increments until remote reading eddy-current displacement transducers indicated and confirmed that the blanket was centered in the guides. In addition to the guides above the cover plate, the upper ends (above the splash plates) of adjacent previously installed modules were protected by stationary module guides which prevented the module being installed from swinging out of its assigned envelope into an installed module. This concept was based on installation of reflector modules prior to blanket modules. The sequence for installation of blanket modules was not specified.

This concept was rejected because of the difficulty of performance and the relatively high risk of damage to fuel modules caused by installing them within their in-core clearance envelopes (as small as 0.014 inch clearance between modules).

2. First Guide Plate Concept

The second major guidance and alignment system developed was based on the use of precisely located guide plates which extended downward from a cover plate supported on the barrel flange. The guide structure was to be optically aligned by using the existing alignment plate used for core barrel assembly. The positioning of the module in the guides was accomplished by moving the crane in small increments by manual drive until remote reading eddy-current displacement transducers indicated and confirmed that the module was centered in its guides.

This concept sequenced blanket installation prior to reflector module installation and allowed usage of the unoccupied reflector envelopes for additional clearance while lowering a module adjacent to installed modules. This clearance was obtained by moving the installation space enveloped 0.125 inch radially outward from the installed envelope. The sequence was from the center module outward with reflectors installed last.

The guide plate concept was rejected because of the complexity of the guide components, the long manufacturing period required, and the resulting high cost.

3. Miscellaneous Guidance Systems

Additional combinations of the concepts presented and additional less promising concepts were considered and rejected. These included the use of thin sheets of stainless steel as shims or shields between adjacent modules during installation. This concept, though relatively inexpensive, was rejected because of the concern that the thin material could wedge and then tear or scuff, leaving remnants in the assembled core. It would also be difficult to keep the thin material flat during handling and use.

The use of guide rods attached to and extending upward from the installed fuel assemblies to act as guidance devices for modules being inserted was also considered. This concept was rejected since the guide rods would need to be extremely long unsupported posts to accommodate the length of travel of the blanket guide as it is being lowered from the point where it could contact an adjacent module until it is engaged in the penetration in the bottom plate. The long length would make it difficult to establish accurate alignment with respect to the vertical centerline of the blanket.

IV. SUMMARY

The close clearances between the installed LWBR blanket fuel assemblies, the reflectors, and the exposed structural grids of the blankets made it desirable that these assemblies be leveled prior to actual insertion and that the maximum space envelope for each individual module be made available prior to its insertion in the core. The installation equipment, consisting of the leveling stand, in-core module positioning equipment, and the blanket module guide system, performed successfully during installation of the LWBR fuel. The LWBR fuel and reflector assemblies were installed without hangups between adjacent modules or damage to any assembly. Some electrical malfunctions of the leveling stand sensors and readouts did occur during use, but these problems did not detract from the successful application of the leveling principle, or significantly delay the installation of the fuel and reflector modules.

Most of the problems with the leveling stand sensors were caused by either loose connections or frayed cables, which were readily corrected by adjustment or replacement of the cables. Late in the module installation program an interaction developed between the oscillator-demodulators, which was solved by electrically isolating these items from the leveling stand frame. Random failures of two units occurred. One readout unit overheated because of excessive captivation, consisting of a closely fitting nylon reinforced PVC covering. Existing spares, initially stocked to about 25 percent of operating components, proved adequate to support the leveling of the LWBR modules.

APPENDIX G

DEVELOPMENT OF THE LWBR PRESSURE BOUNDARY WELDING

APPENDIX G

DEVELOPMENT OF THE LWBR PRESSURE BOUNDARY WELDING

I. INTRODUCTION

The development of the LWBR closure head area pressure boundary welding consisted of qualifying weld procedures and welders for four different types of component welds. As shown in Figure G-1, the production welding consisted of the following:

1. Twelve control drive mechanism (CDM) vent valve plug welds and 47 instrumentation welds. (Since the base materials and weld filler metal material types were the same and the weld profile and essential welding variables were equivalent for both of these welds, the procedure and welder qualifications for the insrumentation welding also were considered qualified for welding the LWBR CDM vent valve plugs to the CDM motor tube extensions and are classified as one type of weld.)
2. Six bypass inlet flow (BIF) seal welds.
3. Two main closure seal welds.
4. Twelve control drive mechanism to mechanism port seal welds.

The first three weld types were manual welds, while the CDM seal welding was performed using an automatic welding machine.

All of the LWBR closure head area welding utilized the gas tungsten-arc welding (GTAW)-ASME Boiler Pressure and Vessel Code (BPVC) designation or, as it is sometimes called, the tungsten inert gas (TIG) welding process. Both TIG and GTAW are equivalent designations for the same welding process. Except for the 348 CRES main closure seals which were welded to 304L and 308/308L CRES clad material, the remaining closure head area boundary welds involved Ni-Cr-Fe (Inconel) Alloy 600 components welded to Ni-Cr-Fe (Inconel) Alloy 600 components.

II. MANUAL WELDING

A. Main Closure Seal Welds (see Figure G-2)

1. Functional Requirements

The upper main closure seal was welded to form a seal between the upper barrel support flange and the reactor vessel. Using a liquid penetrant inspection technique for the root pass and each weld layer, the criteria for both

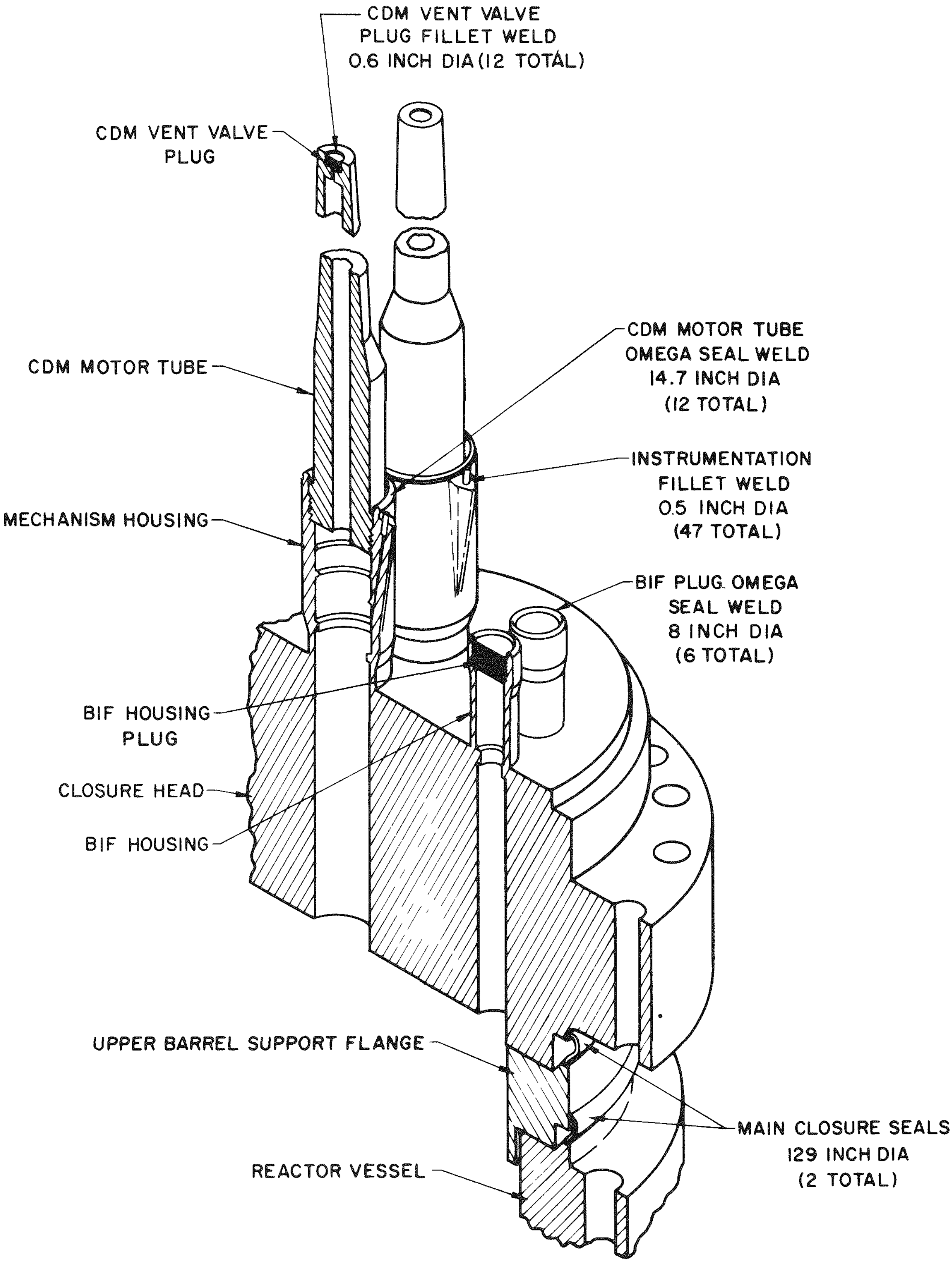


FIGURE G-1

LOCATION OF THE PRESSURE BOUNDARY WELDS
ON THE LWBR REACTOR

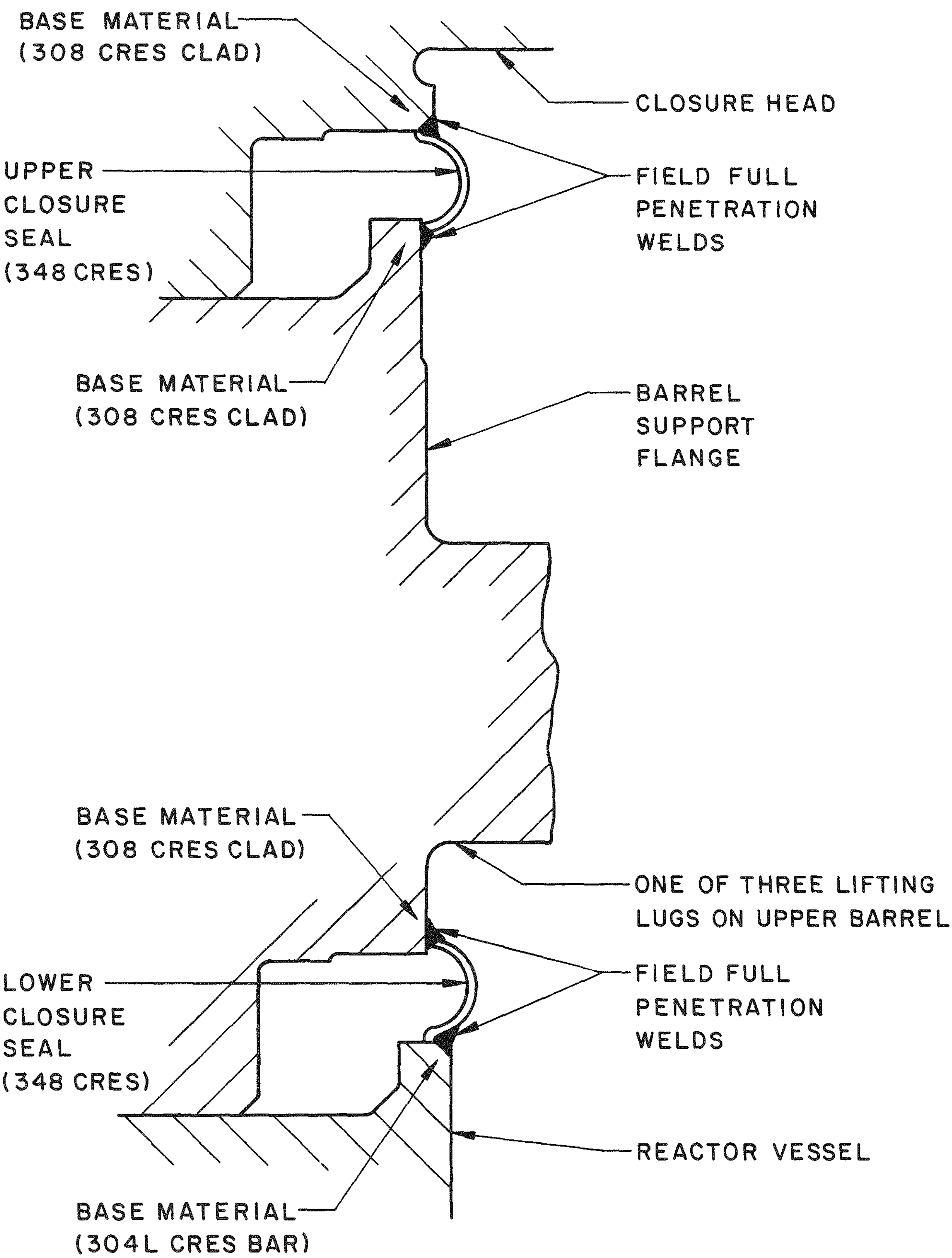


FIGURE G-2
DETAIL VIEW OF LWBR MAIN
CLOSURE SEAL AREAS

production and mockup weld acceptance were (1) no cracks or linear indications permitted, (2) no rounded indications with a maximum dimension larger than 1/16 inch permitted, (3) no more than three rounded indications in a line separated by 1/16 inch or less edge to edge permitted, and (4) no more than nine rounded indications in any 6 square inches of surface permitted with the major dimension of this area not to exceed 6 inches with the area taken in the most unfavorable location relative to the indications being evaluated. Upon completion of welding, the mockup test assemblies were examined for weld contour and liquid penetrant inspected prior to sectioning. The test assemblies were then cut to obtain access for weld underbead examination.

2. Design Parameters

The nominal seal thickness was 0.193 inch and the nominal outside diameter was 2.75 inches. The upper main closure production seal had a 129.743 inch average diameter and the lower main closure production seal had a 128.747 inch average diameter. The qualification mockups measured 12 inches in length. Both the production and mockup seals were made from 348 CRES tubing.

