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A Chronology of the Beryllium-Replacement Shutdown at the High Flux Isotope Reactor

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The overall planning of the beryllium-replacement shutdown was performed primarily by G. A. Bowden, C. D. Cagle, B. L. Corbett, G. R. Hicks, E. L. Hutto, R. V. McCord, K. H. Poteet, L. P. Pugh, and E. F. Roy. The designing of special tools and jigs was done by Hicks, Hutto, and Pugh. Liaison with outside contractors was performed primarily by Bowden and Hicks. All of those mentioned above were involved in preparing procedures, check lists, etc. A. A. Abbatiello, a consultant engineer, assisted with solving the problem of the leak at the HB-1 adaptor flange.

DESCRIPTION OF THE HIGH FLUX ISOTOPE REACTOR

The High Flux Isotope Reactor (HFIR) is a beryllium reflected, light-water cooled and moderated, flux-trap-type production and research reactor which utilizes highly enriched uranium-235 fuel. The design power level of the reactor is 100 MW. The primary purpose of the reactor is to produce californium-252 and to provide irradiation facilities for the various experimenters at the Oak Ridge National Laboratory.

The reactor core consists of a series of concentric annular regions, each ∿2 ft high. A 5-in.-diameter hole forms the center of the core; the target holder, containing plutonium-242 and other transuranium isotopes, is placed in this center position where the thermal neutron flux level is $\sim 5 \times 10^{15}$ neutrons cm^{-2} sec^{-1}. (See Figure 1 in Appendix A.)

The fuel region is composed of two concentric fuel elements. The inner element contains 171 fuel plates, and the outer element contains 369 fuel plates. The individual fuel plates are 0.050 in. thick and consist of complex sandwich-type construction composed of U_3O_8-Al clad in aluminum. (See Figure 2.) The inner fuel element contains 2.8 g of boron-10, a burnable poison. The total fuel content of both fuel pieces is 9.4 kg of uranium-235. The reactor will operate at the design power level for 23 days before a fuel element is depleted.

The control plates, in the form of two, thin, poison-bearing concentric cylinders, are located in the annular region between the outer fuel and the beryllium reflector. The innermost cylinder is moved in the downward direction to increase core reactivity; and the outer cylinder, which is made up of four individual quadrant plates, is moved in the upward direction to increase core reactivity.

The fuel region is surrounded and reflected by a concentric ring of beryllium ∿1 ft thick; in the axial direction, the core is reflected by water. (See Figures 3, 4, and 5.)

The reactor primary-coolant-system flow rate is ∿17,000 gpm, and the system is pressurized to 650 psig. The flow is routed to the tube side of three heat exchangers; a portion of the flow from each heat exchanger is routed to letdown valves, which control the pressure, and on to a demineralizer system. The secondary coolant, which flows through the shell side of the heat exchangers, dissipates heat to the atmosphere via a four-bay induced-draft cooling tower. The 8-ft-diameter reactor pressure vessel is located in one of three interconnecting pools. (See Figures 1 and 6.)

BACKGROUND

During a routine inspection of the components in the reactor vessel in February of 1974, a few cracks were discovered in the permanent beryllium reflector. This component is the outermost of three reflector rings which surround the HFIR fuel element. The damage, attributed to the internal stresses caused by the buildup of helium in the crystalline structure of the beryllium metal, was not unique; however, the permanent beryllium was designed for a nominal life time of ten years. At the time the cracks were discovered, the reactor had been in service for 7.1 years with an accumulated energy of 235×10^3 MWd and with annual operating times of between 90% and 94%.

Due to the results of damage caused by neutron irradiation, the innermost of the three beryllium-reflector rings had already been replaced on three occasions: after exposure to fluences of 2.1×10^{22} nvt, 2.3×10^{22} nvt, and 3.6×10^{22} nvt ($E > 0.821$ MeV), respectively. The intermediate beryllium ring was replaced on one occasion after accumulating a fluence of 2.5×10^{22} nvt. The permanent beryllium was exposed to a fluence of 1.8×10^{22} nvt.

The two inner reflector rings were designed to be replaced with relative ease; whereas the replacement of the outer reflector ring presented a major operation that would require a complete disassembly of the vessel components, removal of the four engineering-test facilities (EF's), removal of the four horizontal-beam-tube facilities (HB's), and the coordinated effort of design engineers, numerous craft personnel, and Reactor Operations personnel. (See Figures 7, 8, and 9.)

In view of the difficulty of assessing the damage and the desire to avoid major cracking, it was decided to replace the permanent beryllium. Since there was no immediate problem relative to the safe operation of the reactor, the HFIR was operated at the design power level of 100 MW while preparations were being made for the beryllium replacement.

To ensure the safe operation of the reactor during the interim, special instrumentation was installed to alert the console operator to shut down the reactor if any abnormal condition developed that was conceivably a result of the cracked beryllium reflector. In addition, more frequent visual inspections of the permanent beryllium were initiated to monitor the propagation of the cracks. Before the replacement shutdown was begun, the cracking had become worse. (See Figures 10 through 13.)

INTRODUCTION

The preparations for the replacement of the damaged beryllium reflector included the writing of over 350 pages of procedures and check lists, the preparation of over 180 engineering drawings, and the design and fabrication of over 200 special tools and jigs that would be used to disassemble and reassemble highly radioactive reactor components underwater. Prior to the shutdown, the reactor operators were given special training in the use of some of the new tools using the reactor mockup.

The new beryllium blank, one of the largest pieces of beryllium ever manufactured, was fabricated in Ohio (at a cost of $88,500), machined in California, Ohio, and Florida (at a cost of $128,270), and subjected to a final inspection in Florida. The new engineering facility tubes, beam tubes, thimbles, and sleeves were fabricated in Massachusetts (at a cost of $41,300). The total cost of off-plant-site materials and fabrication for the beryllium-replacement project was $276,310.

In addition to the preparatory work, the general plan for the replacement of the cracked beryllium consisted of:

1. Removal of the reactor-vessel components.
2. Removal of the vessel head.
3. Removal of the four engineering-test facility tubes (EF's).
4. Removal of the four horizontal-beam tubes (HB's).
5. Removal of the cracked beryllium.
6. Inspection of the reactor vessel and its components by the Inspection Engineering Department.
7. Installation of the new beryllium reflector.
8. Installation of the new horizontal-beam tubes.
9. Installation of the new engineering-test facility tubes.
10. Removal and replacement of the beam-tube flow and pressure-monitoring lines.
11. Reinstallation of the reactor-vessel components.

12. Reinstallation of the vessel head.
13. Performing special hydraulic tests.
14. Refueling and starting up of the reactor.

Upon the completion of operating cycle No. 121 on June 3, 1975, the HFIR was refueled with a depleted fuel element so that the reactor could be operated for special testing purposes without achieving criticality. The purpose of these tests was to determine the performance of a new type of journal bearing which had been installed on one of the four control plates. After 24 hours of scramming the control rods from various withdrawn positions, the testing was terminated and the beryllium-replacement shutdown was begun (June 6, 1975).

Although a great deal of maintenance work was performed during the reactor shutdown, only that work directly related to the replacement of the damaged beryllium and other reactor-vessel components is included in this report. A list of the other jobs that were performed during the shutdown is given in Appendix B.

SHUTDOWN WORK

The duration of the beryllium-replacement shutdown was estimated to be 5 to 6 months; the actual time was 12 weeks and 3 days. The following is a chronology of this shutdown work.

June 6, 1975 through June 8, 1975

The disassembly of the reactor-vessel components was begun; those items not having excessively high radiation levels were placed in plastic bags and transferred to a flat-bed trailer for temporary storage outside the reactor building. This was done to alleviate an anticipated over-crowded condition in the storage pools and on the decontamination pad. To avoid a possible problem with relocating the many items placed in plastic bags, a tag and file system was initiated. The more radioactive of the components removed from the vessel were stored in the pool.

The initial disassembly of the vessel was relatively routine. The only problem of any significance encountered was with the removal of the lower tracks. Two efforts at removing the tracks, by different shift crews, were unsuccessful; however, since the tracks would not interfere with the removal of the damaged beryllium, further efforts at removal were abandoned at this time. Although this was a slight departure from the planned, sequential disassembly of vessel components, it presented no problem in the overall work plan. The problem with the lower tracks was resolved at a later date and will be covered in the sequence of events.

The vessel disassembly accomplished during the first week of the shutdown included:

1. Removal of the experiments and/or experiment-tube facilities (RB-7, VXF-7, VXF-10, and VXF-5). (See Figure 14.) A minor problem was encountered with the removal of the experiment tube in VXF-5; after hours of unsuccessful attempts to free the tube from the in-core facility, the efforts were abandoned temporarily. The problem was resolved by disconnecting the experiment tube from the vessel-head flange, VH-1, so that it would not interfere with the removal of the vessel head. During the following week, the vessel head was removed which improved access to the experiment tube in VXF-5; the tube was then removed successfully. At this time it was noted that the experiment tube was actually in VXF-4 instead of VXF-5; this accounted for the interference encountered while attempting to remove the tube.
2. Removal of the No. 5 control cylinder and the four control plates. The No. 1 control-plate coupling was reported difficult to operate; it was later inspected, found defective, and replaced.
3. Removal of the upper tracks and the semipermanent beryllium.
4. Removal of the southeast flow-distributor keeper post. The northwest keeper post could not be removed because of a binding problem with the port through the vessel head. This problem was resolved at the time by allowing the keeper post to remain installed until after the vessel head was removed.
5. Removal of beryllium plugs from VXF positions 5, 6, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22. The VXF-1 position contained a broken beryllium plug that could not be removed by the usual procedure; however, when the permanent beryllium was raised, the broken beryllium plug was removed by raising it from the bottom side.

6. Removal of the inlet strainer. Initially, this item was placed on the storage truck. However, the radiation level was too high (5 R/hr), and it was returned to the pool for storage underwater. Although one of the Allen screws securing the strainer was reported to be galled, this did not present any problems with the removal of the strainer. (NOTE: There was a slight deviation from the procedure at this point. The removal of the shock absorbers, scheduled early in the disassembly sequence, was postponed until after the other work in the vessel was completed.)

June 9, 1975 through June 15, 1975

The 44 vessel-head studs were removed and placed in boxes for storage. (To remove the nuts from the studs, the studs were stretched $\sim$0.015 in. using the bolt-tensioner tool.) Prior to storage, all the studs and nuts were subjected to ultrasonic testing for the detection of possible cracks. No abnormalities were detected.

The 14-ton vessel head was removed from the top of the reactor vessel. The radiation level of the vessel head was $\sim$230 mr/hr on the bottom side; this was attributed primarily to surface contamination.

The initial attempt at removing the stuck keeper post by connecting it to the three-ton crane resulted in a broken cable. (This was the cable used to connect the keeper post to the hook of the small crane. No problems developed as a result of the break.) When the vessel head was suspended over the decontamination pad, it was lowered slightly to allow the bottom of the stuck keeper post to come in contact with the floor; this forced the stuck keeper post up through the port in the vessel head. (See Figures 15 and 16.) The keeper post was decontaminated and sent to the shop for machining to correct the binding problem.

The vessel head was transferred to the storage truck. Prior to removal from the reactor bay, the vessel head was subjected to an ultrasonic test to determine if any cracks had developed. (See Figure 17.) No abnormalities were detected.

After the top head of the vessel was removed, the vessel top seal plate and work platform were installed; a gasket on the bottom side of the plate was designed to prevent water corrosion problems with the vessel's carbon-steel stud holes. (See Figures 18 through 21.) Some minor difficulty was encountered with one of the seal-plate holddown bolts; this problem was temporarily solved by installing a vessel-head stud until the holddown bolt was remachined on the following day.

To obtain some data on the compression of the Belleville spring (also referred to as Belleville washer) and to obtain a reference point when reinstalling components, the distance from the top of the reflector pedestal to the top of the Belleville spring was measured using a special gauging tool. (The Belleville spring fits over and around the outer shroud and secures the shroud to the "bird cage" section of the reflector container and pedestal assembly.) (See Figure 5.)

All but one of the 24 Belleville spring nuts were removed; one was galled. To resolve this problem a special tool was fabricated to drill the outside of the nut down to the threads of the stud; however, this proved unsuccessful. The nut and stud were both removed on the following day by repeating the normal procedure.

The Belleville spring and the outer shroud were removed from the vessel and placed in the east storage pool. A special in-pool storage rack had been constructed to accommodate these components. (See Figures 22 and 23.) The rack also allowed the outer shroud to be rotated 180^{o} to permit replacement of the underside gasket.

The RP-1 and RP-2 flanges were removed from the outer shroud (these are for pressure taps for the hydraulic data). Some minor problems with galling of the studs that secure these flanges were encountered.

After the outer shroud was removed, the top surface of the permanent beryllium was exposed and could be inspected. Four cracks on the top side were visible; two extended from the outer periphery of the beryllium to the inside surface and two extended from the periphery to two of the experiment holes. (See Figure 24.)

The two inlet-water flow distributors were removed from the reactor vessel and placed on the flat-bed trailer.

The backup clamps and the two-bolt Marman clamps were removed from three of the 4 engineering-test facilities, EF-1, 3, and 4; the 2 two-bolt Marman clamps were removed from EF-2. A bolt tensioner and a special clamp-separating tool were used for this operation. (See Figures 25 and 26.) The procedure called for lowering the reactor-pool water to gain access to the adaptor flanges; however, because of the radiation level, this was only done on one occasion. A minor problem with the removal of the EF-3 Marman clamp was resolved after the threads on the studs were chased. (During this in-pool work, a 2-in.-long clevis pin was dropped into the reactor vessel; it was retrieved at a later date.)

The face-shield plug was removed from EF-1 (in the experiment room) and temporarily replaced with a "pipe extension". The tube-adaptor plugs and the gaskets were removed from EF-1, 3, and 4. (NOTE: With the exception of EF-2, all the EF adaptor flanges and the HB tube adaptor flanges had backup clamps installed over the two-bolt Marman clamps. These auxiliary clamps were installed in 1970 when it was discovered that one of the 1-in.-diameter studs used to tighten the Marman flange on HB-1 had broken and fallen to the bottom of the pool. The break had occurred at a roll-pin hole that had been drilled in the wrong place. The EF-2 facility had 2 adaptor flanges, 2 two-bolt Marman clamps, a facility beam tube, an extension tube, a water-jacket tube, and an experiment; the EF-2 facility flanges did not have any backup clamps installed because of the lack of space.) (See Figures 27 and 28.)

The water-guide-sleeve tubes were removed from EF-1, 3, and 4; the EF-2 tube was removed on the following week. These tubes screw into a threaded connection which is welded to the bottom of the inside wall of the reactor vessel. The upper part of these 11 1/2-ft-long tubes terminates at the flange; the adaptor plug, used in EF-1, 3, and 4, fits inside the tube. To unscrew and subsequently disconnect the water-guide sleeve, a special 30-ft-long tool was designed to secure the inside of the tube using expandable rubber gaskets. To position this long tool, the two steel-plate panels were removed from the south and west walls of the reactor bay; and the "cherry picker" crane, positioned outside the building, was used to manipulate the tool. (See Figures 29 and 30.) A special in-pool work platform was made to allow the operators to manipulate the new tools for this operation. (See Figure 31.)

After the 11 1/2-ft-long water-guide sleeves were freed at the clamp connection, the tubes were withdrawn from the reactor vessel in increments.

After each withdrawal, the tubes were cut into ∿4-ft sections by holding a special pipe-cutting tool, in the pool, stationary while rotating the water-guide sleeve with the special holding tool in the experiment room. (See Figure 32.)

A 16-in. pipe extension was installed on the EF flanges in the experiment room during the removal of the sleeve; the extension served to guide the 30-ft tool and to prevent pool water from leaking into the experiment room when the water level in the reactor pool was raised.

The radiation level of a section cut from the EF-3 tube was ∿1 R/hr through ∿6 in. of water. The radiation level of the water-guide-sleeve tool was ∿15 R/hr at contact after this operation; this was primarily from cobalt-60 which contaminated the rubber expansion end of the tool. When not used, this tool was stored in the deep-well tool-storage pit.

After the sleeves were cut, the sections were placed on the floor of the reactor pool for temporary storage. A minor problem was encountered when the staff broke off the guide flange used during the cutting operation on EF-1. The tool, used to prevent the cut end of the tube from sliding back into the reactor, was repaired on the following day.

Measurements were made of the height of the beryllium reflector, relative to the top of the reflector container, to obtain reference points to be used during the reassembly procedure.

June 16, 1975 through June 22, 1975

The EF-2 shield plug was removed from the EF-2 facility and stored in the experiment room. The ionization chamber in EF-2 was disconnected and removed to the vault for storage. (See Figures 33 and 34.) The radiation level of the chamber was ∿2 R/hr. (Reiterating, the EF-2 facility was the only one of the four engineering-test facilities to contain a facility beam tube, an extension tube, a water-jacket tube, and an experiment.) The beam tube, which was fluted on the outside for cooling by reactor vessel water, fit inside the water-guide-sleeve tube. The extension tube was secured to a second adaptor flange and extended to the facility penetration in the experiment room. The experiment was an ionization chamber used by Instrumentation and Controls Division (I&C) personnel for noise analysis; the signal from this channel was sent to the computer.

Some difficulty was encountered with cutting the water-guide sleeve, and considerable difficulty was encountered with cutting the fluted tube. Broken cutting wheels were replaced on several occasions. (See Figure 35.) A different type of cutting wheel was installed, and the beam-tube-cutting tool was tried (the beam-tube-cutting tool was straight while the EF cutting tool was offset by 41°). Eventually, a hacksaw was used to complete the cuts.

Neoprene rubber gaskets were installed on the four EF plugs. The plugs were installed in the adaptor flanges, and the Marman clamps were temporarily reinstalled (using a socket wrench, not the bolt tensioner). This was done so that the pool water level could be lowered without draining the vessel and to prevent possible damage to the sealing surfaces of the flanges. Some minor difficulty was encountered with the installation of the Marman clamp on the plug in EF-2; however, the difficulty was resolved.

An estimate of the time allotted for the removal of the four engineering-test facilities was seven days of two shifts per day; the actual time was seven days. [A normal complement of personnel on each shift consisted of three reactor operators, a shift engineer, a design engineer, two millwrights, a rigger and operator, and a Plant and Equipment Division (P&E) foreman; other P&E crafts were called upon as needed.]

The reactor-bay floor area became slightly contaminated when the boilermakers began cleaning the vessel-head studs using a motorized wire brush. Further cleaning was performed by hand.

The faulty-fuel-element heat exchangers were removed from the reactor pool in order to gain access to the HB-2 beam tube.

The backup clamps were removed from the HB-1, 2, 3, and 4 Marman flanges. The induced radiation level of these clamps was $\sim$1 1/2 R/hr. The removal of the HB-1 backup clamp was very difficult because of bolt-tensioner troubles.

The Marman clamps were removed from HB-1 and HB-2. During this operation, a hose blew off the bolt-tensioner tool and had to be replaced. This type of difficulty was encountered on several occasions. During removal of the HB-3 Marman clamp, one of the two studs broke; part of the break surface was dark in color, indicating that partial failure had occurred some time ago. The break occurred at a small hole that had been drilled through the stud during fabrication, as mentioned earlier. (The hole was intended to secure the stud in the flange; however, it had been drilled in the wrong place.)

When the 7,700-lb shutter for the HB-1 facility was raised, it was learned that it could not be raised as high as it should for the holding rig; this problem was resolved by modifying the holding rig. The radiation level at the HB-1 flange in the beam room was ∿3 R/hr at contact and ∿15 mr/hr 8 ft away.

At this point, the four horizontal-beam-tube facilities were prepared for removal from the permanent beryllium. The general procedure for removing a horizontal-beam tube consisted of:

1. Disconnecting and plugging the service piping in the beam room.
2. Removing the shutter drive assembly.
3. Removing the backup and Marman clamps from the adaptor flanges.
4. Removing the water-collector clamps.
5. Removing the collimator and shield assembly.
6. Installing a split dam around the beam tube (to prevent pool water from entering the shield-liner cavity).
7. Removing a Conoseal retaining flange and seal (in the beam room).
8. Removing the pool-seal flange and expansion-joint assembly.
9. Removing the "removable" shield from the beam-hole liner.
10. Retracting the beam tube into a water-filled caisson.
11. Cutting the end of the beam tube closest to the reactor, after it cleared the beryllium reflector.
12. Cutting the tube into ∿3-ft sections and lowering the sections to the bottom of the reactor pool for temporary storage.
13. Retracting the remaining "cold" end of the tube into the caisson for eventual disposal in the burial ground.
14. Replacing the split dam with a solid dam.
15. Disconnecting the caisson.

(See Figures 36 through 40.) Communications between three millwrights, located in the beam room, and three reactor operators, located in (or at) the reactor pool, were required to effect this operation.

The sequential order for removal of the beam tubes was to first remove HB-4 and then HB-3, 2, and 1; however, HB-1 was removed first to allow more time to investigate the Marman-flange leak problem that had existed for the past five years. (The actual order of removal was HB-1, 4, 3, and 2.)

Some of the minor problems which were encountered with the removal of the first beam tube, HB-1, were:

1. Some difficulty was encountered with obtaining a water-tight seal with the split dam (this problem was resolved by replacing the inner rubber gasket).
2. The shutter stand was too narrow for the bellows flange.
3. The flight-tube-tunnel car was too small for the bellows storage rack.
4. The lifting lug on the adaptor end of the caisson was in the way for removal of the shield plug.
5. One bolt on the HB-1 split shield had become galled during removal.
6. Some water leak problems were encountered with the seals between the caisson and the shield-penetration flange.
7. The first cutting of the HB-1 tube, using the special cutting tool, was unsuccessful (this problem was resolved by using the hacksaw underwater tool).

There were other minor problems encountered during removal of the beam tubes. When the collimator was removed from the HB-4 facility, it was learned that the metal plates designed to cover the tracks in the beam-room floor did not fit; the plates were modified. The split shield on the HB-2 facility could not be removed because of trouble with the securing bolts; it was left installed and sent to the burial ground along with that section of the beam tube. Two of the studs securing the HB-1 and HB-4 water-collector clamps were found to be loose by $\sim$1/2 turn.

The floor area in the beam room became contaminated during the removal of the beam tubes. The source of the contamination was primarily from the collimators (the radiation level of the collimators, when removed, was $\sim$2 R/hr) and reactor-pool water which leaked on to the floor when the seal made between the caisson and the shield-penetration flange was inadequate. The predominant radionuclide was iron-55; since its energy level was low enough to escape detection by the survey meter, frequent smear checks by the health physicists were necessary during this overall operation.

Although all these problems were relatively minor, they did represent delays to an accumulative degree. The time required to remove the first beam-tube facility was approximately two days; subsequent beam-tube removals required half this time.

June 23, 1975 through June 29, 1975

Using the underwater periscope, the cut section of the HB-1 facility tube containing the adaptor flange was examined to help determine the cause of the in-pool leak which had existed for the past five years. A groove in the adaptor flange, about 1/8 in. in diameter, was detected. Impressions were made of the eroded surfaces using Apeizon and then plaster of paris. The HB-1 Conoseal gasket was found to have two places where pieces of the seal were missing; these places were believed to coincide with eroded places on the adaptor flange. (See Figure 41.) The surfaces of the HB-3 and HB-4 adaptor flanges on the vessel were examined also and were found to be satisfactory. Blank flanges were installed in the adaptor flanges of the disassembled beam tubes to ensure that their sealing surfaces did not become marred during the remainder of the shutdown.

As part of the preparations for removing the damaged beryllium, measurements were made of the clearance between the six guide fingers on the reflector-container ribs (the "bird cage") and the beryllium reflector. Although the nominal clearance was 15 mils, the measurements made indicated that the clearance had been reduced to less than 3 mils due to the swelling of the beryllium. Special debris-collector pans and special inner and outer peripheral retainers were installed in the vessel to prevent particles or sections of beryllium from falling into the vessel in the event the beryllium fell apart during the removal procedure. (See Figure 42.)

The scheme for lifting the beryllium consisted of inserting special tools into and through each of the twenty available VXF experiment holes; the bottom of each tool, when in the locked position, secured the beryllium from the bottom side. In addition, three threaded rods were inserted into the top surface of the beryllium. The 23 rods extended to a circular lifting plate above the surface of the water. The plate was leveled to ensure that a uniform lifting force would be applied on the beryllium from each lifting point. (See Figures 43 and 44.)

The initial efforts at raising the beryllium were unsuccessful because of a binding problem with the individual pads on the bottom of each rib of the bird cage. (The design clearance between the outer, bottom rim of the beryllium and these pads was 1 mil.) Lifting forces up to 4,000 lbs applied to the special lifting rig failed to move the beryllium. After the force was increased to 6,000 lbs, measurements were made to determine if the beryllium had been lifted some small amount. At this point, the gain was only 40 mils (to clear the lower base of the bird cage, the beryllium had to be raised $\sim$1/2 in.). Without exceeding the 6,000-lb lifting force but by applying a tapping technique around the periphery of the reflector pedestal using the slide-hammer tool, the beryllium was finally freed. The weight of the beryllium and the special lifting rig, in water, was 1,200 lbs. No further difficulties were encountered with removing the permanent-beryllium reflector from the reflector pedestal (the six upper keyways presented no problem).

An inspection of the beryllium at this time, prior to removal from the reactor vessel, revealed that the bottom corners were sharp and clean and that the inside surface was intact. One small piece of debris (about a 1-in.-diameter section) was observed to be atop the pedestal after the beryllium was raised; no other fragmentation of the beryllium was noted. The debris was not confirmed to be beryllium and was not retrieved at this time. After the beryllium was removed from the vessel, it was placed in the east storage pool. (See Figure 45.)

The clarity of the water in the reactor vessel decreased considerably after the beryllium was removed. To resolve the visibility problem, the reactor primary-cleanup system was placed in operation for a short period of time.