There were two dimensional design changes to the LWBR main closure seal design as a result of experience gained during welding of main closure seal mockups at Bettis. During preliminary welding qualification work, there consistently occurred an unacceptable lack of full penetration on the seal weld prep with a 0.045-0.055 inch land and 45 degree weld prep angle. Better access and full penetration was obtained by using a weld prep with a 0.027 ± 0.005 inch land and a 60 degree weld prep angle (see Figure G-3). No problems were encountered in obtaining full penetration welds on the other 0.062 inch weld prep side of the closure seal.

3. Equipment Description

Commercial welding machines of 300 amp capacity were used during procedure and welder qualifications. All welding machines were equipped with high frequency arc start and a foot pedal operated slope control. D-C straight polarity current was used for all welding. Flow meters were employed to meter the helium and argon gases used for torch shielding gas and also to meter the argon gas for purging the back side of the seal. A portable oxygen analyzer was used to measure the oxygen content of the exit purge gas.

The electrodes were 3/32 inch diameter, 2-percent thoriated tungsten ground to requirements. The ER308 type filler metal met the requirements of MIL-E-19933 and Section II, Part C, SFA 509 (ER308) and Section III, Subsection NB,

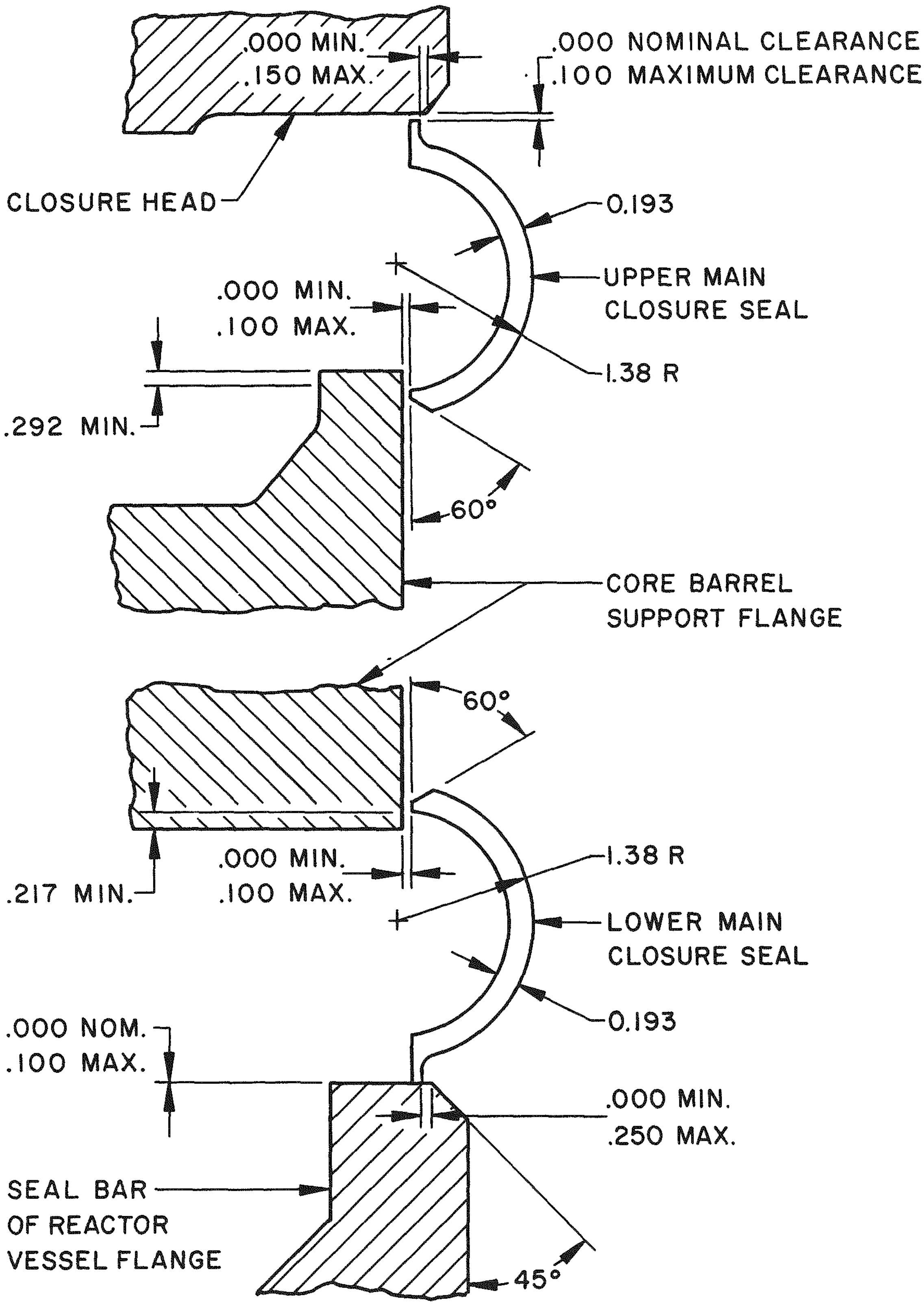


FIGURE G-3
MAIN CLOSURE SEAL DESIGN AND FITUP

subparagraphs 2432.2 (Chemical Analysis) and 2433 (Delta Ferrite) of the 1974 ASME BPVC. The maximum interpass temperature permitted was 200 F, and no welding was permitted on material at a temperature less than 60 F.

4. Testing, Qualification, and Field Welding

Immediately prior to welding, the weld joint area was cleaned using a clean, lint-free cloth saturated with acetone. The weld joint area was sealed with 2-inch wide high temperature glass cloth tape. Glass cloth tape was also applied to the base metal of the seal outside the heat affected zone to reduce weld spatter and arcing damage during welding. The weld joint area was then purged with argon gas at a flow of 20 to 30 CFH. When the oxygen content of the purge gas registered less than 1 percent, the argon purge was adjusted to 5 CFH and the test assembly was ready for tacking and welding.

The lower main closure seal assembly was first tack welded. The first three layers of weld metal were then deposited. Upon completion of the first three layers, the purge hole was closed, and then the remaining layers were welded. Weld starts and stops were ground, as necessary. Each weld pass was wire brushed, and each layer was liquid penetrant inspected prior to depositing subsequent layers.

Helium shielding gas was used in the welding torch only on the root pass for both the upper and lower weld. It was found that the deeper penetrating characteristics of the helium arc enabled the welder to more easily achieve 100 percent penetration of the weld joint, particularly when there was a zero root gap. In the most restricted access, under the upper core barrel alignment lugs, the filler metal was preplaced in the weld joint for the root pass. This greatly enhanced the welder's ability to observe the weld puddle during the root pass welding operation.

Two consecutive mockups had to be welded successfully by each of the seven Bettis welders to qualify to the 1974 ASME Boiler and Pressure Vessel Code Section III, Subsection Paragraphs NB-4360 (Manual Welding) and NB-5370 and Section IX including the latest addenda criteria. The manner in which each welder qualified also qualified the procedure. No problems were encountered in qualifying the welders or during field welding of the main closure seals.

5. Recommendations

Based on successful implementation during main closure seal mockup welding qualification efforts at Bettis, the following recommendations are made for future similar welding applications.

a. Test and Qualification weld liquid penetrant (LP) inspection should be conducted in the same vertical positions as during production weld LP inspection to give each QC inspector familiarity with using the LP materials under actual access and joint geometry conditions.

b. It was found that providing a borescope access path on the test and qualification mockup base would facilitate weld underbead inspection especially after the important root pass. If full penetration was not achieved after root pass welding, a new qualification mockup would be started immediately thereby saving four days welding on an unacceptable mockup.

c. Aluminum weld mockup backing plates must be added to simulate the cooling rate during testing and qualification to that which would occur during field welding.

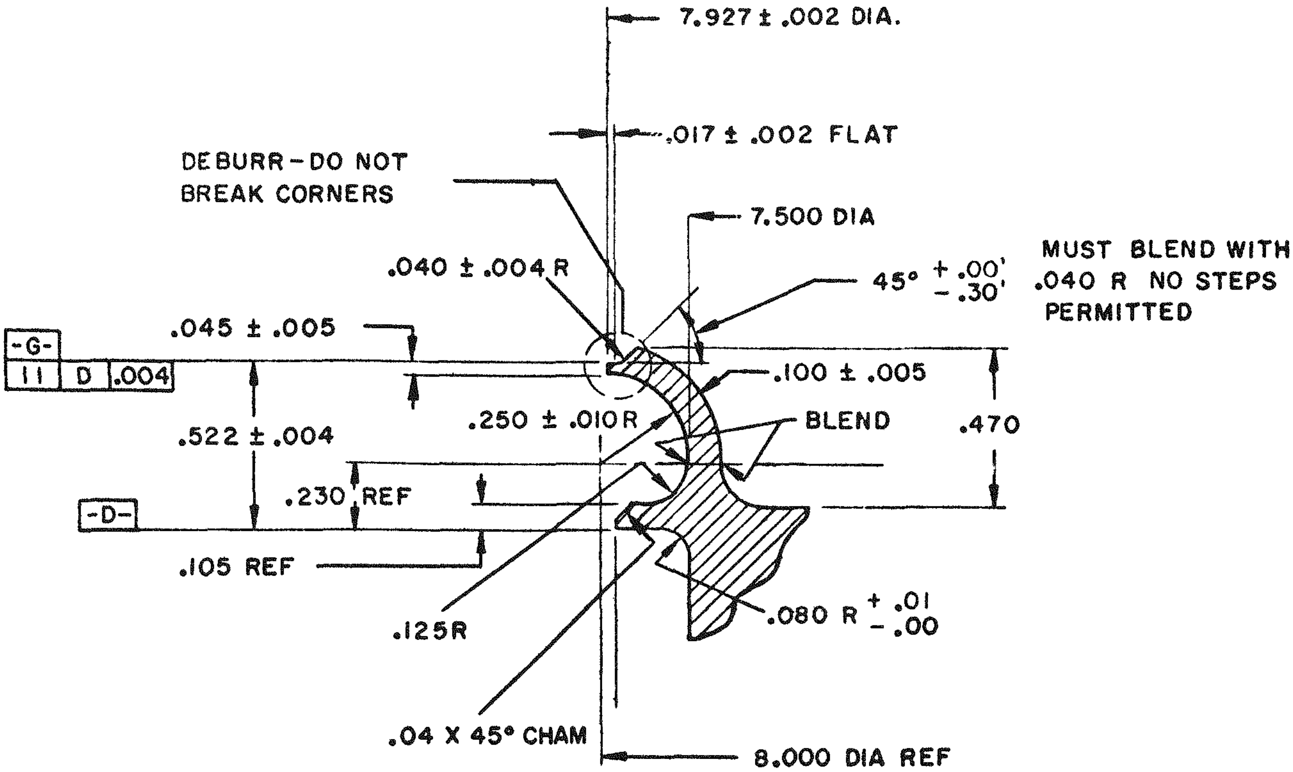
B. By-pass Inlet Flow (BIF) Seal Welds

1. Functional Requirements

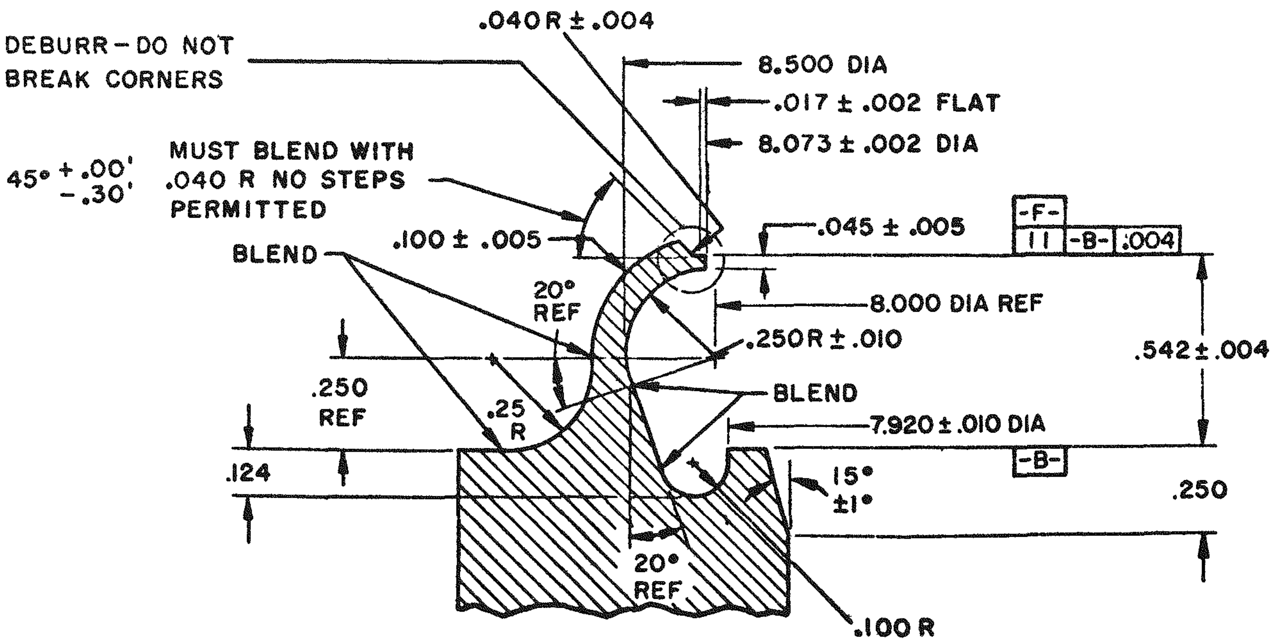
The omega seals between the BIF housing plugs and the BIF housings were welded to form a seal at six locations on the LWBR closure head. The liquid penetration (LP) inspection criteria that no cracks or linear indications were permitted and the three other LP criteria were the same criteria delineated for the main closure seals in Section II.A.1 of Appendix G. The qualified root gap between the BIF housing plug seal and BIF housing seal was 0.067 to 0.082 inch and the qualified vertical mismatch range was + 0.008 to -0.008 inch. The BIF seal qualification mockups were welded in a mockup stand which duplicated the height of the production weld and duplicated the purge gas flow paths and gas volumes that were encountered in field welding.