After another unsuccessful attempt was made at removing the lower tracks, an inspection of the tracks was made to determine the cause of the binding problem. The inspection revealed that one of the eight shafts used to actuate dowel-type circumferential positioners on the tracks was not in place and that four of the other rods were loose. At this time, the positioners, which protrude through the tracks and contact surfaces on the inside of the lower section of the beryllium support pedestal, were considered to be the major cause of the binding problem rather than some problem caused by a fragment from the damaged beryllium. While maintaining a force of 600 lbs on the regular track-lifting tool, the slide-hammer tool was used to tap around the top peripheral plate of the tracks. This solved the binding problem, and the tracks were removed to storage.

The large O-ring on the reactor pedestal was removed from the reactor vessel. The orifices were removed from the beam-tube flow collector clamps; the clamps were removed from the reactor vessel also.

By the end of this week, the four horizontal-beam tubes, the cracked beryllium, and the lower tracks had been removed. The original time estimated to complete this phase of the disassembly was 21 days; the actual time was 14 days.

June 30, 1975 through July 6, 1975

While secured in its special holder located in the east pool, the outer shroud was rotated 180° to allow replacement of the bottom-side O-ring. The obsolete, swing-bolt retainer ring, which had complicated working with the VXF experiments, was removed from the shroud at this time also.

Since the clarity of the water in the reactor vessel was fairly poor after the removal of the beryllium and the lower tracks, the reactor primary-cleanup system was again temporarily placed in service to improve underwater visibility and to prepare for an inspection of the reactor-vessel components.

Personnel from the Inspection Engineering Department began an inspection of the reactor vessel and its components which lasted a few weeks. The purpose of the inspection was to determine the integrity of welds, cladding, and internal components. The equipment used during this work included an underwater TV camera and video-tape machine for indirect viewing and a boroscope, mirrors, and binoculars for direct viewing. Ultrasonic-testing equipment was used for a volumetric inspection. (See Figures 46 and 47.) To minimize possible conflicts with other in-pool work, the inspections were performed on the 12-8 shifts.

Initially, the vessel inspection was focused on surfaces of the bird cage (the beryllium-reflector pedestal) in order to determine the cause of the beryllium binding problems. It was learned that all four of the bottom aluminum keys attached to the bird cage were heavily scratched on the side surfaces and edges adjacent to the surface that had been in contact with the permanent beryllium. The small pads, which are part of each rib of the aluminum bird cage (at about the same elevation of the keys), were not damaged.

The 24 lower guides on the bird cage were found to be in satisfactory condition; however, two of the six upper guide keys were found to be slightly scratched. These surfaces were later filed and buffed. The O-ring grooves on the top side of the cage and the matching grooves on the bottom side of the outer shroud were brushed also. After installing temporary covers over the four shock-absorber tubes, a water jet was used to clean the surfaces of the bird cage.

The pads on the ribs on the beryllium-support pedestal were checked with a go-no-go gauge; and the fuel-grid support pedestal, where the fuel grid seats, was checked in a similar manner. No abnormalities were found in either case.

One of the three studs used to secure the lower tracks was found to be damaged and was replaced. The outside threads were acceptable; however, the inside ones, used with the bolt tensioner, were not acceptable.

At this point, the major portion of the vessel-disassembly procedure had been achieved and the initial phase of the reassembly was begun.

The new permanent-beryllium reflector was installed in the reactor vessel; it was transferred using three new lifting rods that were inserted into the threaded holes in the top side of the beryllium. (See Figures 48 and 49.) When the lifting assembly was removed, mud washed out of one of the three new tools and settled atop the newly installed beryllium; the mud was later washed off using a water jet. A protection plate, which had been installed atop the beryllium after the problem with the mud, was removed.

A new Belleville-spring holddown stud was installed on the top of the bird cage assembly; this replaced the stud that was removed because of a galling problem encountered during removal of the washer.

Some debris was removed from outside the stack region of the reactor vessel. The material consisted of an old 2-in.-diameter O-ring and a 1/2 in. x 7 in. stud; the stud was from the old fuel grid.

The RP-1 and RP-2 flanges, located on the outside of the outer shroud, were inspected because of a minor galling problem encountered when the studs were removed during the first week of the shutdown; no abnormal condition was detected.

The 24 studs that engage and secure the Belleville spring were inspected and found to be satisfactory. One stud was observed to be slightly higher than the others by about one thread; however, the stud could not be lowered any further.

The initial efforts at installing the outer shroud were unsuccessful because of binding when the shroud was slightly above the seated position. The shroud was raised to allow an inspection to be made of the bottom-side O-ring; however, no abnormalities that would have contributed to the seating problem were detected. The outer shroud was finally seated after a leveling device was made and used to ensure that the shroud was level while being seated.

The initial efforts at installing the Belleville spring were unsuccessful because of an alignment problem with the 24 securing studs on the outer shroud as the washer was being installed.

July 7, 1975 through July 13, 1975

The inspection of the reactor vessel and vessel components during the midnight shifts was continued. No cracks in the welds, etc., were detected. A stud which had been removed from one of the beam-tube flanges was cleaned and subjected to a dye-penetrant test. No flaws were detected.

The efforts at seating the Belleville spring during the latter part of the previous week were continued. Special guide tools were made to facilitate the alignment of the washer as it was lowered onto the 24 vertically mounted studs and into its seated position. Unfortunately, the clearance between the top threads of the 24 studs and the inside diameter of the 24 springs on the Belleville spring made the alignment extremely difficult, even with the guide tools on each of the 24 studs. In addition, a special tool had to be made to remove a burr from one of the 24 springs in order to allow the guide tool to be installed.

Success with the seating of the Belleville spring was not achieved until after four 8-hour shifts of concentrated effort. Following the seating, further difficulty was encountered with securing the Belleville spring; one of the 24 studs had to be replaced because of a galling problem that was encountered when the 24 nuts were removed from the studs. As a final check on the installation, the height of the Belleville spring, relative to the top surface of the rim of the bird cage, was gauged to verify proper alignment and seating. No abnormalities were detected. Overall, the installation of this one item, the Belleville spring, was one of the more time-consuming phases of the beryllium-replacement shutdown. Approximately seven shifts, or 3 1/2 days, were spent on the Belleville spring installation; the original estimate was 2 days.

The VXF holes were gauged to ensure the precision alignment requirements between the VXF holes in the outer shroud and the matching holes in the new beryllium underneath the shroud. (See Figure 50.) A problem was encountered with one of the gauging tools because of a minor misalignment with the matching holes. This problem was resolved by modifying the gauging tool.

In an effort to locate the specific leak area on the surface of the HB-1 adaptor flange in the reactor pool, a special aluminum O-ring was installed on the flange. The damaged surface area of the flange, relative to a "v" notched on the O-ring, was identified upon the removal of the O-ring. Some minor difficulty was encountered with compressing the O-ring using the four-bolt Marman clamps. It was decided that the blank flange used in this operation was not identical to the actual flange on the beam tube and was causing an alignment problem. The problem was resolved on the following day by removing the plug from the HB-2 facility, modifying the plug to correct the alignment (concentricity) problem, and using the HB-2 plug in the HB-1 adaptor flange. (The HB-1 plug was not modified because it was found to be damaged.) After obtaining a seal on the HB-1 flange, the special O-ring was removed so that a study could be made of the sealing surface on the O-ring in the area where the leak had been. This study was continued the following week.

Preparations were made for installing the new beam tube in the HB-2 facility. (See Figure 51.) The cooling-water-collector clamp was placed on the HB-2 adaptor flange, and the punch marks on the flanges were identified (these marks were used for alignment when the beam tubes were installed). By the end of the week, the first of the new beam tubes was installed. The installation procedure was, in essence, the reverse of the disassembly procedure given in detail earlier. Some minor problems were encountered with pool water leaking through the solid dam and split dam during the installation of the beam tube (which resulted in extensive contamination of the floor area in the beam room); however, these problems were resolved. The new four-bolt Marman clamp was installed on the HB-2 adaptor flange. (See Figure 52.) To ensure a uniform compression of the Conoseal gasket, impressions of the gap between the mating flanges were made (using Duct seal) after each 500-lb increase in hydraulic pressure of the bolt-tensioner tool. The HB-2 shield-liner cavity was filled with water to check for leaks; no abnormalities were detected.

July 14, 1975 through July 20, 1975

The inspection of the reactor vessel by Inspection Engineering personnel during the midnight shifts was continued. No abnormalities were detected using either the ultrasonic-testing equipment or the underwater TV camera.

The floor area in the beam room was cleaned because of a contamination problem which developed during the installation of the HB-2 beam tube and its components. The source of the contamination was primarily the collimator, which had been stored in the HB-2 flight tunnel. In addition to the cleaning operation, which was continued for two days, the local air-conditioning units were de-energized to minimize the possible spread of airborne contamination. No problems were encountered.

The shield-plug service piping for the HB-2 beam-tube facility was installed.

Preparations were made for installing the second beam tube, HB-4 (this included installing the collector clamp and inspection of the parts, as applicable). After the new beam tube was installed, a major problem developed when the new four-bolt Marman clamp was installed on the adaptor flange. Although the nuts had been checked for freeness prior to installation of the clamp, all four nuts became galled on the studs after turning them only a few revolutions using the underwater wrench tool. The reason for the galling was believed to be associated with the new lubricant (Molykote 505) which had been applied to the studs; the lubricant proved to be water soluble.

A special tool was made to use along with an impact wrench in an effort to remove the galled nuts; however, the efforts were unsuccessful. An attempt at removing the nuts by drilling also proved to be unsuccessful. It was not until after new drilling tools were fabricated, to allow drilling through a nut and then spreading it, that some small degree of success was achieved and one of the galled nuts was removed. Unfortunately, the drilling scheme was very time consuming, due in part to breaking of the drills and fabricating new tools. This method was abandoned later in the week for a different method. The remaining three nuts were removed by sawing through the studs using the hacksaw tool. Thus, the comparatively elementary operation of installing a Marman clamp, because of the galling, became the second time-consuming phase of the beryllium-replacement shutdown. The efforts of over eight shifts were concentrated on removing the four galled nuts.

Some repairs and modifications were made on the water-guide-sleeve removal tool for the EF facilities. The inner mast and the gripping mechanism were removed; the tool was later reassembled without the inner mast. A new, shorter water-guide-sleeve tool was made also. The bolt-tensioner tool was repaired; some seals had failed.

The new EF-1 facility tube was installed in the reactor vessel. Some difficulty was encountered with the insertion of the water-guide-sleeve removal tool. The problem was resolved by removing two of the rubber rings on the end of the tool and replacing them with a metal spacer; the third rubber ring on the tool was replaced with one of a smaller size. An adaptor plug was installed in the flange; however, because it was not made of certified material, it was later replaced with another plug. During this replacement, it was learned that the Conoseal gasket had a rough edge; the gasket was replaced. The machined face of the plug was found to be rough also; however, the edge which makes the seal with the Conoseal gasket was acceptable. The studs for the EF-1 clamp were sprayed with Lubribond "A", and the inside surface of the clamp was coated with Molykote 505. No galling problem was encountered in this application. A Marman clamp was then installed on the plugged adaptor flange. (After a Marman clamp was installed, it was secured with the aid of the bolt-tensioner tool. The hydraulic pressure used to stretch the bolt was increased, in increments, to ∿3,700 psig while the nut was tightened. After about twelve hours, this procedure was repeated to ensure that the nut had been properly secured. Impressions of the two mating flanges were made using Apiezon. A tool was fabricated to gauge the uniformity of the mating flanges; however, due to the angle of the flanges, the tool was very difficult to use. Making impressions was considered the better technique.)

The Marman clamp was removed from the EF-4 facility, and the clamp and plug were removed from the EF-3 facility. When the clamp was to be removed from the EF-2 facility, one of the nuts had become galled on the stud. The stud was removed on the following day with the aid of the hack-saw tool.

The new water-guide-sleeve tubes were installed in EF-2 (Serial No. 74-4), EF-3 (Serial No. 74-3), and EF-4 (Serial No. 74-5). The shield plugs were installed in EF-3 and EF-4 (in the experiment room), and a blank flange was installed in EF-2. Only EF-2 had a facility tube inserted into the water-guide tube; the tube accommodates the noise-monitoring chamber. The remaining EF facilities were to remain plugged at the vessel adaptor flanges.

An examination of the adaptor plug removed from the EF-3 facility revealed worn areas on the nose piece that appeared to indicate that the water-guide-sleeve tube had become unscrewed from its seating place at the bottom of the reactor vessel (one of the worn areas was where the plug had been in contact with the tube). These worn areas had not been detected earlier when the EF-3 plug was initially removed. The plugs from the remaining facilities were checked but did not show this same wear. The threads on one of the two studs on the Marman clamp removed from EF-3 were found to be damaged; the stud was replaced.

The thimble for the No. 2 fission chamber was pressurized to 100 psig with air for leak-checking purposes; no bubbles were detected in the reactor vessel.