2. Design Parameters

The dimensions of the BIF housing and BIF housing plug seal lip areas are shown in Figure G-4. The nominal diameter of the seal weld was 8 inches with the nominal seal wall thickness being 0.100 inch. The weld was a two layer weld with a T-shaped insert being pre-placed for the root pass. A 1/4 to 3/8 inch root gap was made in the insert after fitup for utilizing a purge needle for argon gas supply to the underside of the weld during first and second layer



BIF PLUG



BIF HOUSING

FIGURE G-4
DETAILS OF LWBR BIF
SEAL TEST ASSEMBLIES

welding. The second layer was made utilizing hand fed filler metal in an inboard and outboard pass sequence. Both the first and second layers were also welded using a segment sequence. Purge gas flow was lower during the welding of the root pass segments to prevent weld deposit lift or blow out.

The base materials for the BIF housing and BIF housing plug were Ni-Cr-Fe (Inconel) Alloy 600. The insert material and the 1/16 inch diameter filler metal met the Section II, Part C SFA 5.14 (ER NiCr 3) and the Section III, Subsection NB, Subparagraph NB-2432.2 1974 ASME BPVC requirements.

3. Equipment Description

Commercial welding machines rated at 300 amps were used during all welding. All welding machines were equipped with high frequency arc start and a foot pedal operated slope control. D-C straight polarity current was used for all welding. Flow meters were employed to meter the argon gas used for torch shielding gas and purging. The electrodes were 1/16 inch diameter, 2 percent thoriated tungsten ground to drawing requirements. The welding current ranges were 65-75 amps for root pass welding and 45-60 amps for second layer welding. The argon purge gas flow was 10 to 14 CFH during tack welding and welding of the second layer. During the welding of all segments of the root pass, the argon purge gas flow was 3 to 5 CFH. Minimum purge times were established before welding was permitted. The torch argon gas flow rate was 16 to 20 CFH. The maximum interpass temperature permitted was 250 F with no welding permitted on material at a temperature less than 60 F. A No. 5 gas lens cup was used for all welding.

4. Testing, Qualification and Field Welding

Immediately prior to mockup welding, the weld joint area was cleaned with a clean, lint-free cloth saturated with acetone. With the weld root gap and vertical misalignment measured and the insert and purge needle installed, the weld joint area was covered with high temperature glass cloth tape in a reverse order of segment welding. The argon purge gas was established at 10 to 14 CFH for a minimum of 30 minutes prior to tack welding. The tack welds were placed at each end of the insert and at approximately 1 1/2 inch intervals alternately to the inner seal and to the outer seal around the insert. After the mockup was welded, the purge hole was welded closed using filter metal and the welding parameters of II.B.3.

Two consecutive mockups had to be welded successfully by each of the five Bettis welders to qualify to the 1974 ASME Boiler and Pressure Vessel Case, Section III, Subsection Paragraphs NB-4360 (Manual Welding) and ND-5370 and Section IX including the latest addenda criteria. The manner in which each welder qualified also qualified the procedure. No major problems were encountered in qualifying the welders or field welding of the BIF omega seals.

5. Recommendations

The two minor problems which occurred during the successful BIF welding qualification efforts at Bettis are the basis for the following recommendations.

a. It is not advisable to have omega seal type mockups crepanned from the interior of large forgings. There is a chance that base cracks may appear during mockup welding. In general, large forgings do not receive a uniform amount of working throughout their cross section, and segregation concentrations will be greater in the center portion of the forging. The exterior of the forging normally receives more working and grain refinement than the interior of the forging.

b. Care must be taken during welding of the root passes of an omega seal with underbead purging that the flow of the purge gas is not so high as to cause lifting or ejection of the molten weld puddle.

C. Instrumentation Welds

1. Functional Requirements

The 33 exit water thermocouple plugs, six BIF pressure tap plugs and seven flux thimble connector plugs were welded to the mechanism housing bosses and one flux thimble connector plug was welded to the BIF housing plug on the LWBR closure head. These instrumentation manual welds formed a seal between the instrumentation components and the closure head mechanism and BIF housing components. The liquid penetrant inspection criteria for both production and mockup weld acceptance were (1) no cracks or linear indications permitted, (2) no rounded indications with a maximum dimension larger than 1/64 inch permitted, and (3) no more than five rounded indications were permitted per square inch of weld and no indication within 1/4 inch of any other indication.

The three types of instrumentation plugs are shown in Figure G-5 with design fitup dimensions which were qualified. Go and no-go custom gages were utilized to check the acceptability of the final mockup and field weld dimensions.

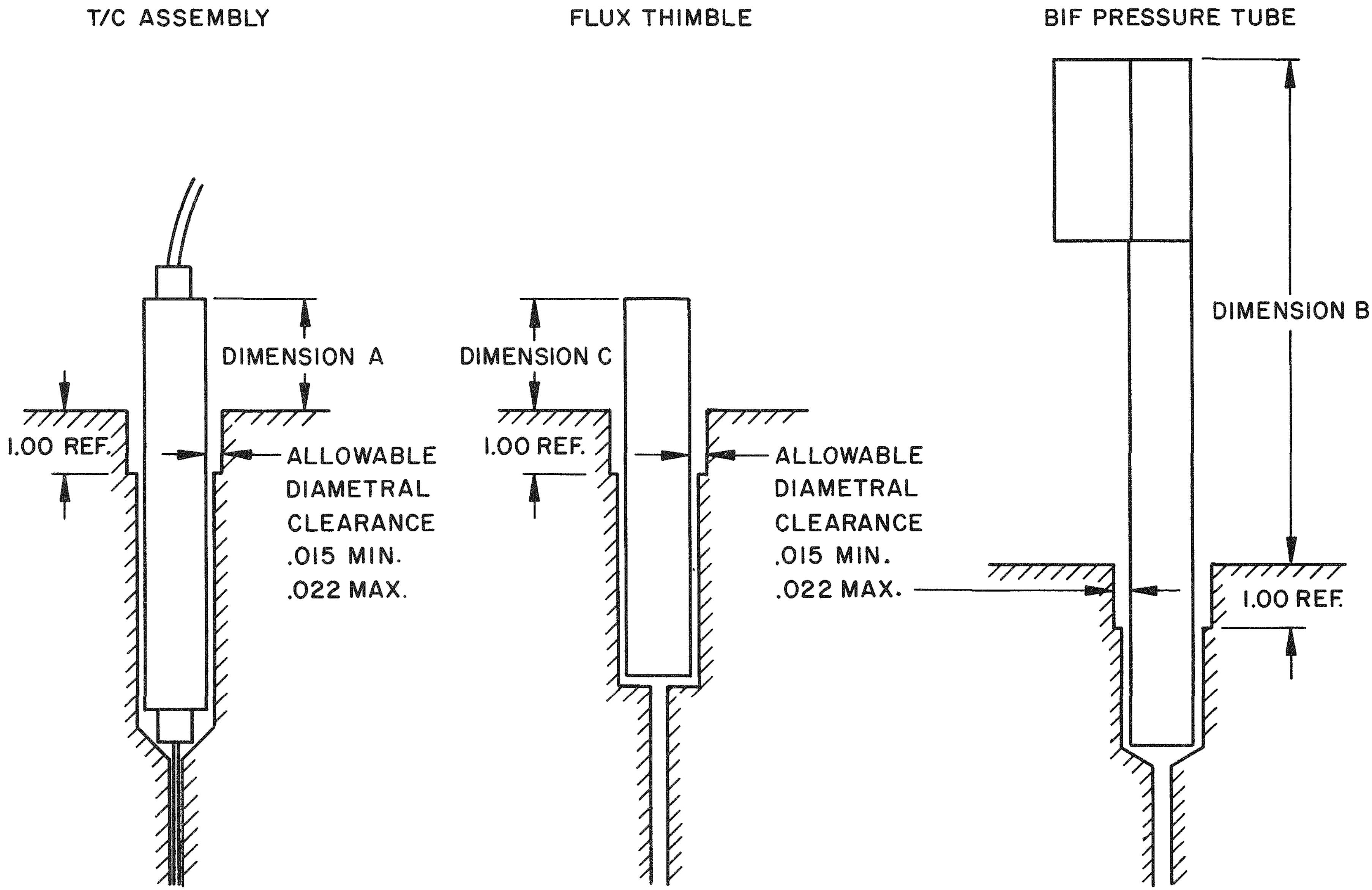


FIGURE G-5
INSTRUMENTATION EXTENSION FROM THE SURFACE OF
THE LWBR CLOSURE HEAD OR BIF HOUSING PLUG

2. Design Parameters

The instrumentation plugs and base materials welded together were Ni-Cr-Fe (Inconel) Alloy 600. The nominal wall thickness of the thermocouple instrumentation plug was 0.154 inch, the BIF pressure tap plug 0.187 inch and the flux thimble plug 0.310 inch. The nominal outside diameter of the instrumentation and BIF pressure tap plugs was 0.499 inch and 0.745 inch for the flux thimble plug. The 1/16 inch diameter filler metal met the Section II, Part C SFA 5.14 (ER Ni Cr3) and the Section III, Subsection NB Subparagraph NB-2432.2, 1974 ASME BPVC requirements.

3. Equipment Description

Commercial welding machines of 300 amp rating were used during procedure and welder qualifications. All welding machines were equipped with high frequency arc start and a foot pedal operated slope control. D-C straight polarity current was used for all welding. Flow meters were employed to meter the argon torch shield gas. The electrodes were 3/32 inch diameter, 2 percent thoriated tungsten ground to drawing requirements. The welding current range used was 75 to 130 amps. The flow of argon through the No. 5 gas cup was 15 to 30 CFH. The maximum interpass temperature permitted was 150 F with no welding permitted on material at a temperature less than 60 F.

4. Testing, Qualification and Field Welding

Two types of qualification were conducted for the instrumentation type welds. Each welder was required to weld two consecutive successful mockups which duplicated the production weld and also the access which the welder would encounter during production welding. The other type of mockup was welded to meet ASME Section IX code requirements for a fillet weld.

a. Production Weld/Access Mockups:

The production weld/access mockup welding consisted of the following:

(1) The test assemblies were machined from Ni-Cr-Fe Alloy 600. The weld joint on the test assemblies was identical to the weld joint on the production component with the exception that the top portion of the BIF pressure tap was tack welded to an exit water thermocouple tube. The purpose of this was to simulate the most restrictive condition for welding in addition to making the weld on the tube with the thinnest side wall.

(2) Without the BIF pressure tap plug installed, one of the two rear T/C plugs was welded. Immediately prior to welding, the weld joint area was wiped with a clean lint free cloth saturated with acetone. The ID of the housing boss hole was measured at the weld joint and the OD of the plug was measured. The welding torch was fitted with a No. 5 standard cup and the 3/32 inch diameter tungsten electrode was adjusted to extend 5/16 inch beyond the gas cup. The gas flow meter was then adjusted to 15 CFH commercial welding grade argon. The arc was started on a Ni-Cr-Fe Alloy 600 block and the welding machine was adjusted for a maximum of 130 amperes.

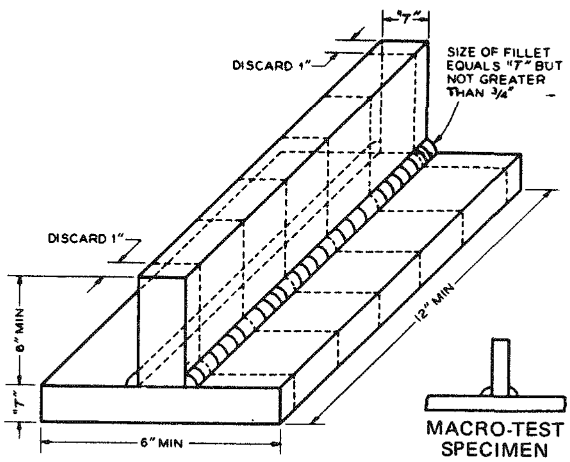
(3) To simulate assembly of the production components, the instrumentation plug was bottomed in the hole, then using the holding fixture, the plug was raised off the bottom of the hole 0.070 inch. Using 1/16 inch diameter filler wire, one tack was made between the tube and base to hold the tube off the bottom of the hole. The tack was visually inspected at 5X magnification and no defects were found. Again, using the 1/16 inch diameter filler wire the root pass and subsequent layers were welded.

(4) The weld start and stops were ground or burred as necessary. The root layer and each weld pass were wire brushed using a stainless steel brush prior to depositing subsequent weld beads. The root pass and each layer were liquid penetrant inspected. The BIF pressure tap plug was then welded in a similar manner.