For various reasons (primarily maintenance costs), a change was made in the personnel work schedule. The full complement of Operations and P&E personnel assigned to weekend work was no longer required. The three rotating shift crews working the 8-4 and 4-12 shifts for seven days a week were changed to two shift crews working the 8-4 shift and one crew working the 4-12 shift for five days a week. As the work schedule allowed, one Operations crew worked on an occasional Saturday, and P&E personnel were called in for weekend work as needed.

July 21, 1975 through July 27, 1975

The Marman clamp was installed on the EF-4 adaptor flange. The two-bolt variety of Marman clamp, along with a backup clamp, were used on all the reassembled EF adaptor flanges (EF-1, 3, and 4). The four-bolt variety of Marman clamp was used on EF-2. Two were installed on the two flanges which were in series. (See Figure 53).

The newly installed HB-4 beam tube was retracted to allow for the removal of the Conoseal gasket and for an inspection to be made of the sealing surfaces of the flanges. This was done as a safety measure because so much difficulty had been encountered during the previous week with the four galled nuts. After the inspection, a new Conoseal gasket and a new four-bolt Marman clamp were installed. The lubricant used on this second occasion was Lubribond "A"; no galling problems were encountered. Some minor problems were encountered with the operation of the bolt-tensioner tool and the split dam; however, these were resolved on the following day by lubricating the parts of the bolt-tensioner tool and by replacing the rubber gaskets on the split dam.

The Marman clamp was secured on the HB-4 adaptor flange.

The Conoseal gasket, adaptor plug, and Marman clamp were installed on the EF-3 facility.

The Conoseal gasket, the EF beam tube, and the first of two Marman clamps were installed on the EF-2 facility. A protective cover for the EF-2 opening was prepared to prevent debris from falling into the open beam tube. The beam-tube extension tube, which is secured by the second Marman clamp, was to be installed after the HB-2 facility was leak checked. This reassembly sequence was necessitated by the accessibility to the in-pool piping.

Measurements were made of the HB-1 beam tube to determine if there would be any difficulty in securing the split dam in an area where a weld had been on the tube. (The new beam tube was originally cut too short, and another section of piping had to be welded on to obtain the required length.) A minor problem was encountered with the installation of the split dam because of the weld; however, this was resolved by modifying the dam.

Based on the information gained earlier regarding the eroded area on the HB-1 adaptor-flange face, a special aluminum O-ring was made and installed in the adaptor flange. The O-ring had an additional piece of aluminum welded on the rim; when aligned and installed properly, the added aluminum was positioned in the eroded area of the sealing surfaces. Upon compression of the flange faces, the small piece of surplus aluminum was forced to flow into the eroded area and subsequently seal it.* (As it turned out later during the leak checks, this scheme to correct the HB-1 leak problem, which had existed for five years, proved to be successful.) Conoseal-type gaskets were installed in all the remaining adaptor flanges.

Another minor problem was encountered during the installation of the HB-1 shield plug; either during the removal of the plug or the reinstallation, the plug was inadvertently rotated 180^{o} and could not be installed because of the eccentricity of the plug. The problem was recognized and corrected. (The plug was designed not to be concentric in order to compensate for the discrepancies in the initial alignment of the beam tube relative to the penetration through the concrete wall.)

The HB-3 beam tube was installed and the Marman clamp secured. The beam-room-floor area became contaminated (again) as a result of this operation. The level of activity was ∿4,500 dis/min/100 cm^2. The cleaning operation was performed primarily on the 12-8 shifts; by the end of the week, the area had been cleaned.

The initial effort at identifying eight of twenty-two 1/4-in.-diameter pressure and flow-monitoring lines at the reactor vessel was not particularly successful and would have been very time consuming had the initial procedure been continued. To solve this problem, all 22 lines were cut at ∿5 ft above the reactor-pool grating and air pressure (applied at the monitoring platform in the experiment room) was used to identify all the lines. The eight pressure and flow-monitoring lines were for HB-1, HB-2,

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*A. A. Abbaciello, Seal Modification for A V-Band Clamped Flange, ORNL-TM-5025 (October, 1975).

HB-3, HB-4, RP-1, RP-2, CR-1, and CR-2. These lines were later routed through vessel-head flanges VH-7, VH-15, VH-17, and VH-21.

The coolant-return lines (CR's) from the water-collector clamps of the engineering-test facilities and the horizontal-beam tubes were modified as follows (see Figure 54):

1. Four EF Lines (collector clamps to CR-1, 3, 4, and 11). No modifications; they remain routed from the water-collector clamps to the "horny pieces".
2. HB-1. The line from the water-collector clamp was rerouted through vessel-head flange VH-21. The line from CR-2, also routed through VH-21, was blanked off outside the reactor vessel; it is a spare for future use.
3. HB-2. The line from the water-collector clamp was rerouted through vessel-head flange VH-7. The line from CR-6, also routed through VH-7, was blanked off outside the reactor vessel; it is a spare for future use.
4. HB-3. The line from the water-collector clamp was rerouted through vessel-head flange VH-15. The line from CR-8, also routed through VH-15, was blanked off outside the reactor vessel; it is a spare for future use.
5. HB-4. The line from the water-collector clamp was rerouted through vessel-head flange VH-15. The line from CR-10, also routed through VH-15, was blanked off outside the reactor vessel; it is a spare for future use.
6. RP-1 and RP-2 (reactor pressure monitors). These were routed through vessel-head flange VH-17.

The new lines from HB-1, 2, 3, and 4 were rerouted for the purpose of locating the flow-monitoring orifices outside the vessel. The flow from the orifices is routed to a manifold and then on to the hydraulic-tube-system line that discharges into the 18-in.-diameter coolant-outlet line from the reactor vessel. The old, high- and low-pressure lines were cut and removed from the reactor vessel.

The purpose of this modification in the pressure and flow-monitoring system was to avoid the problems of having an extended reactor shutdown if one of the flow-monitoring Autoclave fittings on the beam-tube facilities developed a leak.

The work platform was removed from atop the reactor vessel along with the four metal sections that were installed to seal the rubber gasket over the peripheral stud holes. When the rubber gaskets were removed, water was found in most of the 44 stud holes. The holes were dried, the rubber gaskets were reinstalled, and four new metal plates were installed. (A bolt used to secure one of the peripheral plates was not installed because it started to gall during the initial installation.) The new plates were similar to the old ones; however, the new plates did not complete the sealing circle around the top of the vessel. Instead, four gaps in the circle allowed for the installation of four positioning plates; these metal plates completed the sealing circle. The purpose of the positioning plates was to mock up the VH holes in the top head and allow the pipefitters to make more accurate measurements when routing the pressure and flow-monitoring tubing through the four vessel-head flanges mentioned earlier.

Some of the brackets for the flow and pressure-monitoring lines were installed in the reactor vessel. Difficulty was encountered with the HB-1 lower-support bracket; it did not fit as intended. In addition, the HB-1 water-collector-clamp tubing had to be rerouted because it interferred with the bundle of pressure-monitoring tubing entering the north side of the reactor-vessel wall. The CR-2 piping had to be rerouted also.

A small screw was found lying atop the No. 2 ionization chamber housing in the reactor vessel; it was retrieved. The screw was believed to have fallen from the ultrasonic-testing equipment used by personnel from Inspection Engineering during the inspection of the welds, etc.

On the following day, a 3-in.-long, 3/8-in.-diameter stud was accidentally dropped into the reactor vessel; it was retrieved at a later time.

July 28, 1975 through August 3, 1975

The shield plug, the bellows assembly, and the collimator were installed in the HB-3 facility. The final tensioning procedure was performed on the Marman clamp, and the impressions were made of the separation of the flanges. The results were satisfactory.

Blank flanges were installed on the CR-8 and CR-10 piping connections located on the fuel and reflector-support and sleeve assembly (the "horny pieces"). A flange with a pipe connection was installed on CR-6, and a flange and pipe were connected to RP-1 located on the outer shroud. Some modifications were made to the CR-2 piping, which was to be routed through vessel-head flange VH-21.

The newly installed piping for the coolant-return lines was leak checked. Special tools were used to perform this test since the reactor vessel could not be pressurized at this time. The CR-8 installation leaked under 20 psig pressure. The gasket was replaced and the CR-8 flange was reinstalled; however, the leak problem was not corrected at this time. The CR-2, 6, and 10 installations were found to be leaking. An investigation into this problem revealed that the centering diameters of the flanges, although made to print specifications, were too large. The correct diameters were determined by making impressions of the mating flanges located in the vessel. The blank flanges were removed from CR-8 and CR-10; they were remachined to the proper diameter and then reinstalled. The CR-2 and CR-6 flanges, which were for piping connections, were removed for the machining modifications also. Unfortunately, the CR-8 and CR-10 flanges still leaked when tested to ∿100 psig after the machining modifications. The problem was finally resolved by replacing the stainless-steel gasket with aluminum O-rings. Minor difficulty was also encountered with the bolts on the CR-2 flanges. The bolts and gasket were replaced later in the week, and the subsequent leak checks were satisfactory.

The water-collector clamp was removed from HB-1 in order to revise the piping bends; the clamp interfered with the 1/4-in.-diameter tubing bundle entering the northeast side of the reactor vessel. Some minor problems were encountered with the reinstallation of the collector clamps on the other beam tubes because of a faulty torque wrench; these problems were resolved. The HB-1 collector clamp was removed again later in the week for further piping modifications. It was then reinstalled satisfactorily.

The 1/4-in.-diameter tubing of the flow and pressure-monitoring system that was cut during the previous week was reconnected using Autoclave fittings.

The HB-1 collimator was installed. With the exception of reconnecting the tubing lines at the facility, the major portion of the beam-tube installation had been completed.

The top flange of the reactor vessel, from the stud holes to the inner and outer vessel walls, was subjected to ultrasonic testing. No flaws were detected.

A considerable amount of work was directed toward completing jobs mentioned earlier, including securing the water-collector clamps on HB-2, 3, and 4 and installing the flow and pressure-monitoring lines in the vessel.

Some of the special tools made for the shutdown work which were no longer needed were transferred to storage.

The clamps used to secure the two inlet-flow distributors were rebuilt (new studs, new helicoils, etc., were installed).

Cleaning of the reactor vessel using the underwater vacuum cleaner was begun. Some minor problems were encountered with the hoses on the cleaning rig; however, these were resolved the following day. This in-pool job was one of the few in which relatively high radiation fields were encountered.

The pool-coolant system was placed in operation (usually on the 12-8 shifts) to maintain the temperature of the fuel-storage pools within limits.

The reactor-vessel head and the two flow distributors were returned to the reactor bay from storage.

A thorough inspection was made of the reactor-vessel components by Operations personnel; no abnormalities were observed.

The northwest inlet-flow distributor was installed in the reactor vessel with considerable difficulty. After the clamp was installed and torqued to 80 ft-lbs, an impression of the gap was taken; the gap width, as indicated by the impression, was satisfactory. The southwest distributor was installed without any problems. (See Figure 55.)

August 4, 1975 through August 10, 1975

All the in-vessel clamps and brackets used to secure the flow and pressure-monitoring tubing were checked for proper torque, etc. The work on reconnecting the 1/2-in.-diameter and 1/4-in.-diameter lines outside the reactor vessel was continued.

The 44 vessel-head stud holes were dried and cleaned with alcohol. The threaded surfaces were then examined and brushed clean as needed. Lubrication of the threaded surfaces with Lubribond was begun. However, on the following day the holes were re-examined, and some were still found to contain rust spots. All the holes were recleaned and then sprayed with Lubribond. During the final examination, a small piece of metal (an ∿1-in.-long sliver) was found missing from one of the threads in stud hole No. 19. The stud for hole No. 19 was examined but showed no irregularities. The finding was considered of no potential consequence.

The vessel-head studs were delivered to the reactor bay from storage. On the following day they were gauged for length prior to installation in the vessel head. (See Figure 56.) After the studs were installed, the 14-ton vessel head was installed and secured. With a pressure of ∿7,000 psig from the bolt-tensioner tool, the 3-in.-diameter bolts were stretched ∿25 mils for this operation. (See Figure 57.)

The upper tracks were transferred to the work platform in the east pool for bearing replacement and inspection. A 2-in.-long scratch was found on one of the surfaces; it was examined and considered to be of no significance.

The experiment-access flanges on the top head were installed. The two keeper posts for the inlet-flow distributors were installed through flanged ports VH-6 and VH-14; the flanges were installed and secured also.

Preparations were made for pressurizing the reactor primary-coolant system. This included installing temporary plugs in the flanges serving the new flow and pressure-monitoring lines and installing blank flanges on the pressure-relief-valve connections on the heat-exchanger lines in Cell 110.

The reactor primary-coolant system was pressurized to 100 psig, and a leak check was performed. The system was depressurized after it was learned that vessel-head flange VH-4 was leaking. An investigation revealed that the flanges still contained the experiment-facility washers; these were replaced. The primary system was pressurized to 75 psig, then to 200 psig, and then to 400 psig; the system was again checked for water leaks. A leak was found at the temperature-sensor (TE-100-2B) fitting in the pipe tunnel. At the 200 psig pressurization level, there was about a 15 gpm makeup at the head tank; at the 400 psig level, the makeup rate was 27 gpm. The system was depressurized. A large makeup rate was still noted even after depressurization; however, this makeup rate was attributed to the compression of a large volume of air in the system and not to a leak.