(5) Upon completion of welding, the test assemblies were sectioned transverse to the weld in a manner to give four metallographic specimens from each test assembly. Each of the cross sections was made in areas of a weld start and stop due to the sequencing of the weld and the method of sectioning.

b. The ASME Code type mockups (Figure G-6) were welded as follows:

(1) Prior to welding, the weld joint area for a distance of two inches on each plate for both the procedure and performance test assemblies was mechanically cleaned by grinding to bright metal. The plates for the procedure qualification test assembly were then assembled by the use of heavy angle blocks and "C" clamps. The joint area was then wiped with a clean lint-free cloth saturated with acetone. Using an HW17 torch fitted with a No. 5 gas cup, 1/16 inch diameter filler metal and the parameters used for the



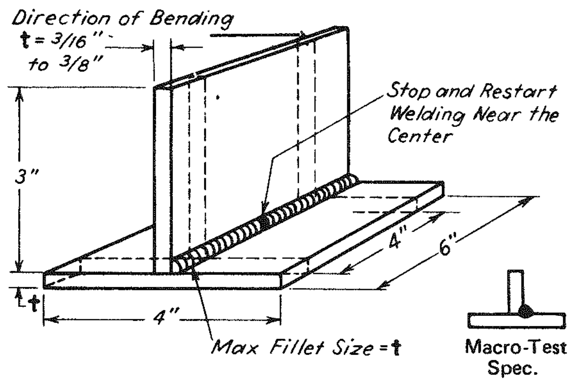
"T" MAXIMUM THICKNESS OF BASE METAL IN THE VESSEL AT POINT OF WELDING OR 1", WHICHEVER IS SMALLER.

MACRO TEST: THE FILLET SHALL SHOW FUSION AT THE ROOT OF THE WELD BUT NOT NECESSARILY BEYOND THE ROOT. THE WELD METAL AND HEAT AFFECTED ZONE SHALL BE FREE OF CRACKS. BOTH LEGS OF THE FILLET SHALL BE EQUAL TO WITHIN 1/8 INCH.

QW-462.4(a) FILLET WELDS—PROCEDURE

For the test assembly described herein:

T vertical member = 5/16 inch
T horizontal member = 1-3/8 inch



QW-462.4(b) FILLET WELDS—PERFORMANCE

For the test assembly described herein:

T vertical & horizontal members = 5/16 inch

FIGURE G-6

PROCEDURE QUALIFICATION TEST ASSEMBLY FOR THE INSTRUMENTATION WELDS

(from Section IX of the ASME Boiler and Pressure Vessel Code) access mockups, a root pass was made for approximately one-half of the weld joint length (6 inches) on one side of the "T" joint. The clamps were then released and refitted to the side where the partial root pass had been made and a 6-inch long root pass was made on the side opposite to where no welding had been done. The clamps were then removed and the weld stops were ground. The root pass was then completed on each side of the joint. The welds were then wire brushed and liquid penetrant inspected. Using the same parameters and 3/32-inch diameter filler wire the remaining weld passes were made in the same sequence as the root pass. This enabled the weld to be made with a minimum amount of distortion in the vertical member of the test assembly. Each layer of weld was liquid penetrant inspected.

(2) The performance qualification test assembly was welded from one side only, using the same parameters described above for the procedure qualification test assembly.

(3) During welding of the procedure and performance qualification test assemblies, the root pass and each subsequent layer were liquid penetrant inspected. Upon completion of welding, the test assemblies were submitted to an independent testing laboratory for performing the ASME BPVC Section IX destructive test assembly transversely to provide five sections each approximately 2 inches long. One face of each cross section was polished, etched, and visually examined. The performance qualification test assembly was cut transversely to provide a center section 4 inches long and two end sections, each approximately 1 inch long. The vertical member of the 4-inch specimen center section was loaded laterally in such a way that the root of the weld was in tension. The specimen was bent flat upon itself. In addition, one end of one of the end specimens was polished, etched, and visually examined.

Seven welders at Bettis qualified on both types of assemblies with no problems encountered. In addition to the test assemblies, an additional test assembly with a simulated brazed thermocouple joint in place was welded to ensure that the welding heat would not remelt the braze. This test assembly was hydrostatically tested to a pressure of 3750 + 50 -0 psig at room temperature for a period of 1 hour and found to be satisfactory with no leakage.

5. Recommendation

a. The instrumentation welds were successfully made on both the qualification and production weld stages. This recommendation concerns the care which must be taken during production welding of the plugs of this type in parallel. Since each weld layer was required to be liquid penetrant (LP) inspected, signoffs should be required to each weld layer for each individual instrumentation plug to prevent inadvertent welding without an LP inspection taking place.

b. Evidence suggests the production flux thimble connector plug welds distorted the plugs even though welding of the flux thimble connector plugs had been tested prior to actual installation at Shippingport. Further discussion of this problem is contained in Appendix J. This problem highlighted the difficulty of simulating actual conditions in a mockup.

D. CDM Vent Valve Plug Welds

1. Functional Requirements

The 12 Control Drive Mechanism (CDM) vent valve plugs were welded to motor tube extensions of the CDMs. These welds formed a seal between the plugs and CDM motor tube extensions. The liquid penetrant inspection criterion was the same as for the instrumentation welds.

2. Design Parameters

The CDM vent valve plugs and motor tube extensions were both Ni-Cr-Fe (Inconel) Alloy 600. The nominal wall thickness of the CDM vent valve plug at the point of root pass welding was 0.110 inch and the nominal outside diameter was 0.615 inch. The 0.045-inch diameter filler metal met the Section II, Part C SFA 5.14 (ER NICr3) and the Section III, Subsection NB, Subparagraph NB-2432.2 1974 ASME BPVC requirements.

3. Equipment Description

The welding machines and associated equipment were the same as utilized on the instrumentation welding. The electrodes were 3/32 inch diameter, 2 percent thoriated tungsten ground to drawing requirements. The welding current range was 40 to 100 amps. The flow of argon through the No. 6 gas cup was 10 to 15 CFH. The maximum interpass temperature permitted was 350 F with no welding permitted on material at a temperature less than 60 F.

4. Testing and Qualification

Since the base materials and filler metal material types were the same and the weld profile and essesntial welding variables were equivalent per QW-256 of Section IX of the 1974 ASME BPVC, the procedure and welders qualified for the instrumentation welds were also considered qualified for the CDM vent valve plug welding. However, access mockups with the actual configuration were welded and examined to ensure that no problems existed.

5. Recommendations

The production welding of the CDM vent valve plugs was successful. The recommendations for future similar welding endeavors are (a) care should be taken that all water is removed from the vent cavity using syringes or hypodermic needles if required, and (b) as in this case some weld qualifications can be considered applicable to other similar weld configurations.

III. AUTOMATIC MACHINE WELDING OF THE CDM MOTOR TUBES

A. Background Information

Automatic machine welding was selected for this weld because of the space access limitation around the CDM seals. The weld is a horizontal full penetration groove weld of the 0.100 inch thick omega seal membranes.

The CDM center-to-center distance is 17.174 inches while the CDM motor tube immediately above the seal is a 13.44-inch diameter. This provides an annulus of less than 4 inches which extends up above the seal approximately 20 inches. At this point the motor tube tapers to an 8.5-inch diameter. This configuration provides limited access when welding around the back side of the motor tube. Although tests showed that manual welding of the seal was possible, it was concluded that the weld should be made by an automatic welding machine.

B. Description of the Machine Welding

1. Functional Requirements

The omega seals between the motor tubes and the mechanism housings were welded to form a seal at 12 locations on the LWBR closure head. The liquid penetrant inspection criteria of no cracks or linear indications, and the three other criteria contained in Section II.A.1, were applied to these welds. The qualified root gap between the motor tube seal and the mechanism housing seal was 0.067 to 0.080 inch and the qualified vertical mismatch range was +0.008 to -0.008 inch.

2. Design Parameters

The nominal seal thickness was 0.100 inch and the nominal diameter of the seal weld was 14.87 inches. The weld was a two layer weld which used two preformed inserts and four welding passes. The first pass consumed a T-shaped insert and filled the basic groove. The cover passes consisted of a "running tack" pass which fused a second insert of circular cross section to the weld, and an inboard and outboard pass which washed the material over the inner and outer fusion lines of the first pass weld. The base materials for the mechanism housing and the motor tube were Ni-Cr-Fe (Inconel) Alloy 600. The insert material met the Section II, Part C SFA 5.14 (ER NiCr 3) and the Section III, Subsection NB, subparagraph NB-2432.2 1974 ASME BPVC requirements.

3. Equipment Description

The welding equipment consisted of a programmable, automatic tungsten inert gas welding power supply/control unit and an electrically driven rotating apparatus which carried the welding torch. Automatic voltage control of welding arc voltage was incorporated into the electronic circuitry of the welding machine. The equipment was designed so that interlocks prevented initiation of the welding arc if any one of the preselected welding conditions was not met. Figure G-7 shows a schematic diagram of the welding equipment, and Figure G-8 shows the torch guide assembly.

4. Testing and Qualification

In mid-1972, process development for the CDM welding procedure was begun at Bettis. The welding equipment used was a modified PWR-2 seal welding power supply and a Laboratory universal rotating apparatus. Nine random heat test assemblies were welded during process development, which resulted in what was considered to be an acceptable preliminary welding process. Two test assemblies from the same heat were then welded to worst case conditions. The results of these test assemblies demonstrated that the preliminary process was capable of producing acceptable CDM seal welds. Same heat test assemblies were used because of the apparent sensitivity of the welding parameters to the particular combination of material heats.

After fabrication of the welding equipment had been completed, several segmented development mockups were welded to check out the equipment and test out the adequacy of the preliminary welding process. The results of these mockups showed that the equipment performed well and that, aside from an adjustment