The pool-cleanup pump was used to pump the reactor-pool water to its lowest level possible in order to allow the beam-tube flanges to be leak checked. The EF plugs in the experiment room were removed to allow visual leak checking also.

The reactor primary-coolant system was again pressurized, in increments of about 200 psig, to about 900 psig; this was the maximum pressure that could be attained with the 4B pressurizer pump (the normal operating pressure is 650 psig). On this occasion, it was learned that the VH-1 and VH-4 vessel-head flanges were leaking. The system was again depressurized. The nuts securing the larger flange were torqued to 175 ft-lbs (the normal value is 155 ft-lbs), and the nuts on the smaller of the two flanges were retorqued to ∿75 ft-lbs (the normal value is 60 ft-lbs).

After the system was repressurized to 900 psig, the VH-1 and VH-4 flanges were still leaking. The Autoclave plug on the VH-15 flange developed a leak also. There were no detectable leaks from either the EF or the HB facility flanges. The system was then depressurized. (The beam-tube Marman flanges were not only leak checked visually; they were also checked by positioning blotter paper under each flange for ∿15 minutes to see if any water had dripped from the underside of the flange connection after that period of time.)

During the leak-checking procedure of the EF and HB flanges in the reactor pool, the radiation level at the grating was ∿400 mr/hr; the radiation level at the pool railing was ∿70 mr/hr. The highest exposure received by one of two operators performing the work from atop the reactor tank top was 70 mr. During the following week, while performing the in-pool work with the reactor water level maintained lower than usual, three reactor operators received doses of 85, 55, and 50 mr, respectively (taken from a single pocket meter report). These were among the highest exposures received by any Operations personnel during the beryllium-replacement shutdown; the highest single exposure for any craft personnel was ∿155 mr (for one of the millwrights working on the beam tubes). These values were unusually high and were not indicative of the overall exposure values received by personnel during the shutdown work. (See Appendix C for radiation exposures received by Operations, P&E, Inspection Engineering, Health Physics, and experiment personnel during the work performed during the beryllium-replacement shutdown.)

For the purpose of leak testing, the reactor primary-coolant system was pressurized and depressurized in the following sequence during the week: 0 → 100 psig → 0 → 400 psig → 0 → 900 psig → 0 → 900 psig → 0 → 900 psig → 600 psig → 900 psig → 0.

August 11, 1975 through August 17, 1975

New stainless steel O-rings were installed on vessel-head flanges VH-1 and VH-4; the Autoclave plug on the VH-15 flange was tightened, also. The system was again pressurized, to ∿250 psig, and then leak checked. Unfortunately, flanges VH-1 and VH-4 were still leaking. After the system was depressurized, the VH-4 securing nuts were retorqued to 185 ft-lbs; those on VH-1 were retorqued to 75 ft-lbs.

After the PU-4A pressurizer pump was repaired (a faulty seal was replaced), the system was pressurized to 1,075 psig. At this pressure, flanges VH-1 and VH-4 still leaked. An investigation into this problem revealed that the O-rings used on the two flanges were not the correct ones and were replaced (the O-rings removed had 150 lbs rating; the new ones installed had 1,000 lbs rating). Blotting paper was again placed under the adaptor flanges of the four beam tubes, and the system was pressurized to 1,075 psig for one hour. No water had leaked onto the paper during this high-pressure leak test.

The shield-penetration plugs were installed and secured in the EF-1, 3, and 4 facilities. The backup clamps were installed and tensioned on EF-1, 3, and 4.

The service piping was reinstalled at the HB-1 and HB-3 facility flanges in the beam room. The assembly-clamp ring was installed and secured on HB-1, 2, 3, and 4. The collimator cavity of each beam tube was leak checked with helium pressure to 30 psig. The HB-2 and HB-4 cavities were satisfactory; the HB-1 and HB-4 cavities were found to be leaking. It was learned later that the HB-3 pressure gauge was leaking; however, after the gauge was replaced, the HB-3 collimator cavity was still found to be leaking. The HB-2 and HB-4 collimator cavities were leak checked using Freon and were found to be satisfactory.

In order to correct the leak problem with the HB-1 and HB-3 collimator cavity, the collimators had to be removed to allow replacement of the O-ring on each flange. The service piping was again disconnected from the HB-1 facility flange, and the collimator was removed. The gasket-seating surface of the beam tube was reworked; the leaking O-ring was replaced; and the collimator was reinstalled. After the service piping was reconnected, the collimator cavity was again leak checked, with helium, and was found to be satisfactory. The floor area around the HB-2 flight tunnel in the beam room became slightly contaminated during this work and was cleaned.

Some damaged threads on the inlet-flow strainer were reworked because of a galling problem which was encountered when the strainer was removed early in the shutdown. The strainer was later installed without any difficulty.

The faulty-fuel-element heat exchanger and the shroud flange were transferred to the reactor bay from storage. The heat exchanger and some of the piping were later installed in the reactor pool. Some of the in-pool grating supports were removed to allow maintenance personnel to work on the flow and pressure-monitoring system. One of the new pieces of flanged piping (that made a connection between valve HV-299 and the primary-coolant-return line) did not fit in its designated space and was removed for modification.

The control-rod shock absorbers were replaced. The No. 4 shock was placed in the No. 1 position; the No. 2 shock was placed in the No. 2 position; the No. 5 shock was placed in the No. 3 position; and the No. 3 shock was placed in the No. 4 position.

For the purpose of leak testing, the reactor primary-coolant system was pressurized and depressurized in the following sequence during the week: 0 → 250 psig → 0 → 1,075 psig → 0 → 1,075 psig → 0.

August 18, 1975 through August 24, 1975

The HB-3 collimator was removed to replace the leaking O-ring and to rework the flange-seating surface on the end of the beam tube. The collimator was then reinstalled, and the collimator cavity was leak checked. No leak problems were encountered on this second occasion.

The HB-1 collimator was hydrotested at 240 psig; no leaks were detected. (The procedure required that all four beam-tube facilities be hydrotested; however, the test was not performed on HB-2, 3, or 4 because the collimator assembly had not been disassembled on these three facilities.)

The bearings were installed on the new set of lower tracks. A coupling on control plate No. 9-1 was inspected and later replaced. The four extension tubes for the control plates were installed in the reactor vessel.

As a result of the work on the rod-drive components, the subpile room became contaminated (smears probed to 250 mr/hr). By the end of the week, the cleanup work had been completed.

A blank flange was installed on the EF-2 facility in the experiment room.

Stainless-steel plugs were installed in vessel-head flanges VH-1 and VH-4. The other ports in the head were checked, from the underside, to ensure that plugs were installed in each.

The HB-2, 3, and 4 water-shield plugs were filled, and all the beam tube shutters were installed and closed.

Preparations were made to check the performance of the control-rod drive mechanism without the control plates being installed and in the low-power Mode 3. However, the "noise" problem in the electronics had not been resolved, and some difficulties were encountered. At first, the magnet currents could not be raised to their normal value of 1.85 and the current indicators were very erratic. After "red modules" (a bypass feature in the instrumentation) were inserted in the "RATE" trip of Channel No. 3 and in the CRM trips of Channels No. 1 and No. 3, the magnet currents could be raised adequately to allow withdrawal of the four extension tubes. The magnet current for the No. 2 rod, as indicated on Channel No. 3, pulsed to zero during this work when a fuse in the magnet amplifier failed. This problem was corrected.

The initial rod-performance data were questionable. The data obtained on the No. 2 rod appeared indicative of timer problems. There were no data on the release and response times obtained on rod No. 4. The time-of-flight data obtained on rods No. 3 and No. 4 were half the values of those obtained on rod No. 1, and the variations in the flight-time values obtained on the No. 1 rod were too great to be of any real value. The push rods on the No. 1 and No. 2 rod drives were reset to engage the upper set of balls with the acceleration spring. The magnet currents were adjusted to 1.85; the magnet amplifier in Channel No. 3, for the No. 2 drive, was changed out because the current could not be adjusted. The rod-performance test was repeated. Although no release and response times were obtained on rod Nos. 3 and 4, the other values on the rods were within a more acceptable range.

The vent line from the faulty-fuel-element storage rack was reconnected to the special building hot exhaust (SBHE) system.

The work on the flow and pressure-monitoring lines in the reactor pool was continued.

The semipermanent beryllium, the removable beryllium, and the upper tracks were installed in the reactor vessel.

The reactor primary-coolant system was pressurized to 300 psig for leak testing purposes. The newly installed piping from vessel-head flanges VH-7 and VH-17 was leaking. The system was depressurized, and the leak problems were corrected. The system was again pressurized, initially to 300 psig and then to 900 psig. One small leak was found at the No. 2 safety channel inlet-temperature sensor (the leak was repaired on the following week). The system was depressurized.

The EF-2 shield plug and the extension tube were installed. The second of two Marman clamps was installed. When the water level was raised in the reactor pool, water leaked into the experiment room via two 1/4-in.-diameter Autoclave fittings on the EF-2 facility; these were repaired.

For the purpose of leak testing, the reactor primary-coolant system was pressurized and depressurized in the following sequence during the week: 0 → 300 psig → 900 psig → 0.

August 25, 1976 through August 29, 1975

The personnel work schedule was returned to the normal A, B, C, and D rotating-shift coverage with three men on each shift and three men on the day shift.

The outer control plates and the inner control cylinder were installed in the reactor vessel. At this time it was realized that two of the four shock-absorber-tube covers were unaccounted for. After an unproductive search of the reactor pool and other storage areas was made, it was decided to disassemble the vessel components, as necessary, in order to find the two missing covers. After the inner control cylinder, the four control plates, the upper tracks, the removable beryllium, and the lower tracks were removed, the two missing covers were found in the reactor vessel under the permanent beryllium. After the missing covers were removed from the vessel, the reactor-core components were reinstalled. (A slight scratch was noted on control plate No. 9-3. The plate was examined; and the scratch, believed to be an old one, was considered to be of no significance.)

The grating was reinstalled in the reactor pool; and the two sump pumps, used to control the pool-water level during the shutdown work, were removed from the reactor pool.

Beryllium plugs were inserted into all the VXF experiment holes. The two quad holders and RB-4, 5, 6, 7, and 8 were worked and inventoried. Corrosion specimens were installed in PN-1 and PN-2; a strainer was installed in PN-3.

The ionization chamber was reinstalled in the EF-2 facility in the experiment room.

The shroud flange and the fuel grid were installed in the reactor vessel. New fuel elements 118-I and 118-O were delivered to the reactor bay and were installed in the reactor vessel. The count-rate channels showed only a negligible increase in counts when the new fuel was installed; however, the counting rate increased considerably when the target was installed in the core. This was attributed to the fact that many of the components in the reactor vessel were new; hence, there was a lower level of source neutrons than usual. The target bundle, on the other hand, contained its usual two to three hundred milligrams of californium.

Some decontamination work was performed in the beam room; the final cleaning work in the beam room was completed by the end of the week.

The reactor primary-coolant system was pressurized to 400 psig for the purpose of leak checking and removing entrapped air from the system. Shortly after, the pressurizer pump (PU-4A) was de-energized and the block valves were closed when it was learned that the drain-line valve on the decay header had been left open. The system pressure decreased to ∿150 psig. After the valve was closed, some difficulty was encountered with starting the PU-4A pressurizer pump. However, it was started, and the system pressure was increased to ∿380 psig. While at 380 psig, the pressurizer pump was de-energized to allow some work to be performed on the west demineralizer. When the pressurizer pump was to be returned to service, at first it could not be restarted; after it was energized (by resetting the local switches), the "RPM" controller for the magnetic clutch was inoperative. The PU-4A pump was then removed from service to allow an investigation to be made. The system pressure decreased to ∿100 psig during this time.

While checking the PU-4A pressurizer pump, valve No. 1021 on the demineralizer system was found to be leaking; this was later repaired. It was also learned that a line blind to one of the prefilters had not been changed to the open mode; this was corrected also.

The PU-4B pressurizer pump was placed in service, and the system pressure was increased to ∿580 psig.

As part of the preparations for operating the reactor, the pony-motor battery test was performed on PU-1E, PU-1F, and PU-1G; the fourth unit, in heat exchanger cell No. 110, was not available for testing. The test was interrupted for ∿20 minutes while the three primary pumps were operated to help remove the entrapped air from the system.

The system pressure was decreased to ∿100 psig, increased to ∿640 psig, and then lowered to ∿100 psig. The pressure was increased to the 640 psig level while the primary pumps were being operated; it was then lowered to ∿100 psig to allow I&C personnel to bleed air from the instrumentation. After the air was bled from the instruments, the system pressure was increased to 650 psig.

The initial hydraulic-data printouts obtained from the computer were mostly within range; however, it was not until after a solenoid valve on the N-16 system (in the subpile room) was opened that the data were normal.