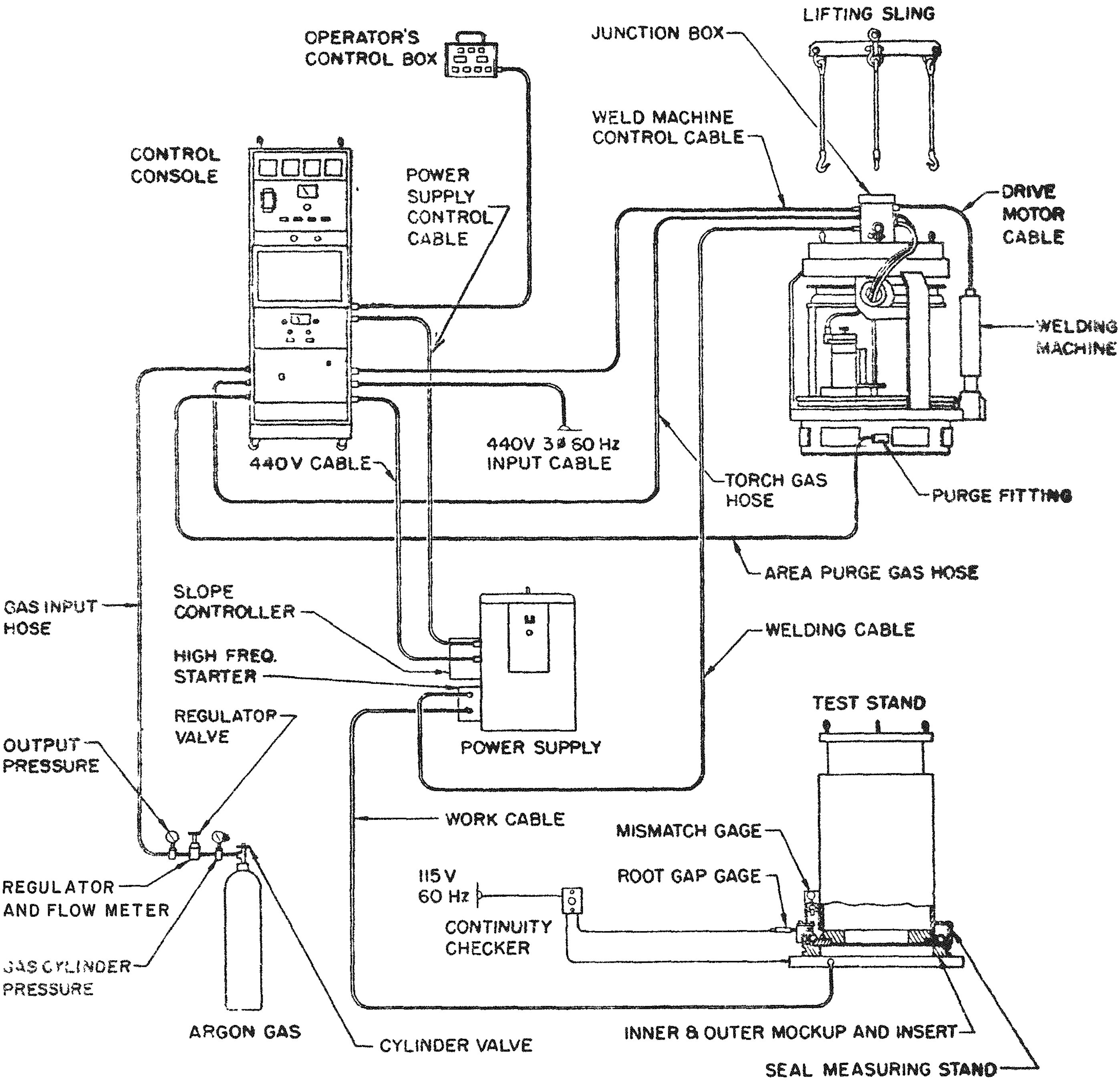


FIGURE G-7
GENERAL ARRANGEMENT
OF THE CDM AUTOMATIC
WELDING MACHINE

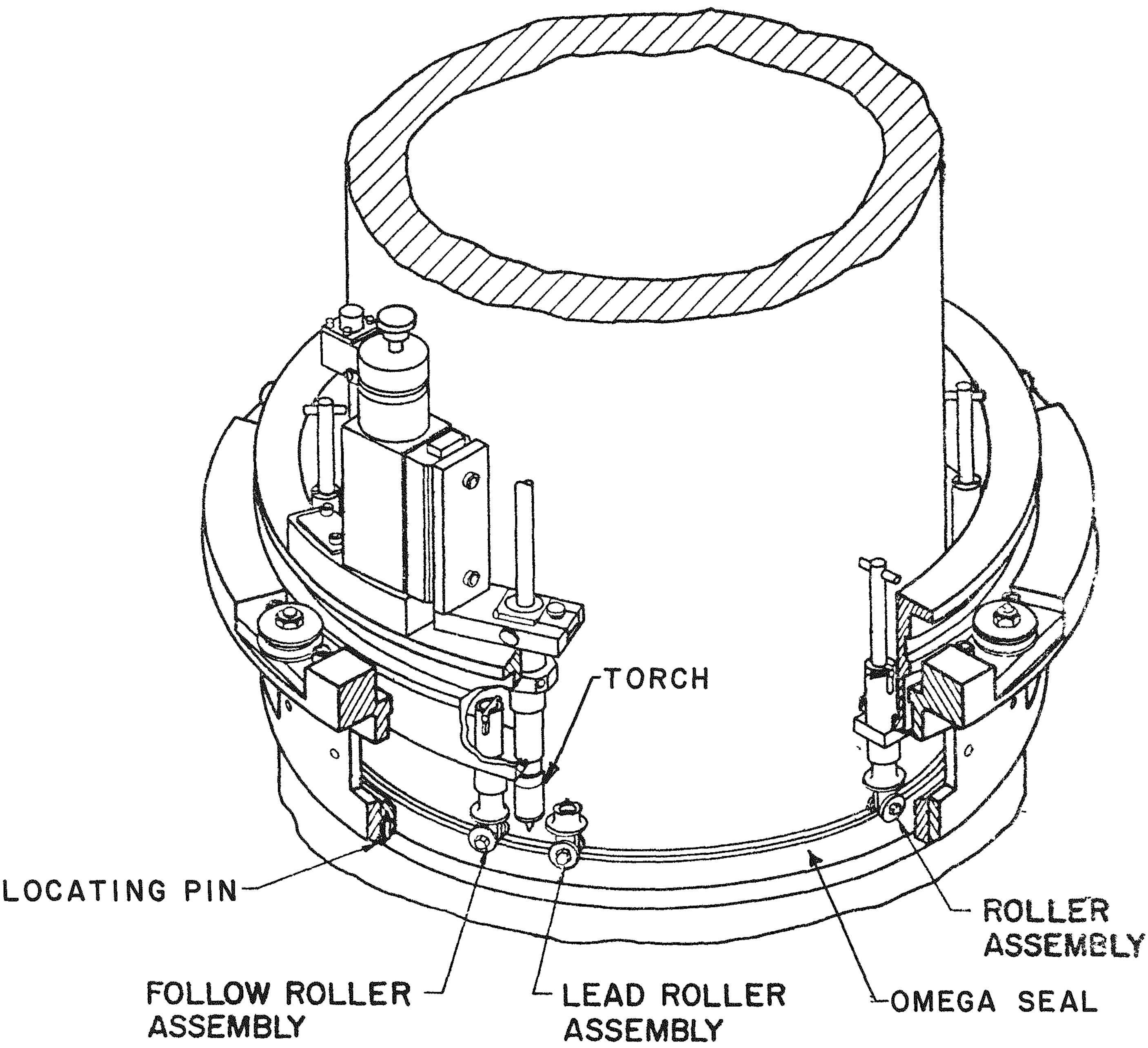


FIGURE G-8
TORCH GUIDE ASSEMBLY

to the first pass overlap length, the original welding parameters should be used for procedure qualification. The welding procedure process parameters that were used are listed in Table G-I.

At least six consecutive test assemblies representing the range of dimensions to be qualified are required to establish the reproducibility of the welding procedure as required by Section NB 4366.1 of the ASME Code for qualification of specially designed seal welds. To demonstrate this capability, the test assemblies conformed to the following guidelines:

Test Assembly Number Note (1)	Inner Lip Thickness Note (5)	Outer Lip Thickness Note (5)	Root Gap Note (5)	Vertical Mismatch Notes (2), (4), (5)	Welding Current Note (3)
1	max.	max.	max.	max. neg.	max.
2	min.	min.	min.	max. pos.	max.
3	min.	min.	max.	max. pos.	max.
4	max.	max.	min.	max. neg.	min.
5	min.	max.	max.	max. pos.	min.
6	max.	min.	min.	max. neg.	min.

NOTES:
(1) The sequence in which test assemblies are welded is not mandatory.
(2) Vertical mismatch is measured at the top face of the root diameters.
(3) Maximum current shall be upper limit value specified in the welding procedure plus 2 minus 1 amps. Minimum current shall be lower limit value specified in the welding procedure, plus 1 minus 2 amps.
(4) Negative vertical mismatch: Inner ring low.
(5) For maximum dimensions, the tolerance should be plus 0.003 minus 0.002 inch on the absolute value of the dimension. For minimum dimensions, the tolerance shall be plus 0.002 minus 0.003 inch.

In addition to the liquid penetrant and dimensional inspection of the weld, the test assemblies were sectioned to permit examination of the weld cross sections and underbead (underside of weld) in accordance with the requirements of Code Section NB 4367.

Seven test assemblies (WQ-1 through WQ-7) were welded to qualify the CDM seal welding procedure. Test assembly WQ-1 was welded and evaluated and found to have a 3/32-inch linear liquid penetrant indication on the weld underbead at the end of the first pass overlap. Metallographic examination showed that the indication was associated with a patch of porosity 0.015 inch in diameter. The test assembly was therefore rejected. The defect was attributed to the first

TABLE G-I. PROCESS PARAMETERS FOR LWBR CDM SEAL WELDING

A. Geometry Parameters

1. Inner Lip Thickness	0.045 in ± 0.005 in
2. Outer Lip Thickness	0.045 in ± 0.005 in
3. Root Gap	0.073 in ± 0.005 in
4. Seal Mismatch	± 0.008 in

B. Welding Process Parameters

1. First Pass

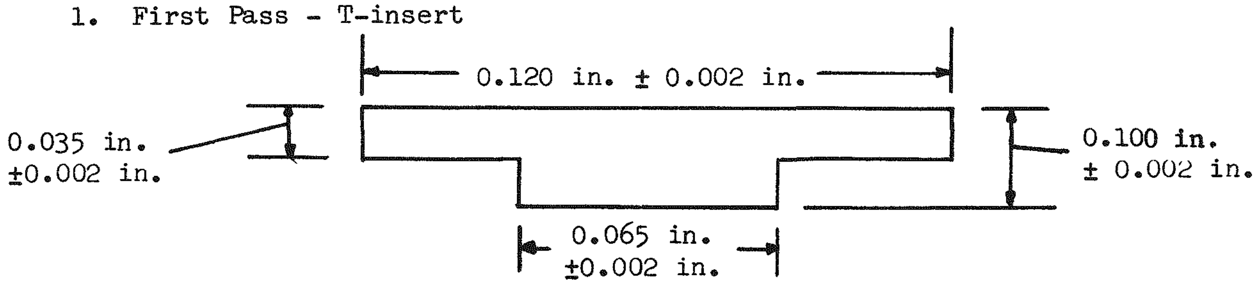
a. Weld Current	85 ± 2 amperes
b. Weld Speed	5 ipm
c. Arc Voltage	9.2 volts (measured directly across arc)
d. Decay Current (final)	30 amps maximum
e. Torch Position - Root Gap Centerline	± 0.005 in

2. Cover Passes

a. Weld Current	121 ± 1 amps - running tack and inboard pass, 113 ± 1 amps - outboard pass
b. Weld Speed	10 ipm
c. Arc Voltage	9.7 volts (measured directly across arc)
d. Decay Current (final)	30 amps maximum
e. Torch Position -	
Running Tack - Root Gap Centerline	± 0.005 in
Inboard Pass - Inboard	0.040 in ± 0.005 in
Outboard Pass - Outboard	0.035 in ± 0.005 in

C. Welding Insert Parameters

1. First Pass - T-insert



2. Cover Pass - Round insert 0.090 in. ± 0.002 in. diameter

pass decay rate being too short. For subsequent welds, the decay was lengthened to 20 seconds and the rate decreased. No further problems in this area were encountered after the change.

The required series of six consecutive mockups for procedure qualification consists of test assemblies WQ-2 and WQ-7. It should be noted that, while the root pass was qualified over a range of 83-87 amperes, all mockups had the running tack and inboard pass welded at 121 amperes and the outboard pass welded at 113 amperes. This approach was taken because other welding development programs have shown that the first pass has been much more susceptible to weld integrity problems. Thus, more effort is directed toward establishing an acceptable first pass welding procedure than for the cover passes, which are used to build up the weld wall to satisfy dimensional or structural requirements. Therefore, Bettis desired to demonstrate that the first pass weld has a safety margin to both sides of the nominal welding parameters, while it was felt that it was not necessary to do so for the cover passes. With the exception of one incident which occurred on test assembly WQ-5, all welding was performed to the requirements of the procedure and without any problem areas. The one incident which did occur involved the first pass welding insert lifting at the start of the weld and contacting the torch, thus extinguishing the arc. No damage to the test assembly was incurred. The cause of the incident has been determined to be that the gap in the insert was not aligned with the welding electrode. Welding operators were reinstructed in this area. A checkpoint to check alignment over the insert end was inserted into the procedure. No further problems were encountered in this area.

Bettis seal welding procedures typically specify a relatively short (12 to 24 hours) maximum elapsed time between insert pickling and seal welding. However, since no pickling facilities exist at the Shippingport site, pickling of LWBR CDM inserts had to be done at Bettis before shipment to the site. In light of this, the procedure proposed a maximum time limit of two weeks between pickling and welding. To provide grounds for this proposal, all inserts except one first pass insert for qualification welding were pickled approximately six months before welding, sealed in polyethylene bags until use, and given an alcohol cleaning immediately before use. The one first pass insert was pickled approximately 24 hours before welding. No deleterious effects of the relatively long time interval between pickling and welding were observed. Neither were any differences noted between welds made with inserts pickled six months before welding and the weld made with the insert pickled 24 hours before welding.

As each qualification weld was made, the top of the first pass, the top of the finished weld, and the weld underbead were liquid penetrant inspected. The results of the liquid penetrant inspection are given in Table G-II. All test assemblies are acceptable to the liquid penetrant test requirements of the 1974 ASME Boiler and Pressure Vessel Code as supplemented by MEP-S-902E.

Each weld was sectioned in accordance with Paragraph NB 4367 of the ASME Code and evaluated in accordance with Paragraph NB 5370. No unacceptable conditions were observed in any metallographic section. Each metallographic section, in addition to being evaluated for cracking, lack of penetration, porosity, and complete insert melting, was dimensionally analyzed for critical dimensions. All dimensions were well within required limits and, taking into account the differing geometry and welding parameters between mockups, were consistent from mockup to mockup.

TABLE G-II. RESULTS OF LIQUID OF LIQUID PENETRANT INSPECTION OF CEM SEAL WELD TEST ASSEMBLIES

Test Assembly No.	First Pass Top	Finished Weld Top	Underbead
WQ-2	No Indications	No Indications	No Indications
WQ-3	No Indications	No Indications	No Indications
WQ-4	No Indications	No Indications	No Indications
WQ-5	No Indications	No Indications	No Indications
WQ-6	One Indication Less than 1/16 in.	One Indication Less than 1/32 in.	No Indications
WQ-7	No Indications	No Indications	One Indication Less than 1/16 in.

APPENDIX H

NUCLEAR SAFETY CONSIDERATIONS OF THE LWBR INSTALLATION

I. INTRODUCTION

The nuclear safety of the LWBR installation operations was one of the most important aspects in the development of the installation equipment design and the detailed assembly procedures. These safety concerns were most apparent in the controls exercised for the storage and handling of the individual fuel assemblies throughout the installation period.

As shown by the calculated reactivity coefficient (k_{eff}) of the LWBR seed and blanket fuel assemblies for various conditions (Table H-I), no condition of the fuel in the absence of a moderator (water) results in a critical configuration. However, flooding the fuel assemblies with water together with another accident condition (such as rearrangement of the fuel rods within a seed or blanket fuel assembly resulting from severe damage to the fuel assembly) could result in criticality. Controls were thus imposed to prevent the occurrence of the double accident condition of water flooding the fuel and either damage to the fuel assemblies or arrangement of the fuel assemblies into a critical configuration.

Three areas of the LWBR installation required the implementation of criticality control measures: the receipt and storage of the fuel assemblies, the installation of the fuel assemblies into the reactor vessel, and the initial fill of the fueled reactor. Since the thorium reflector modules, not containing fissile material, presented no criticality hazard, criticality concerns were directed only to the LWBR seed and blanket fuel assemblies.

II. RECEIPT AND STORAGE OF LWBR (SEED AND BLANKET) FUEL ASSEMBLIES

The design of the new fuel storage facility, including the receiving area, was developed to provide protection against achieving accidental criticality during the operations of moving the fuel assemblies into their storage locations and during the storage period.