When the negative pressure was established in the deaerators, the negative pressure in the reactor deaerator increased to ∿9 psia and, on occasion, decreased to ∿15 psia. The problem was at first believed to be caused by not having water in the barometric leg. The deaerator was allowed to overflow on several occasions to fill the leg; however, this did not resolve the problem. It was then believed that the steam jets were plugged; these were disassembled and were found to be in satisfactory condition. I&C personnel found and replaced a ruptured air-pressure gauge in the output-signal instrumentation for the deaerator's level-control valve; however, this had no effect on the problem. On the following day, it was learned that the off-gas-line valve in the pool demineralizer cell had been left closed during some of the shutdown work; when it was opened, the negative pressure increased to the normal value of ∿1 psia.

The insulation on the wiring to the position indicator for the HB-4 rotating shutter was found to be damaged; the wiring was replaced. The position indicator switches were reset also.

The rod-performance test was made. The data were:

Parameter	#1 Rod	#2 Rod	#3 Rod	#4 Rod	
Release time, ms	15.0	13.0	15.5	16.5	(2/3)
	9.5	8.5	10.0	10.5	(3/3)
Response time, ms	31.5	28.0	32.0	31.0	(2/3)
	24.5	22.5	25.5	24.5	(3/3)
Time-of-flight, ms	307.0	289.0	297.0	297.0	(2/3)
	294.0	283.0	293.0	293.0	(3/3)

The radiation-block-valve test was performed. [The system pressure increased to ∿760 psig when the Faulty Fuel Element Detector (FFED) trip was initiated; the pressure decayed to ∿600 psig in 4 minutes and 20 seconds.]

After the three primary pumps were operated for about four hours, the system was depressurized and the access hatch was removed to allow an inspection to be made of the strainer and the top of the fuel for debris. Some debris (shavings and some light-colored material, believed to be beryllium oxide, etc.) was removed from the strainer; the material, which probed ∿4 R/hr, was removed to the decontamination pad. Upon completion of the inspection, the hatch was reinstalled and the system was again pressurized.

Flow was established to the beam tubes and the rod-drive seals.

The primary-pump check-valve-performance test was made.

While investigating the cause of an abnormal letdown flow rate, a considerable amount of water was lost to the ILW system; it was learned later that a prefilter drain-line valve (to the ILW system) had been left open.

The rod-performance data obtained prior to reactor startup were:

Parameter	#1 Rod	#2 Rod	#3 Rod	#4 Rod	
Release time, ms	15.5	13.5	15.0	16.5	(2/3)
	11.0	9.0	11.0	11.0	(3/3)
Response time, ms	32.0	28.5	32.0	31.5	(2/3)
	26.0	23.5	26.5	25.0	(3/3)
Time-of-flight, ms	298.5	289.0	297.5	298.0	(2/3)
	301.5	291.0	290.5	299.0	(3/3)

At 1238 on August 29, the reactor was made critical at a power level of 10 MW, thus officially terminating the beryllium-replacement shutdown. This shutdown, which lasted 12 weeks and 3 days, was the longest shutdown in the history of the HFIR. The critical rod position was 18.315 in.; the predicted value was 17.97 in. ±0.25 in. The predicted value was later rechecked and was found to be in error; the revised value was 18.26 in. The cold flow rate was 16,686 gpm.

The reactor power level was held at the 10 MW level for 1.750 hours to allow for a thorough check to be made of the various systems. At the power level of 60 MW, a number of momentary alarms were initiated by the strainer ΔP instrumentation. I&C personnel bled the transmitter lines again and rezeroed the ΔP cell; however, these actions failed to correct the problem. After due deliberation, the reactor power level was raised to 100 MW, and the alarm setpoint for the strainer was raised from 350 to 375 in. H_2O. The increase in strainer ΔP was considered to be real and to be the result of some more debris collected by the strainer.

The reactor primary-coolant system was pressurized and depressurized in the following sequence during this last week of the beryllium-replacement shutdown: 0 → 400 psig → 150 psig → 380 psig → 100 psig → 580 psig → 100 psig → 640 psig → 100 psig → 650 psig → 760 psig → 600 psig → 650 psig → 0 → 650 psig → 400 psig → 650 psig → 0 → 650 psig.

SUMMARY

In less than 15 months after the cracks were discovered in the permanent-beryllium reflector, preparations for the replacement of the beryllium had been completed. This work included the design and fabrication of over 200 special tools, the preparation of over 180 engineering drawings, the writing of over 350 pages of procedures, the fabrication of new engineering-test-facility tubes and new beam tubes, and the manufacture, fabrication and testing of a new piece of beryllium. During the preparatory work, the reactor was operated at the design power level of 100 MW. To ensure safe operations during the interim, special annunciator instrumentation was installed and special operating procedures were practiced.

The inspection of the reactor vessel, the vessel-to-nozzle welds, internal components, and primary piping branch lines was completed as permitted by accessibility and found to be in acceptable condition. The percent coverage of all welds was sufficient to provide assurance of good weld quality and to meet the basic requirements of ASME, Section XI.

The only time-consuming problems encountered during the shutdown were: (1) the seating of the Belleville spring; and (2) the installation of the Marman clamp on the HB-4 adaptor flange. There were about a dozen cases where galling presented a problem; although these were accumulative in regard to delays, they did not present any significant complication. (The items with which there were galling problems are listed in Appendix C.)

There were no unusual radiation and/or contamination problems during the beryllium replacement shutdown. The control of the contamination zones in the reactor bay was remarkably good. Considering all the work performed in the reactor pool during the three months of the shutdown, there was actually less contamination of the floor area than there is during a relatively routine shutdown when control plates are changed out. The only time-consuming contamination problem (in regard to cleaning) was encountered during the removal and insertion of the beam-tube collimators.

The highest, accumulative radiation doses received by Reactor Operations personnel during the three months of the beryllium-replacement shutdown, in mrem, were 718, 681, and 479; the highest for P&E personnel were 680, 465, and 450. The quarterly dose limit, as specified in 10 CFR 20, is 1,500 mrem; the limit specified for Reactor Operations personnel is half this value or 750 mrem per quarter. In essence, even the highest doses were within the safest limits. (Refer to Appendix D for a summary of the radiation exposures received by persons actively participating in the shutdown work.) These data were obtained from the daily pocket-meter reports, from the pool entry cards, and from the film-badge reports. It should be noted that pocket-meter data are not recorded for daily doses of less than 20 mr; consequently, they do not reflect the total exposure received for all the in-pool work when doses of less than the 20 mr were received. The card file for the in-pool work indicates all the radiation received during the in-pool portion of the shutdown work. The film-badge data cover the period of time between June 30 and August 19, which was about half the period of the shutdown. In those cases where the pocket-meter figures are higher than those of the card file, it is indicative of work performed in areas other than the reactor pool.

There were no industrial-type accidents during the shutdown. One of the millwrights did bump his head while working on the beam-tube installation in the beam room; however, the injury was minor.

Because of known leaks that had existed in some of the HB flow and pressure-monitoring lines located in the reactor vessel prior to the shutdown, some modification to the routing of the CR (coolant return) lines from the beam-tube water-collector clamps was made. In essence, these modifications were that the CR lines are no longer routed to the "horny pieces"; they are now routed through flanges in the vessel head and are connected to the hydraulic-tube discharge line in the reactor pool. The advantage of this is that, if similar leaks develop in the beam tube flow and pressure-monitoring lines, they can be isolated, checked, and repaired with considerably less complication than they could have with the old piping scheme. There were no modifications in the EF flow and pressure-monitoring lines because the consequences of leaks in this case would be minimal.

As mentioned earlier, there were a number of other jobs scheduled and performed during the beryllium-replacement shutdown (a list of these jobs is given in Appendix B). The major jobs were:

1. Removal of the deposits (primarily phosphates) from the secondary water (shell) side of the four heat exchangers. This work, which was performed by Dow Industrial Services, required some temporary piping to the heat exchangers. The procedure consisted of circulating a heated solution of sulfuric acid (150°F, 14% concentration) through each heat exchanger for about six hours. The initial attempt at cleaning, using a different descaling solution, was

unsuccessful; however, the second attempt, using the sulfuric acid, cleaned the tubes in the heat exchangers very well. This operation corrected a heat-transfer problem with the secondary coolant which had existed for some time.

2. Installation of viewing ports (with an inside diameter of ∿10 in.) in the shell side of heat exchangers B, C, and D (in cells 112, 111, and 110) as specified in Mechanical Design Change Memorandum No. 45.
3. Removal, overhauling, and reinsertion of all the flow-control valves in the secondary-water side of the four heat exchangers. (See Figure 58.)
4. Installation of a manually operated valve in the 12-in.-diameter bypass line around the cooling tower. This valve was installed upstream of the automatically operated butterfly valve in the bypass line to permit manual shutoff and repairs of the butterfly valve during operation, if required (Mechanical Design Change Memorandum No. 45).
5. Construction of an addition to the HFIR building, south side, beam-room level, for the benefit of the experimenters. (See Figure 59.)

During the three months following the reactor startup, the work of reinstalling the shielding blocks, the rotating shutters, and the electronic equipment at the beam-tube facilities was continued. (See Figures 60, 61, 62, 63, and 64.)

Considering the overall magnitude of this undertaking, the beryllium-replacement shutdown progressed exceptionally well and was completed two months earlier than predicted.

In addition to the reactor operators and supervisors, Inspection Engineering personnel, the craft personnel, and the Health Physics personnel who performed very well during the shutdown work, special credit is given to those individuals who planned the shutdown operation, designed the many special tools, and actively participated in the shutdown work; these were A. A. Abbatiello, G. R. Hicks, E. L. Hutto, and L. P. Pugh.

APPENDIX A

DIAGRAMS AND PHOTOGRAPHS

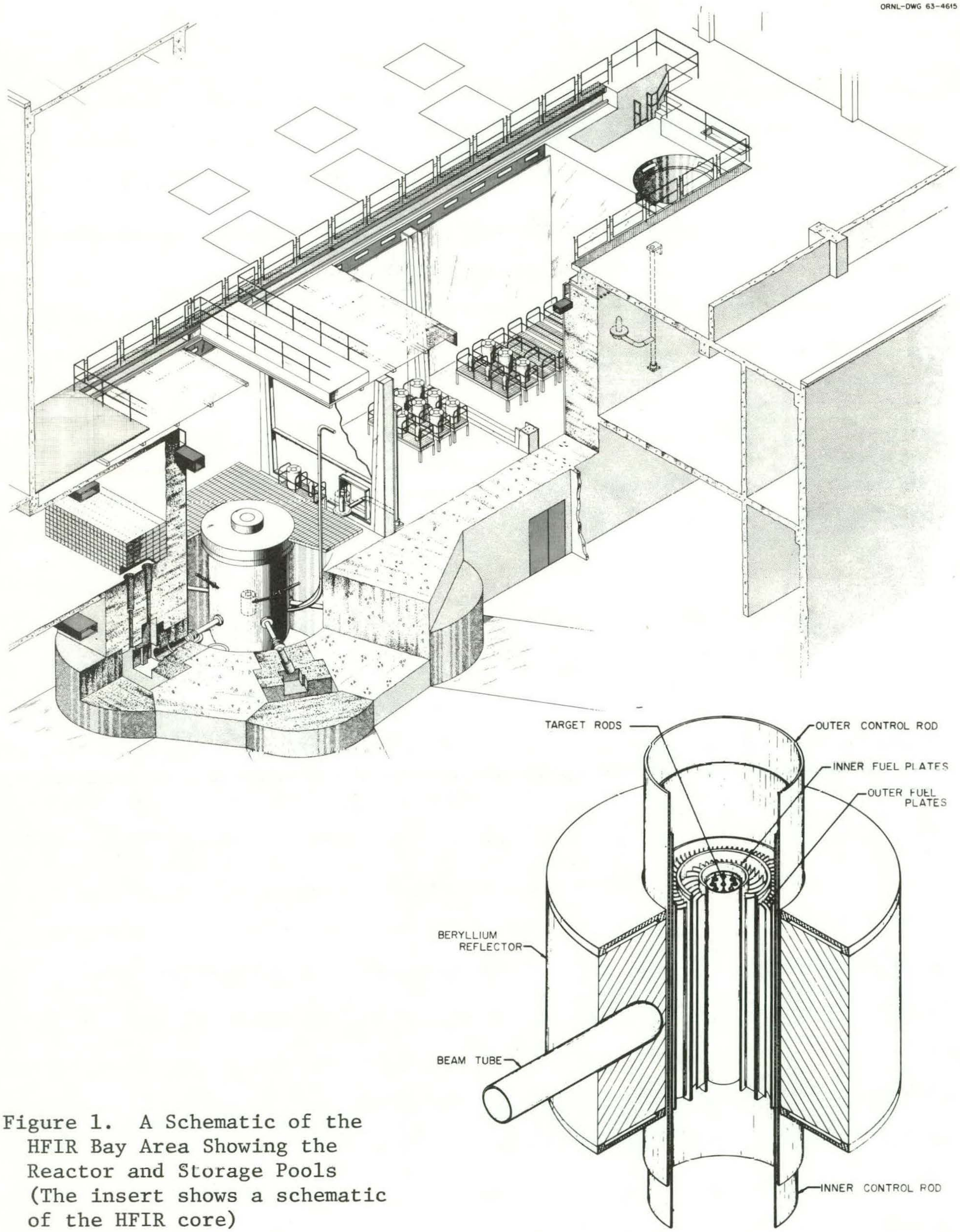

Figure 1. A Schematic of the HFIR Bay Area Showing the Reactor and Storage Pools (The insert shows a schematic of the HFIR core)