The LWBR seed and blanket fuel assemblies were stored in a storage facility constructed within a dry storage pit. The facility incorporated 24 storage locations (a separate storage space for each of the twelve seed and twelve blanket fuel assemblies). The spacing between individual fuel assembly storage

TABLE H-I. REACTIVITY (K_{eff}) OF LWBR SEED AND BLANKET FUEL ASSEMBLIES FOR VARIOUS CONDITIONS

Fuel Assembly Type	Condition	K_{eff}
Blanket	Dry, nominal configuration	<0.60
	Moderated and reflected by water	0.81
	Dropped into most reactive configuration (fuel assembly damaged), moderated and reflected by water	*
Seed	Dry, nominal configuration	<0.60
	Moderated and reflected by water	0.89
	Dropped into most reactive configuration (fuel assembly damaged), moderated and reflected by water	*
Seed Inserted into Blanket	Seed fully inserted, dry	0.60
	Seed fully inserted, moderated and reflected by water	0.85

*Analyses of the structural damage to the seed and blanket fuel assemblies that could occur from a hypothetical drop within the physical confines of the fuel handling area indicated that the damage would not cause a "most reactive" rearrangement. These analyses indicated that dropping the assembly combined with water moderation would still remain subcritical.

locations in the racks was established to maintain a greater than 12 inch edge-to-edge distance between assemblies. In air, with this spacing and a fuel assembly installed at each location, the array of fuel is shut down by over 40 percent $\Delta k/k$. In water, with this spacing, fuel assemblies are decoupled from each other and the most reactive LWBR fuel assembly is shut down by approximately 9 percent $\Delta k/k$. Even though the presence of water surrounding the stored fuel would not result in criticality, additional steps were taken to minimize the potential for water moderation of the fuel assemblies during handling and storage. During handling of the seed and blanket fuel assemblies, all water lines in the vicinity of the fuel handling area were drained to prevent accidental water release. The new fuel storage facility incorporated a permanent pump, activated automatically by a float switch and capable of pumping 100 gallons per minute against a 50 foot head, to drain the storage pit in the unlikely event that water entered the storage area. In addition, a moisture detector alarm was installed to notify plant personnel if water entered the storage pit. The alarm activated before the pump switch.

Administrative control required that only one fuel module be handled at one time to reduce the possibility of an inadvertent criticality. In addition, the LWBR fuel storage facility incorporated missile shields to protect the stored module in the event of a tornado or an airplane accident.

Administrative, procedural and mandatory equipment design requirements were established to minimize the possibility of damaging a seed or blanket fuel assembly. The fuel handling tools were designed to positively grapple and lock onto the fuel assemblies. In addition the fuel handling tools incorporated two locks to prevent inadvertent ungrappling. The fuel handling procedure required unlocking of the secondary lock followed by verification of the locking of the primary lock before the secondary lock was relocked and the fuel lifted from storage. The locked condition of the secondary tool lock was visually verified before the fuel was lifted.

Mechanical stops were installed on the bridge crane rails to prevent the passage of a fuel assembly over the adjacent stored fuel assemblies.

III. WATER EXCLUSION DURING INSTALLATION OF THE LWBR FUEL ASSEMBLIES

The LWBR fuel assemblies were installed in the reactor vessel with the vessel drained of water to well below the fuel assembly level. This was necessary to prevent criticality from occurring during the insertion of the the movable seed fuel assembly into its corresponding blanket fuel assembly. The design of the LWBR is such that criticality is achieved by raising the movable seed fuel assemblies within the blanket fuel assemblies in the presence of a moderator (water). The design of the fuel assemblies required that a seed be installed into the blanket, and in doing so, the seed is passed through the blanket zone where criticality would occur if a moderator were present. This potential criticality condition exists during insertion of the seed fuel assembly until the seed is lowered to within two feet above its fully inserted position. Installation of the blanket and reflector fuel assemblies presented no such criticality hazard.

To provide assurance that no additional water would enter the reactor vessel during fuel installation, the reactor vessel was isolated from potential sources of water, and the water level of the reactor vessel was continuously monitored during the seed insertion operations.

Double valve isolation (or its equivalent) from the reactor vessel, and inter-valve drain, was provided for all water sources systems which penetrated the reactor vessel or the reactor coolant loops. The major plant systems that required isolation included the reactor coolant system, the pressurizer and pressure relief systems, the coolant charging system, the safety injection system, and the core removal cooling system. The reactor coolant loops were placed in dry layup and the manual isolation valves were shut. The hydraulic operated valves were left open, since these valves cannot be operated with air on either side of the valve and it was impossible to prevent trapping air against the shut hydraulic valves when the reactor vessel was refilled. The heat exchanger tubes provided the second barrier between the secondary coolant loops (in wet layup) and the reactor vessel. The other plant systems were similarly isolated by double valve isolation using a combination of shutting stop valves, gagging relief valves, and draining the water from the components.

The reactor vessel water level was monitored using the Bubbler Water Level Indicating System. The bubbler sytem uses a slow flow of nitrogen gas to measure the water level in the reactor vessel over the range from elevation 685 ft, 4 in. to elevation 717 ft, 9 in. Level indication is accomplished by the relationship of the water head height to the pressure required to force nitrogen gas through an underwater outlet. Flow-controlled nitrogen is passed through two separate core instrumentation lines that are part of the LWBR core barrel. Two of the seed high pressure taps, which pass through the core barrel from the northwest core support flange instrumentation nozzle to the core barrel bottom plate at elevation 685 ft, 3 in., were used to conduct the nitrogen gas to the bottom of the reactor vessel.

Two independent channels of instrumentaion, consisting of a differential pressure detector, an alarm unit, and a digital voltmeter, were connnected to the nitrogen lines and each channel was provided with visual and audible alarms in the plant operator's control room and the fuel handling area.

IV. INITIAL FILL OF THE REACTOR VESSEL

The shutdown reactivity for the all-fuel-assemblies-installed, all movable-assemblies-down condition was determined to be approximately 15 percent $\Delta k/k$ (k_{eff} = 0.85) for the nominally fueled and water moderated LWBR at 68 F. This determination was made using the LWBR nuclear calculational model prior to the actual fuel installation. For a critical configuration to occur during the initial fill, one or more manufacturing errors would have had to occur during the fabrication and installation of the fuel assemblies. These accidents, considered incredible because of the stringent quality control requirements imposed on the manufacturing, included:

1. Incorrect ^{233}U content in a large number of fuel pellets.
2. Incorrect positioning of fuel pellets in a large number of fuel rods.
3. Incorrect positioning of a large number of fuel rods in the seed or blanket fuel assemblies.
4. Incorrect loading of the seed or blanket fuel assemblies into the reactor vessel (i.e., a complete seed or blanket fuel assembly installed upside down).

Although the analyses indicated that the core would be subcritical throughout the initial fill, safety precautions were incorporated into the fill concept to prevent an unexpected nuclear excursion.

A slow feed rate, with the capability of stopping the inlet water flow and removing water from the vessel, was selected as the initial fill technique. This method consisted of introducing demineralized water at a temperature of approximately 75 to 100 F into the reactor vessel at a flow rate of 5.0 ± 0.1 gallons per minute, while an independent, continuously operating, recirculating pump circulated the water in the vessel at approximately 15 to 20 gallons per minute. The fill system had the capability to stop the inlet flow, either manually or automatically, and the recirculation system could redirect the water flow to provide for draining the vessel, also either manually or automatically. This system of a slow fill rate, with the capability of stopping the fill and draining water from the vessel to provide for negative reactivity insertion in the event of some unexpected nuclear excursion, was more desirable than other systems such as boron injection or cocked (partially withdrawn) movable seed fuel assemblies.

Both of the alternate systems had undesirable features from a nuclear safety and operational standpoint. Boron injection would initially cause the water level in the core to rise and, if the core were only partially covered, the immediate result would be a net increase in core reactivity. The effectiveness of the boron would be delayed until it became well mixed with the water surrounding the core. In addition, residual boron would remain in the core during hot operations and would reduce the breeding capability of the reactor.

Cocking the seed fuel assemblies (raising the movable seeds to provide a negative reactivity capacity, obtained by scramming the partially raised fuel assemblies) was undesirable because it too would cause the water level in the partially filled core to rise due to the large volume of water displaced as the seed fuel assemblies were lowered. The decrease in reactivity resulting from lowering the seeds would be partially offset by the reactivity increase resulting from the water level rise. A dry scram of the movable seed fuel assemblies would also cause severe damage to the fuel assembly structurals, since the core design requires a water buffer on the seed balance piston to prevent unacceptable shock loads on the fuel assemblies during a scram.

The neutron power levels of the core were continuously monitored during the initial fill using the core nuclear instrumentation system neutron detectors. The natural source level for the moderated LWBR core (including multiplication) was estimated to be approximately 2.2×10^7 neutrons/second. With this source level and the reactor vessel filled with water, the signal from the source range detectors was predicted to be only 0.1 count/second above the normal background of 0.3 count/second. This signal is one decade below the indicating range of the nuclear instrumentation. In order to monitor the neutron flux throughout the initial fill, it was desirable to obtain a minimim count rate of approximately 10 counts/second throughout the fill process. This was accomplished by using three neutron sources temporarily placed within the LWBR core to increase the base value of the neutron flux to above the threshold of the nuclear instrumentation system source range detectors.

The neutron sources consisted of three capsules of Californium-252 (Cf^{252}). Each capsule contained approximately 117 micrograms of ^{252}Cf encapsulated in two concentric high integrity stainless steel sleeves. The overall dimensions of the source capsule were approximately 0.118 inch diameter by 1 inch long. The capsules were inserted and removed from the core using titanium sheath extenders. Information on the Californium sources is given in Table H-II.

The sources were inserted into the LWBR core through three of the flux thimble penetrations. These penetrations run from the instrumentation bosses on the mechanism ports, through the closure head and through a guide path in the blanket fuel assembly, to near the bottom of the blanket fuel assembly fuel rods. The flux thimble penetrations passing through the three center (Type I) blankets were selected for source insertion.

The subcritical neutron level of the assembled core was then monitored by the nuclear instrumentation system (with the artificial neutron sources providing the necessary additional neutron flux) throughout the initial fill. The

TABLE H-II. DESCRIPTION OF THE NEUTRON SOURCES USED FOR LWBR INITIAL FILL

Type of Source:	Neutron
Isotope:	Californium-252
Chemical Form:	PD-Cf_2O_3 cermet

Source Identif. No.	Amount of Isotope*	Emission Rate*
MRC-Cf-76	117.7 μgm (107.4 μgm)	2.71×10^8 n/sec (2.47×10^8 n/sec)
MRC-Cf-77	116.1 μgm (106.0 μgm)	2.68×10^8 n/sec (2.44×10^8 n/sec)
MRC-Cf-78	117.5 μgm (107.2 μgm)	2.71×10^8 n/sec (2.47×10^8 n/sec)

*Based on assay of the finished assemblies taken on 12/4/76.
Numbers in parentheses are calculated values for the date of actual usage on 4/20/77.

fill piping was constructed so that if an approach to criticality was detected, the fill could be terminated by an automatic trip energized by the nuclear instruments or by direct operator action before criticality was reached. The recirculation pump would then be changed to further reduce the reactivity level of the core by removing water from the vessel after fill was terminated.

The recirculation system consistently pumped less than anticipated, postulated to be the result of entrained nitrogen gas in the water as a result of the nitrogen gas purge on the vessel. However, the flow rate was adequate to assure reactor safety during the filling of the reactor.

V. SUMMARY

Analyses of the reactivity of the LWBR fuel assemblies throughout the LWBR installation operations indicated that a significant shutdown margin existed throughout the LWBR installation operations. In addition, a shutdown capability existed even if two highly unlikely accidents (such as dropping a fuel assembly and flooding the assembly with water) occurred simultaneously. The single most important operational control that was exercised during the LWBR installation to maintain a significant shutdown margin of the fuel was the restriction on introducing water to the fuel assemblies. This was apparent in the isolation of water sources from the vessel during the receipt, storage, and installation of the LWBR seed and blanket fuel assemblies, and in the method of maintaining a controlled fill of the reactor vessel with water, combined with a capability to quickly reduce reactor water level in the event of an approach to criticality.

The installation of LWBR was performed without a single incident compromising the nuclear safety of the operations, and none of the contingency emergency procedures had to be employed.

APPENDIX I

TRIAL ASSEMBLY OF LWBR COMPONENTS

I. INTRODUCTION

An extensive program for preassembly of the reactor components was performed as part of the Light Water Breeder Reactor (LWBR) installation. This program used the actual components, mating them to their corresponding components, to evaluate their as-built interfaces. Since the LWBR is a prototype reactor, the trial assembly was performed to identify at an early stage any modifications that were needed to eliminate minor interferences or to make the actual assembly operations easier and more reliable. The trial assembly program achieved this and was an important factor in the general efficiency of the LWBR installation. Most of the trial assembly operations occurred on the LWBR core barrel (during its assembly in the clean room) or on the closure head (during its storage within the Fuel Handling Building).

In most cases, the trial assembly disclosed no problems in the mating of components or in the installation equipment. There were, however, several instances where an interference of components occurred. Determining the interferences ahead of the final installation permitted evaluating the problem, identifying a solution, and in some cases, modifying the components without impacting the installation schedule.

The trial assembly served other useful purposes in addition to checking component clearances. It allowed checking out the installation equipment within the actual space restrictions. It also helped familiarize personnel with the use of the equipment and permitted the development of assembly practices not identifiable when performing training on the mockup facilities.

Table I-I lists the major reactor components that were trial assembled. Included in the table are the interfaces which were checked and a description of the trial fit results. Section II further describes some of the important interferences that were discovered during this period.

TABLE I-I. SUMMARY OF LWBR TRIAL ASSEMBLY OPERATIONS

Item Trial Assembled (Quantity)	Mating Component	Reason for Trial Assembly	Evaluation of the Operation
Blanket Module Stub Tubes (12) and Reflector Module Stub Tubes (15)	Core Barrel Bottom Plate	Ensure that the stub tube (which forms the bottom of the assembled fuel assembly) would enter the mating cavity in the bottom plate during fuel installation.	Disclosed an interference of one blanket stub tube with the bottom plate cavity requiring modification of the core barrel. (see text)
BIF Supply Tubes (6)	Core Barrel	Ensure the alignment of the support brackets on the inside of the upper and lower core barrels with the penetration in the bottom plate.	No fit up problems. The load reductions that occurred as the supply tubes passed through the spring-like support brackets were recorded and factored into the installation procedure.
Reflector Modules (15)	Core Barrel	Ensure the availability of an adequate space envelope for the blanket fuel assemblies based on as-built conditions (caused by concern of bowing of the suspended reflector fuel assemblies infringing on the blanket space).	The measured space envelope was adequate. A small amount of rotation of the reflector seal blocks was detected, not enough to intrude into the required space envelope for the blanket fuel assemblies.
Holddown Barrel (1)	Core Barrel and the Installed Reflector Fuel Assemblies	Ensure proper alignment of the holddown barrel bearing pads with the reflector blocks when the holddown barrel was keyed to the core barrel.	No alignment problems. The as-installed clearances between the holddown barrel and reflectors, and reflectors and seal ring, were recorded and factored into the holddown barrel installation procedure to provide the correct preload on the reflector support springs.

TABLE I-I. (Cont)

Item Trial Assembled (Quantity)	Mating Component	Reason for Trial Assembly	Evaluation of the Operation
CDM Motor Tubes (12)	Closure Head Mechanism Ports	Ensure alignment of omega seal halves on the motor tube and mechanism port, and ensure the seal clearances qualified during "qualification welding" would be sufficient.	No alignment problems.
CDM Stators (12)	CDM Motor Tubes (as-installed on the closure head)	Identify alignment difficulties of the stator cooling water lines and electrical connection support blocks with adjacent stators.	No alignment difficulties encountered following precise rotational orientation of stators; stators were match-marked to motor tubes to provide same alignment at final installation. Other problems encountered: 1) Inadequate clearance between stator inside diameter and motor tube outside diameter (see para. II.B). 2) Inaccessibility of cooling water connections, leading to identification of leaking braze joints. (see para II.C). 3) Five non-functional portions of stator winding holding wedges found deformed during trial fit. No other damage found. Deformed portions of wedges were removed.

TABLE I-I. (Cont)

Item Trial Assembled (Quantity)	Mating Component	Reason for Trial Assembly	Evaluation of the Operation
Breechlock Sleeves (12)	Closure Head Suspension Sleeves	Ensure concentricity of the breechlock sleeve with the closure head suspension sleeve for subsequent compression sleeve installation.	No problems encountered.
Service Lead Support Structure (SLSS) (1)	Closure Head and Reactor Chamber Dome	Ensure clearance of the structure with the installed motor tubes and stators. (Also permitted prefabrication of electrical cables and stator cooling water piping using the installed components.)	Disclosed minor installation problems of the SLSS on the closure head. Disclosed small interference of the top of the SLSS with the reactor chamber dome, resulting in modification of the top platform.
Thermocouple Terminal Boxes	Instrumentation Bosses on Closure Head Mechanism Ports	Ensure clearance of boxes with the CDM stators.	Required modifying some of the terminal boxes to permit their installation over installed BIF pressure tap piping. Disclosed need to fabricate special wrench to install mounting screws because of access difficulties.
CDM Translating Assemblies and Tie Rod Nuts (12)	Seed Fuel Assembly Balance Piston	Ensure seating of the translating assembly and nut within the balance piston recess.	No fit up problems encountered. One instance of incorrect orientation of a balance piston on a seed support shaft was detected and corrected.

TABLE I-I. (Cont)

Item Trial Assembled (Quantity)	Mating Component	Reason for Trial Assembly	Evaluation of the Operation
BIF Port Plugs (6)	BIF Ports on the Closure Head	Ensure alignment of omega seal halves on the BIF plug with the closure head BIF port, and ensure the seal clearances qualified during "qualification welding" would be sufficient.	No problems encountered.

II. DESCRIPTION OF THE ASSEMBLY PROBLEMS DISCLOSED BY THE TRIAL ASSEMBLY PROGRAM

A. Discrepant Hexagonal Cavity in the Core Barrel Bottom Plate

During the assembly of the LWBR core barrel, each of the twelve blanket module and fifteen reflector module stub tubes were fitted into their assigned cavities in the core barrel bottom plate at SAPS. (The trial assembly occurred before the stub tubes were assembled to the blanket or reflector fuel assemblies). The purpose of the trial assembly was to ensure adequate clearance of the stub tube with its mating cavity in the core barrel, since any interference occurring during the actual fuel installation would have caused significant delays and great difficulty in resolving the problem. During the performance of this trial fit operation, the stub tube could not be installed in the core barrel bottom plate at the I-2 blanket location. The discrepancy was determined to result from incorrect machining of three of the six corners of the hexagonal cavity. In the bottom plate two of the diagonal measurements were 0.012 inch undersize and the third was 0.026 undersize. Repair was accomplished by hand-grinding the three corners to within the correct tolerance.

B. Undersized Bore on the Control Drive Mechanism (CDM) Stators

Following the trial installation of the CDM motor tubes on the closure head, the Water Jackets Assemblies (WJAs) were installed to resolve any uncertainties concerning the close clearances between adjacent WJAs. The first three stators were installed without problem. However, during installation of the fourth WJA at the II-2 location motor tube, the allowable load decrease was obtained but the WJA was approximately 1 foot from seating. The WJA was removed and an inspection of the stator bore, lower water jacket bore and motor tube diameter was performed, disclosing mild galling of the mating surfaces. Micrometer measurements of the bore on this WJA, and the remaining uninstalled WJAs, were obtained, which indicated that a portion of the lower water jacket bore diameter was distorted resulting in a local undersized condition in the range of 0.003 to 0.009 inch on the 13.450-inch diameter. The distortion was postulated to have occurred as a result of room-temperature stress relief in the copper-nickel water jacket material and had resulted in the bore going out-of-round. A portable honing machine was set up to hone the lower water jacket bores on-site to provide the required clearance with the motor tubes. Subsequent installation proceeded without incident.

C. Inaccessibility of the Stator Cooling Water Connections

After all twelve Water Jacket Assemblies (WJAs) were trial assembled to the closure head and motor tubes, it was determined that the cooling water connections on the inner three mechanism locations were inaccessible for attaching the cooling water lines. This was resolved by fabricating extensions to the lines on the WJAs and, following the removal of the WJAs, brazing the extensions onto the existing lines.

Following the brazing of the extensions on these three WJAs, a hydrostatic test was performed to ensure the integrity of the new brazed joints. The testing resulted in leakage of previously made brazed joints integral to the assembly. These joints had been brazed during WJA manufacture and had been untouched during the attachment of the extensions. As a result a hydrostatic test was performed on the brazed joints of the other nine WJAs. Leakage was found on four of the 12 WJAs. However, the long-term integrity of the braze joints on the non-leaking WJAs was questionable, and all joints on all twelve WJAs were rebrazed. Following the repair of the WJA cooling water line joints, hydrotesting produced no further leaks.

An investigation of the cause of the leakage in the brazed joints disclosed six factors which contributed to the failure. The following list identifies these factors and the corrective actions taken.

1. The alloy used, BAg-1, had a 20 F differential between melting and flowing temperature. Changing to alloy BAg-3 provided a 100 F differential band, making proper temperature control during brazing not quite so dependent on operator skill.
2. The brazing alloy was face fed. Changing to preplaced brazing inserts enhanced the probability of making good joints for three reasons: (a) it became possible to accurately measure and install the required amount of brazing alloy. (b) The operator could readily determine that a joint had been properly heated when the melted brazing alloy become visible at the fillet region. (c) The higher nickel content of BAg-3 makes it less susceptible to interface corrosion when brazing to stainless steel.
3. There was inadequate post-brazing nondestructive examination of the degree of bonding in the original brazed joints. X-ray examination of the original brazed joints had been conducted but was inadequate to detect poor bonding. An ultrasonic examination procedure was developed which gave assurance that adequate bonding existed.

4. The original brazing procedure provided inadequate brazing flux removal. The temperature of the water flush was increased, from 160 F minimum inlet to 160 F minimum exit temperature, the flow rate increased to 1 ft./second, and the time period for the flush increased to 60 minutes minimum from 20 minutes minimum.
5. The mockups used to qualify the brazing procedure and personnel were not representative of the restricted access or mass of the stainless portion of the joints. The mockups used for qualification of the procedure and personnel for rebrazing of the joints simulated the severely restricted access and mass of the actual joints.
6. Copper Tube and Type 304 Stainless Steel, are Difficult to Braze. Brazing of these materials to each other should be avoided.

III. SUMMARY AND CONCLUSIONS

The trial assembly of the LWBR components permitted resolving minor assembly difficulties before attempting the final installation on the reactor, resulting in no delays on the installation schedule. In some cases, such as the discrepant cavity in the core barrel and the out-of-round Control Drive Mechanism Water Jacket Assemblies, significant delays in the installation effort would have occurred had the problems not been identified until actual installation.

A trial assembly program is most useful when the reactor being assembled is a prototype unit, where uncertainties over the accessibility or clearances of the in-place components exist. When a trial assembly is desirable, the objectives of the trial assembly should be clearly defined at its beginning and the schedule should allow time for the resolution of unexpected problems.

APPENDIX J

SUMMARY OF THE PROBLEMS ENCOUNTERED DURING THE LWBR INSTALLATION

APPENDIX J

SUMMARY OF THE PROBLEMS ENCOUNTERED DURING THE LWBR INSTALLATION

I. INTRODUCTION

The LWBR installation occurred without any problems that presented a hazard to personnel or the environment. The problems that were encountered consisted of equipment malfunctions and necessary changes to the design of the reactor components that resulted in a delay of the installation schedule. By identifying the problems encountered during the LWBR installation, it is hoped that the experience gained will prevent occurrence of similar problems in other refuelings. The problems are described in the approximate order of their occurrence during the final assembly operations. Additional problems and deficiencies were encountered during the preinstallation trial assembly, and those difficulties are described in Appendix I.

II. DESCRIPTION OF PROBLEMS

A. Problem 1 - Modifications to the LWBR Core Barrel during Its Assembly

Delays to the core barrel assembly were caused by several design changes that occurred after the components had been released by the manufacturer. These changes, which were identified from the extensive testing and analyses of prototypes and models of the LWBR, required the development of special equipment in an expeditious manner, and in some cases required disassembling assembled components which significantly lengthened the period of core barrel assembly. Most of the modifications were performed on the components in place in the partially assembled barrel. These design changes included:

1. The addition of a 45 degree chamfer around the entire circumference of the lower core barrel bolting flange. The chamfer was required to eliminate a potential interference between the Belleville spring and the bottom outside corner of the flange. The potential interference during core operation was determined from clearance studies performed after completion of the lower barrel fabrication. Portable power grinding equipment was mounted on the flange and traversed around the barrel to provide the chamfer.

2. The addition of a 0.030 inch by 45 degree chamfer on the core barrel bottom plate blanket flow meter holes. During full-size module flow tests performed at Bettis, a 2500-3000 Hz audible noise was noted; the noise was traced to the blanket flow meter and found to be caused by the flow going through the modified venturis and passing by a 0.090-inch diameter hole connecting the venturis to the pressure tap manifold. The noise was eliminated by machining a 0.030 inch by 45 degree chamfer on the downstream edge of the 0.090-inch diameter hole at its point of intersection with the modified venturi. This same modification was then applied to the 128 pressure tap holes in the LWBR core barrel. Access to the 0.090-inch holes was through the approximately 1-inch diameter flow meters.

   The chamfers were applied by using an industrial adaptation of an angle head "dental drill" driving a formed cutting tool (45 degree tapered burr) into the pressure tap holes. Special fixturing and tooling was designed and built to accurately position and locate the cutting tool. In addition, a special gage was made, attached to a borescope and used to accurately measure the applied chamfer.

3. The addition of support brackets for the Safety Injection System fill tubes in the upper core barrel. A review of flow induced vibration, performed subsequent to the assembly of the upper barrel, showed a need for additional support of the fill tubes to prevent possible vibration during in-core service. The need for the additional supports was further confirmed by flow testing of a mockup of the fill tube-to-seal ring joint, as well as natural frequency measurements performed at Shippingport on the fill tubes as installed on the upper core barrel. Two additional H-shaped brackets were welded to each of the three fill tubes and to the inside diameter surface of the upper barrel. One of each set of brackets was located approximately 3 inches above the tube-to-seal ring joint and the second approximately 17 inches above this joint. This additional work on the barrel assembly required an expedited effort in the design and procurement of the brackets and development and qualification of a welding procedure as well as the qualification of the welders.

4. Enlargement of the BIF supply tube penetrations in the vibration damper support brackets located in the upper core barrel. Subsequent to the installation of the upper barrel on the lower barrel, a design change was made to increase the 4.400-inch diameter penetations in the upper

barrel vibration damper support brackets by approximately 0.080 inch to provide additional clearance for insertion of the BIF supply tubes.

This effort was accomplished with the use of a specially designed portable boring machine which was mounted on the top flange of the upper barrel with a boring bar extending down to and supported from the brackets. With this equipment, the penetration diameters were successfully increased in the six brackets.

5. Modification to the filler units. Reviews and studies relative to reflector bowing during core operation, performed subsequent to initial installation of the filler units, resulted in a design change to the as-built fillers to provide additional clearance. The modification effort required that the units be removed from the barrel assembly, shipped to a vendor's plant for machining of the inboard faces, returned to Shippingport and reinstalled into the barrel assembly. As a result of dimensional instability of the units during the machining operations, two of the units failed to satisfy the required space envelope when reinstalled. One unit was removed and returned to the vendor for further metal removal, and the second unit was reinstalled using a tapered shim under its support flange to provide a satisfactory space envelope. The filler unit modification program was a major effort that required approximately 10 months to complete. Performing the machining of the units at the vendor facility presented its own difficulties, in that the residual stresses in the filler units and bowing of the units caused unexpected dimensional changes. This is discussed in Problem 2.