ORNL-LR-DWG 61472AR3

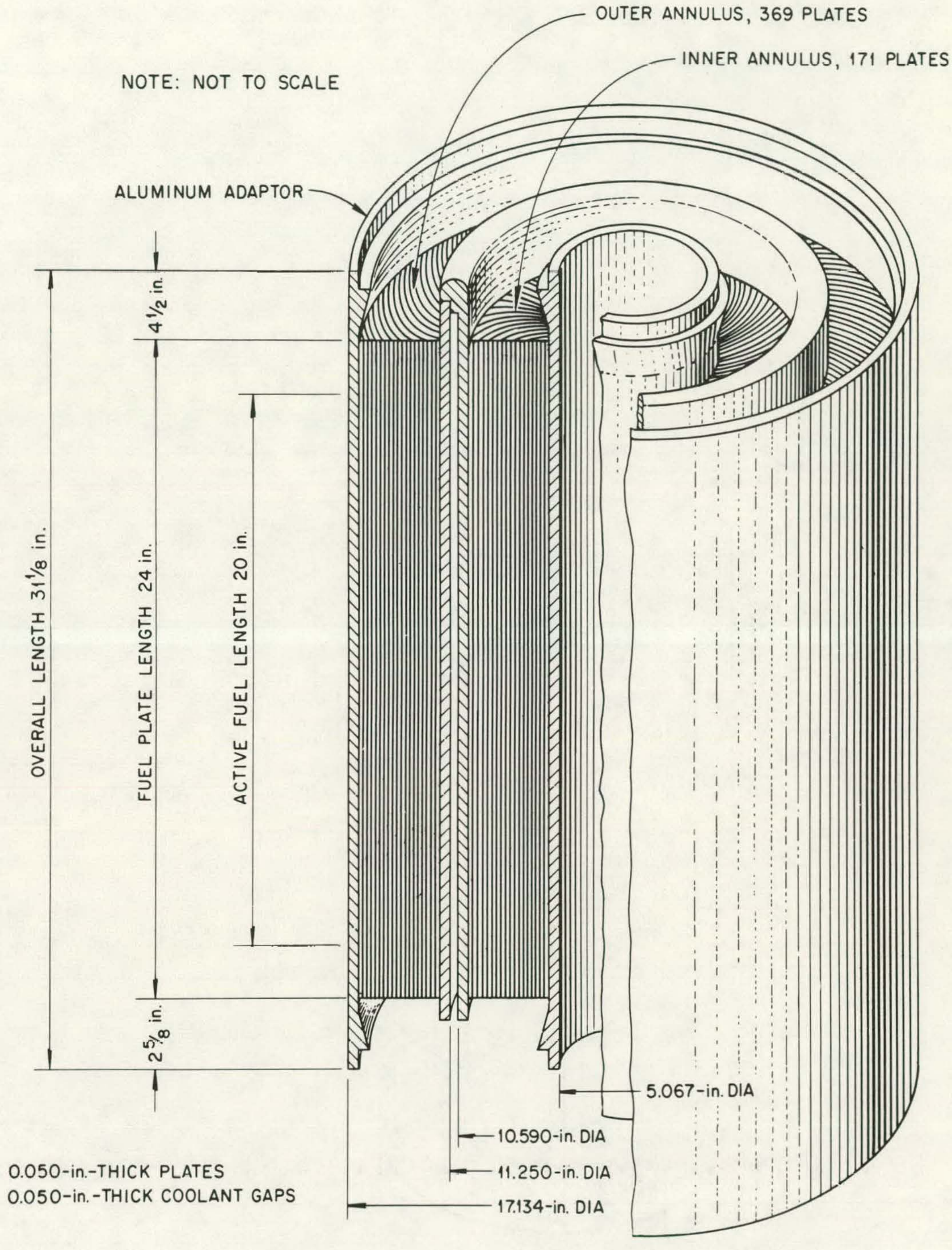

Figure 2. HFIR Fuel Element

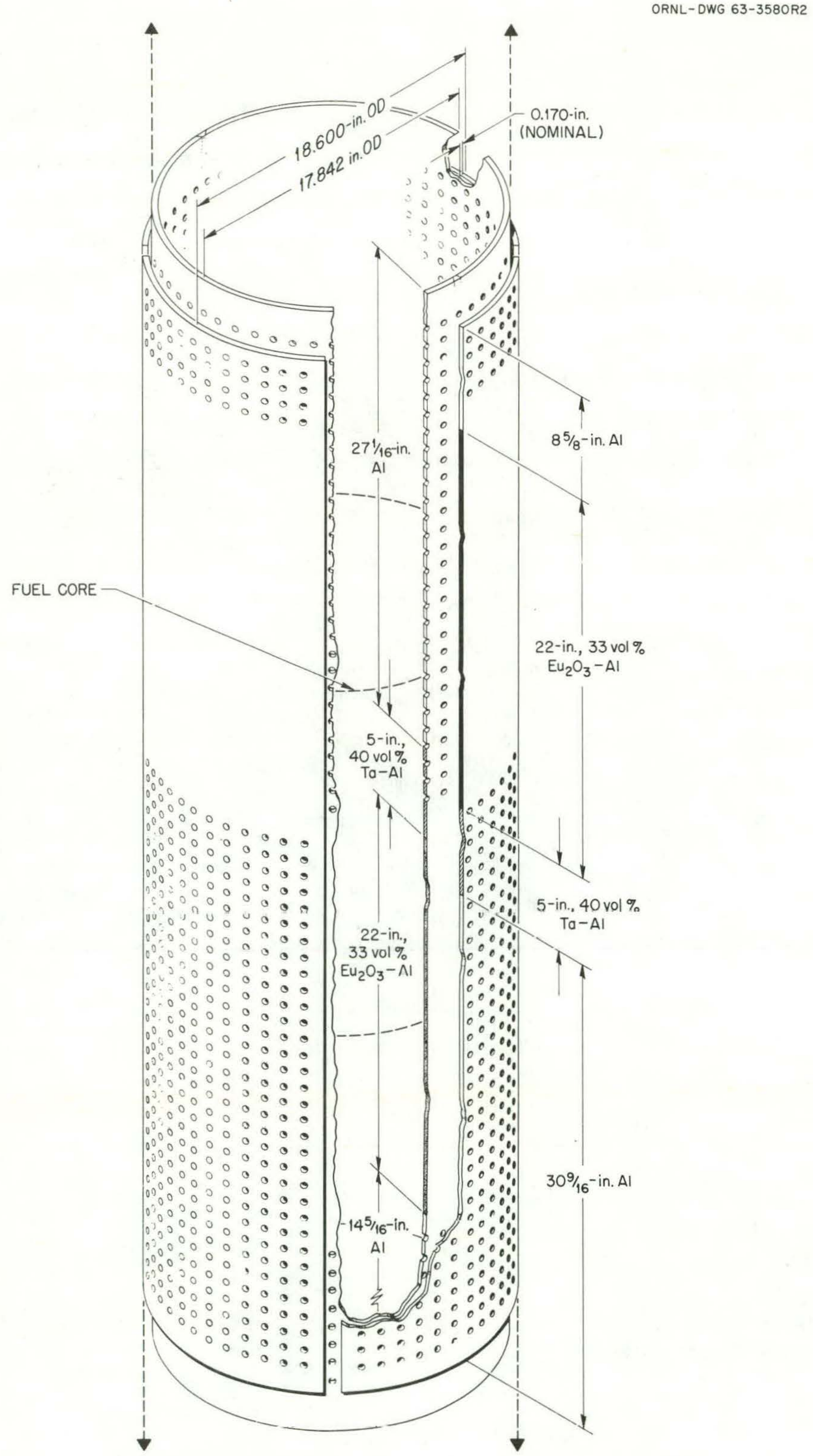

Figure 3. HFIR Control Plates

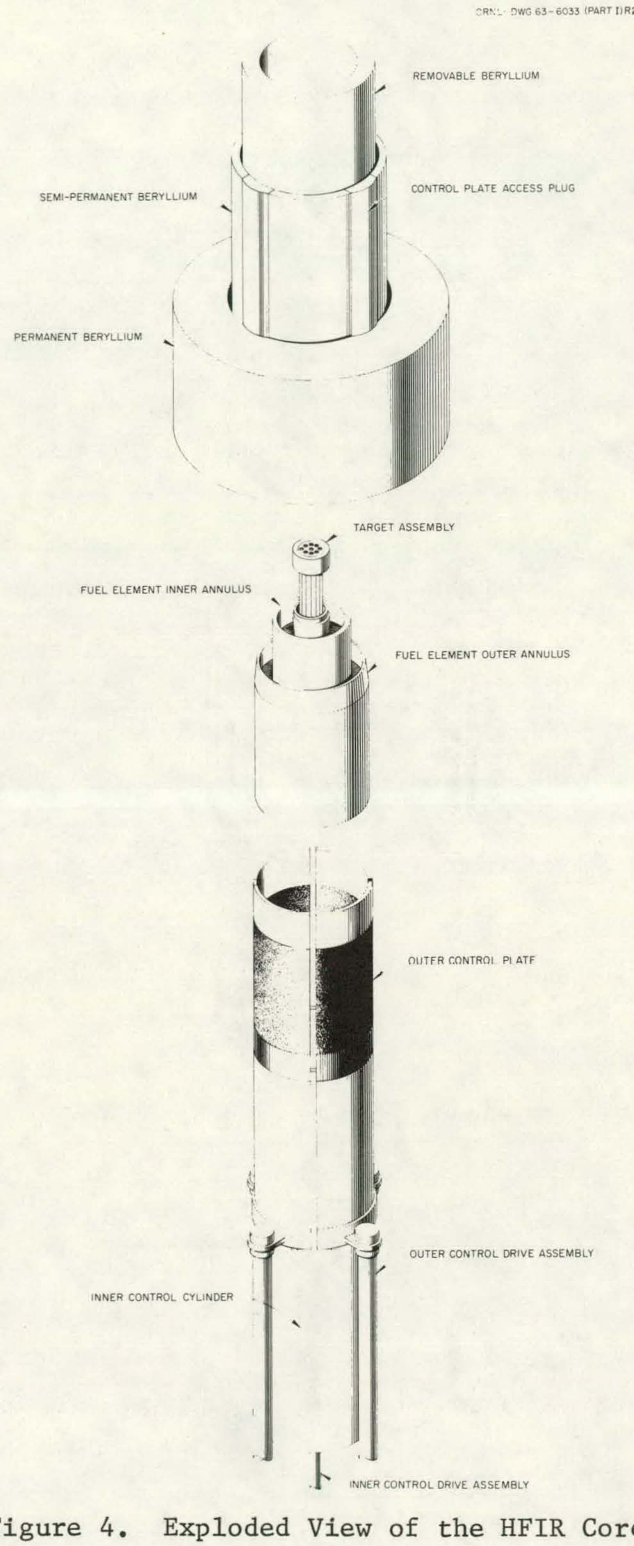

Figure 4. Exploded View of the HFIR Core

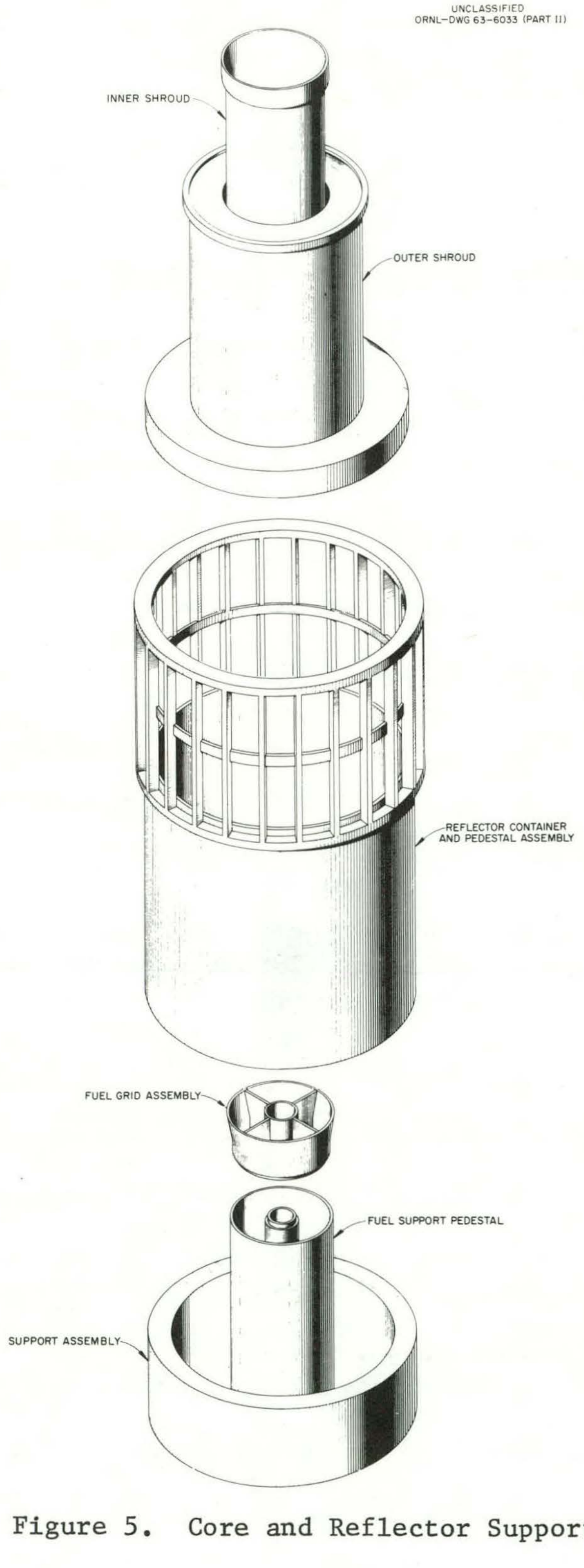