B. Problem 2 - Machining the LWBR Core Barrel Filler Units

The original machining of the core barrel filler units did not provide the required enlarged space envelope for the reflector assemblies because of the instability of the filler units. This instability was caused by two conditions: (1) residual stresses in the filler unit which, when metal was removed during machining, caused warpage of the unit, and (2) the method of attachment of the units to the core barrel which caused flexure of the filler units upon installation. The filler units are 304 stainless steel slabs, approximately 24 inches wide and 130 inches long. The unit cross-sections varied according to type, with the Type VI and Type VII units having the smallest thicknesses (1.803 inch maximum and 2.313 inch maximum, respectively). This small thickness-to-length ratio contributed to warpage of the units following machining and alteration of the residual stresses. The warpage was further compounded by the method of attachment of the filler units. Each unit is suspended by a support flange protruding from the back of the unit near the top, and the lower end is radially located within the core barrel bottom plate by a tab at the base of the filler unit engaging a clearance slot in the bottom plate. The support flange, which supported the entire weight of the filler unit, produced a bending moment on the filler unit which, depending on the acting direction of the residual stresses, either added to or reduced the warpage incurred from machining. During machining at the vendor facility, each unit had to be machined in a series of small increments. Following each increment, the filler unit was supported in a vertical position and its face was mapped relative to a reference surface to determine the next area to be machined. This procedure was repeated numerous times for each of the 15 filler units, resulting in the machining operation on each filler unit requiring over one week to complete.

C. Problem 3 - Installation of the Test Head O-Rings

Sealing the gap between the hydrostatic test head and reactor vessel during the preconditioning and filtering evolution was accomplished using two large diameter O-rings, instead of welding as is used for the LWBR reactor assembly. Installation of two silver-plated self-energizing O-rings into the existing machined grooves in the reactor vessel flange was attempted, but the O-rings could not be seated and appeared to be oversize. Tape measurements, however, confirmed the size of the O-rings, and a second installation attempt resulted in their seating, after shrinking the overall diameter by chilling the O-rings with dry ice. Upon rewarming to ambient temperature, however, the O-rings sprung from their grooves. These O-rings were eventually removed and replaced with two spare nonplated gas filled O-rings procured for the original filtering of the Shippingport plant in 1957. These spare O-rings were seated in the vessel flange grooves without problem.

The seating difficulty encountered with the self-energizing O-rings was attributed to deviations from true flatness and roundness. This condition was further aggravated by the method of installation not conforming to current design practice in that retaining clips to hold the O-rings in the grooves were not provided.

D. Problem 4 - Seating of the LWBR Core Barrel

Following insertion of the LWBR core barrel into the reactor vessel, three clamp-like seating devices were attached to the core barrel flange to fully seat the core barrel. These devices were necessary to fully compress the Belleville spring, which supported the barrel on the thermal shield, prior to initiating fuel installation. After tightening the barrel seating device bolts to the upper torque limit specified in the procedure, 500 foot pounds, barrel seating was questionable. After a review of the seating device allowable loading, the procedure was revised to require retorquing the seating device bolts to 1,200 foot pounds. However, seating dimensions did not greatly decrease at the higher torque values, and the seating measurements indicated the barrel was still not seated in one axis. The data were reviewed and found acceptable based on the fact that the gap was sufficiently small and probably caused by the flatness tolerance on the vessel and barrel mating surfaces.

E. Problem 5 - Excessive Acceleration of two Reflector Assemblies during Shipment

During coupling of the highway tractor to the reflector shipping semi-trailer, the allowable acceleration on two reflector assemblies was exceeded.

The coupling method was initially in accordance with common trucking practice; that is, the tractor was backed under the raised end of the semi-trailer until the fifth wheel lock engaged. During trial shipment using fuel and reflector assembly mockups, no discrepant accelerations were noted. However, during two couplings for two reflector shipments, excessive accelerations occurred.

The first discrepant acceleration occurred during coupling of the trailer and tractor prior to shipment of a type V reflector assembly. The tractor could not get sufficient traction because of ice on the driveway and there was a sudden acceleration during coupling. The Allowable Dynamic Acceleration Limit (ADAL) of 0.84 g in the longitudinal direction was exceeded with a value of 1.96 g maximum. A hydraulic coupling device was subsequently used so that the tractor power was not used during coupling.

The second discrepant acceleration occurred during coupling of the tractor and trailer for shipment of the fifth reflector. The lateral ADAL of 0.84 g was exceeded with a value of 1.4 g. The tractor was being coupled to the trailer with the hydraulic device. The incident resulted because the tractor was not adequately aligned with the trailer. As the slanted plate on the tractor (fifth wheel) engaged the mating piece on the trailer, a lateral load was gradually applied to the dolly (the front supports of the trailer). These lateral forces built up as the tractor was pulled under the trailer until the lateral load exceeded the frictional forces resulting in a sudden shift in the front of the trailer. Subsequent tests demonstrated that such lateral loading would not occur if misalignment of tractor and trailer was no greater than one inch. The procedure was revised to require this degree of alignment before beginning the coupling of the tractor and trailer.

The problems could have been avoided had the tractors been coupled to the semitrailers before the reflector assemblies were loaded. However, space within the Core Module Assembly Area (CMAA) garage was limited so as to exclude the tractor, and for security reasons the fuel and reflector assemblies were loaded in the garage area of the CMAA.

The two reflector modules were considered technically adequate since the results of the reflector grid shipping tests indicated that loads at least as high as 2.56 g were acceptable. This was a margin of 3.1 times the ADAL of 0.84 g. Therefore, the margin even with a 1.96 g load is conservatively 1.31.

F. Problem 6 - Blanket Seating Dimensions

Seating dimensions taken for one of the blanket fuel assemblies did not agree with procedure requirements and, therefore, seating could not be verified. An engineering evaluation of the seating dimensions revealed that the tolerances specified by the procedure did not take into account the barrel bottom plate deflection as the bottom plate was loaded. Based on data taken from previous blanket installations and calculated bottom plate deflections, the procedure was revised to incorporate this additional data.

G. Problem 7 - Blanket/Reflector Leveling Stand Malfunctions

On several occasions, malfunctions of both the eddy-current sensors and voltmeter readouts occurred. Each sensor used for leveling a particular module was either checked out or calibrated prior to the start of the leveling operation. Location of a precisely positioned stainless steel gage plate was determined to indicate sensor/readout operability. Readout malfunctions included failure to respond to the gage plate in front of a sensor, incorrect readings during calibration, and readouts of low intensity. Also, one of the readout sensors during the checkout process began to heat up and smoke. Causes of the mentioned failures were loose or frayed cable connections, temperature variations in the Fuel Handling Building, inadequate readout ventilation, or readout internal failures. These problems were alleviated by tightening or replacing the interconnecting cables and replacing the malfunctioning sensor readout. Spares were available for readout replacement and all malfunctioning readouts were shipped to the vendor for repair. The readout with inadequate ventilation, resulting in overheating, was caused by a nylon reinforced PVC containment designed to prevent uncaptured parts from falling into the reactor pit. The PVC containment was removed and the readout parts were adequately captured by other means.

H. Problem 8 - Compression Sleeve Installation

After installation of the first compression sleeve in location III-3, it was noted that its seated dimension was out of the tolerance band specified by the installation procedure. A similar condition occurred upon installation of the second compression sleeve at the III-4 location.

The compression sleeve seating dimension is important since it is a measure of the compression of the Belleville spring located between the bottom of the compression sleeve and the seed buffer cylinder. The spring deflection is important in that the functional requirement for maximum spring deflection is that the system should not go solid which could reduce the preload between the blanket support tube and the suspension sleeve. On the other hand, the functional requirements for minimum spring deflection are to prevent excessive flow leakage from the BIF flow, to prevent upward travel of the buffer cylinder, and to provide suspension system flexibility to accommodate differential thermal expansion and hydraulic deflections during core operation.

The procedure seating range was based on as-built measurements taken during module and suspension system trial fit operations and adjusted for actual dimensions and preloading. However, the assembling of the individual component dimensions resulted in a seating range somewhat higher. This difference was judged to be a result of an accumulation of small dimensional errors and variations which were additive when the components were actually assembled together. Therefore, it was decided to install spacers between the compression sleeve flange and the breechlock sleeve to ensure that spring bottoming would not occur. This required procedure revision and removal and reinstallation of two installed compression sleeves to install the spacers.

I. Problem 9 - Holddown Barrel Compression Discs

Holddown discs for the holddown barrel were designed to be machined to length, based on the as-built height of the installed holddown barrel, to ensure proper compression of the reflector module support springs. As-built measurements were necessary to ensure that accumulation of tolerances did not permit the reflectors to be clamped either too loosely or too tightly in the core barrel when the LWBR head was in place.

After the holddown discs had been machined to length and installed, they were visably shorter than expected. A recheck of the method of calculating the lengths disclosed that a recess in the LWBR head had been overlooked in the calculation of the length of the discs. Spare discs were machined to the recalculated length and installed.

J. Problem 10 - BIF Low Pressure Tap Insertion

When the BIF low pressure taps were trial fit in the closure head with the head installed on the vessel, the low pressure tap for the location III-2 mechanism port would not enter the penetration in the closure head. Measurements of the length of the pressure tap that had been inserted indicated that the restriction was in the instrumentation spacer inside the mechanism port. Since the breechlock sleeve and compression sleeve had already been installed in the port, removal of the instrumentation spacer for modification would have resulted in a significant delay. This was resolved by procuring a smaller diameter low pressure tap for this location. It should be noted that during a trial fit program at the closure head manufacturer's plant, a thermocouple mockup (approximately 0.070-inch diameter) was used to check both the thermocouple and BIF low pressure tap passages. Since the design diameter of the BIF low pressure tap is approximately 0.103 inch, the trial fit at the vendor was not adequate. It should be noted that the vendor performed the trial fit to specification.

K. Problem 11 - Neutron Source Insertion for LWBR Initial Fill

During the performance of the procedure to install the Californium-252 sources into the flux thimbles in the LWBR head, the mockup sources could only be inserted a fraction of the required distance. In addition, it was noticed that the amount of force required to insert the source built up gradually as the source went deeper into the flux thimble. An attempt to install another mockup source also failed. All mockup sources were checked to determine if they were within tolerance and were found acceptable.

During welding of the flux thimbles into the LWBR head, a review of the tolerances on the openings in the flux thimbles and the length and outside diameter of the sources had been conducted. Some distortion of the flux thimbles was apparently caused by weld shrinkage. The weld shrinkage was postulated to be the result of the very large mass of the head relative to the flux thimbles, and to the restricted access during welding, which was not adequately simulated during development of the welding procedure. Subsequently, openings in all of the flux thimbles had been enlarged about 0.005 inch to provide theoretical diametral clearances of 0.010-0.014 inch.

An insertion adapter attached to the flux thimble, with tygon tubing attached to the outer end of the adapter, had been used to pass the source through the flux thimble. The adapter contained an approximately 90-degree bend with a 7-inch radius. When the insertion adapter was removed, it was observed that the sheath extender (a cable fastened to the source, to move the source in the flux thimble) was kinked in numerous places. The gradual buildup of force encountered when manually inserting neutron sources into the LWBR head was caused by the tendency of the sheath extender to bend into short sine waves within the tubing, causing an increasing number of contact points with corresponding increased frictional loading. This condition was aggravated by the numerous kinks in the vendor supplied sheath extenders to the point where sources could not be fully inserted. This condition was also aggravated by the source insertion adapter design which allowed the sheath extender to bunch up in the larger ID tygon tube window, due to the bends in the sheath extenders. Manual insertion of the sources into the LWBR head was successfully accomplished after the sheath extenders were manually straightened and a revised insertion adapter installed. The revised insertion adapter deleted the use of the tygon tubing and connected directly to the flux thimble port which prevented sheath extender cable binding. New sheath extenders were provided on the sources and the kinked sheath extenders discarded.

L. Problem 12 - Axial Flux Measurement System

The assembly and checkout of the LWBR Axial Flux Measurement System (AFMS) resulted in problems associated with the tubing components of the system. The system is comprised of eight tube paths connecting the flux thimble tubes to drive tables located in the auxiliary chamber. To ensure proper passage and operation of flux wires in the tubing runs, a dummy source and test flux wires were inserted as probes through each tubing length to check for resistance to insertion. In each tubing run, resistance and probe stoppage occurred. Disassembly of the tubing, joint by joint, revealed in many cases the tubing beneath the ferrule fittings was constricted, caused by overtorquing the fittings. General kinking in the tubing lines as well as misalignment of tubing sections were found to cause probe resistance. To correct these situations, new tubing runs were fabricated and field fitted to replace all kinked tubing sections. Tubing joints were reworked to open up the tube inner diameter beneath the ferrule fittings. Also, careful realignment of tubing sections while using a probe was performed to prevent any offsets that might occur in the lines at the joints. Much of one tube was replaced to eliminate unnecessary bends.

It is noted that free passage of flux wires would be aided by avoiding multiple, close spaced, small radius tubing bends, minimizing the number of tubing fittings, minimizing torque requirements for the fittings, and replacing kinked tubing runs rather than attempting manual straightening or use of a tube straightener. Probes which are oversized are very useful in determining constrictive areas through the tubing runs. The probes (cables, sheath extenders, and wires) must be handled with extreme care to avoid kinks and bends which have a drastic effect on the drag, and therefore, the force required to drive them. If any probes are straightened, they should be remeasured since the straightening process lengthens the probes, making position indication incorrect.

III. SUMMARY

The problems that occurred during the LWBR installation were of various causes, with most resulting from dimensional errors incurred during the design or manufacture of the individual components. Most of these dimensional problems might be prevented from recurring by using an intensive program of controls on the design, fabrication, and inspection of the reactor components to ensure the critical interface dimensions of mating components are correct. Other problems, such as the malfunctions of the leveling station or the checkout of the Axial Flux Measurement System, resulted from the in-service operating conditions. These conditions cannot always be identified by the designer. Preventing their recurrence can only be done by applying the experience gained from these problems.

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