Figure 5. Core and Reflector Support

ORNL-DWG 64-4080

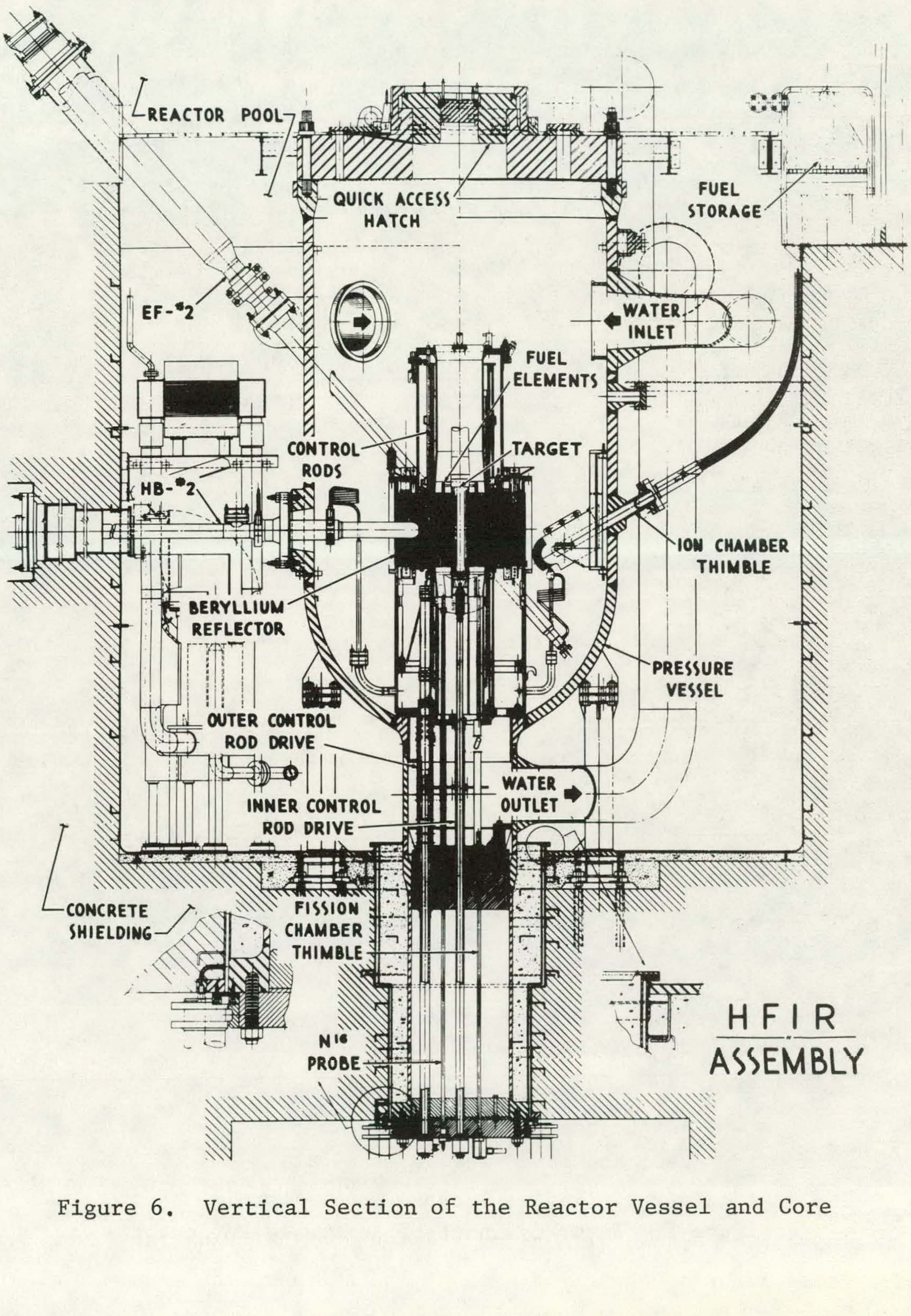

Figure 6. Vertical Section of the Reactor Vessel and Core

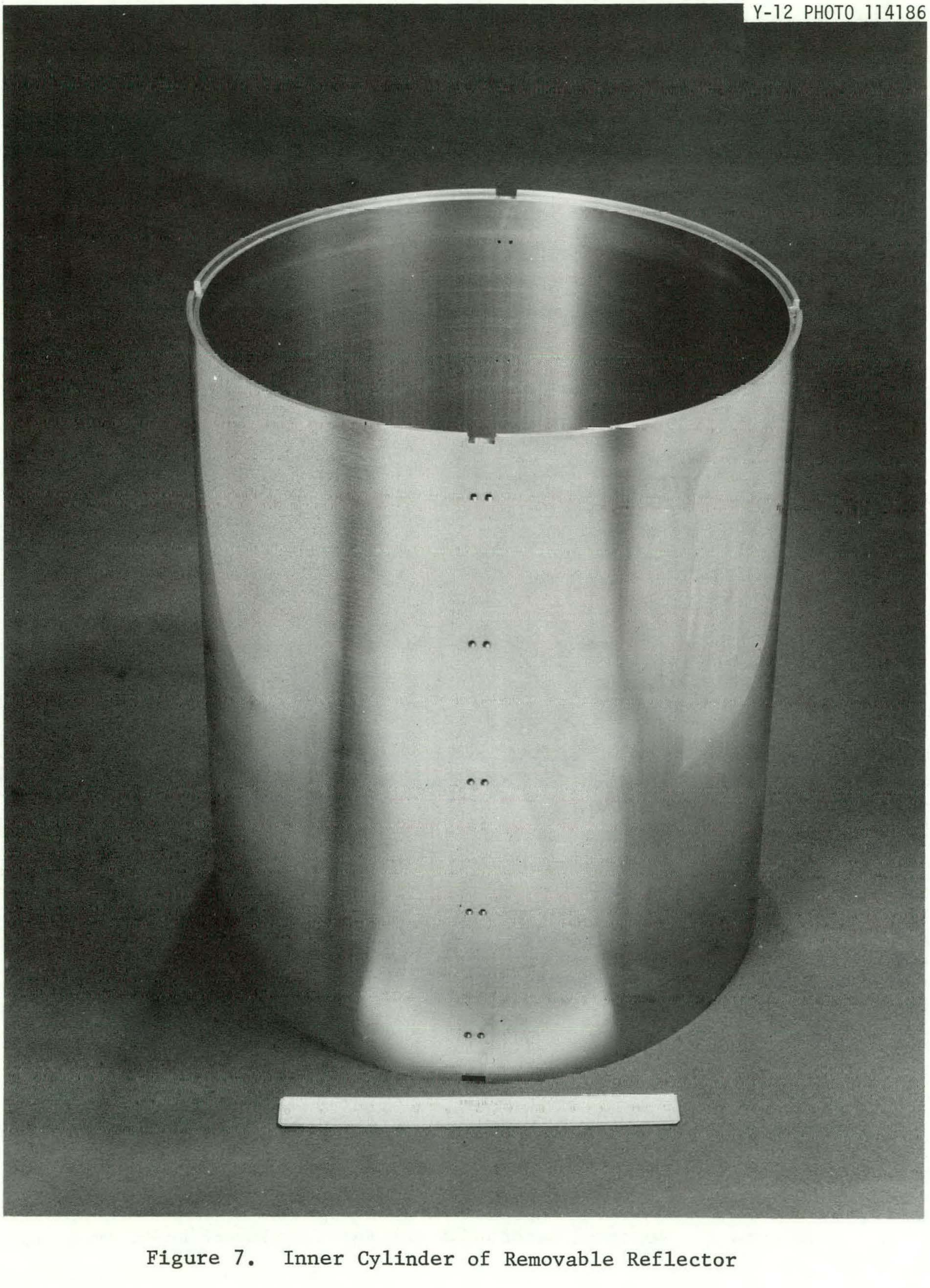

Figure 7. Inner Cylinder of Removable Reflector

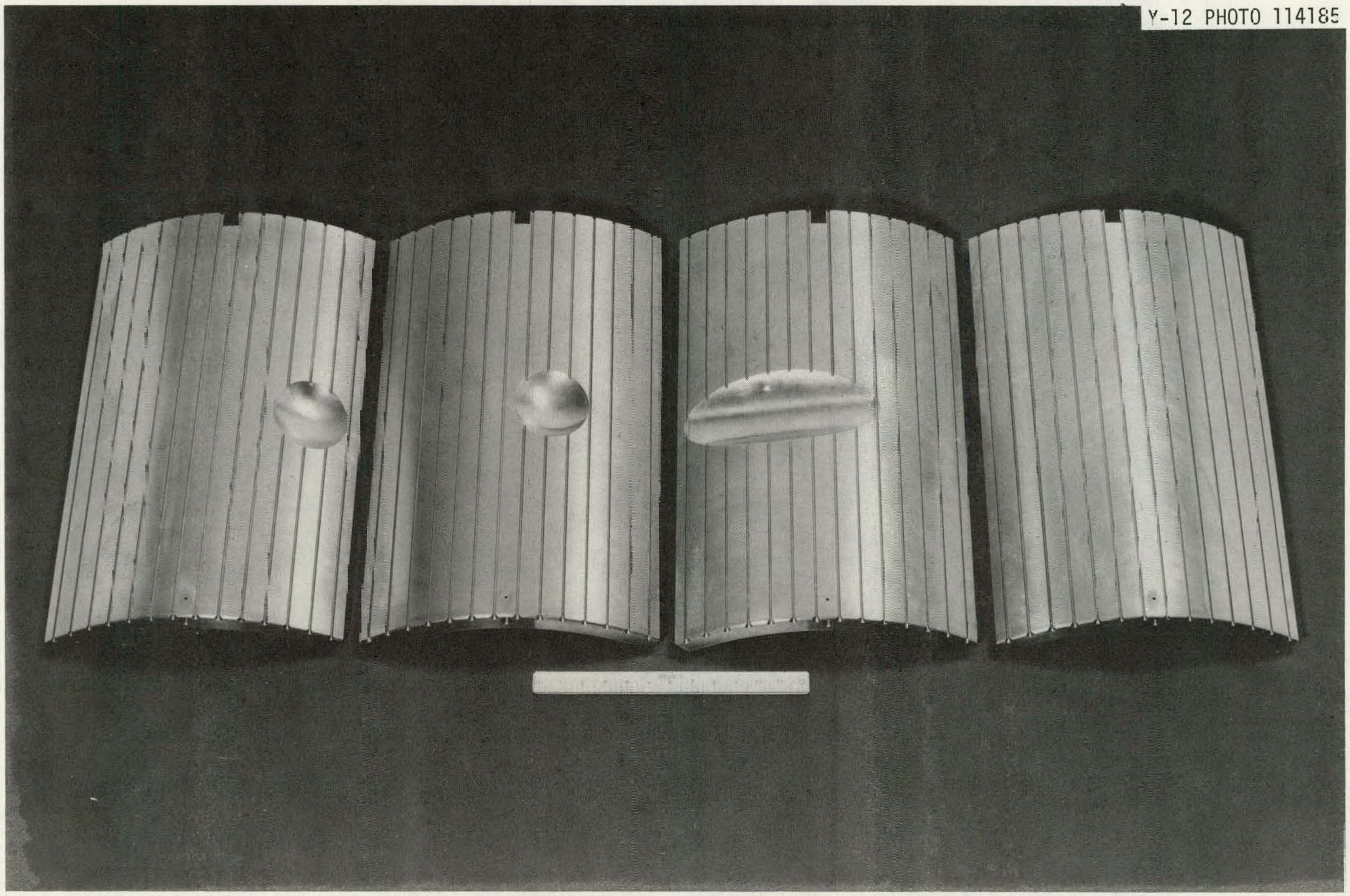

Figure 8. Semipermanent Reflector

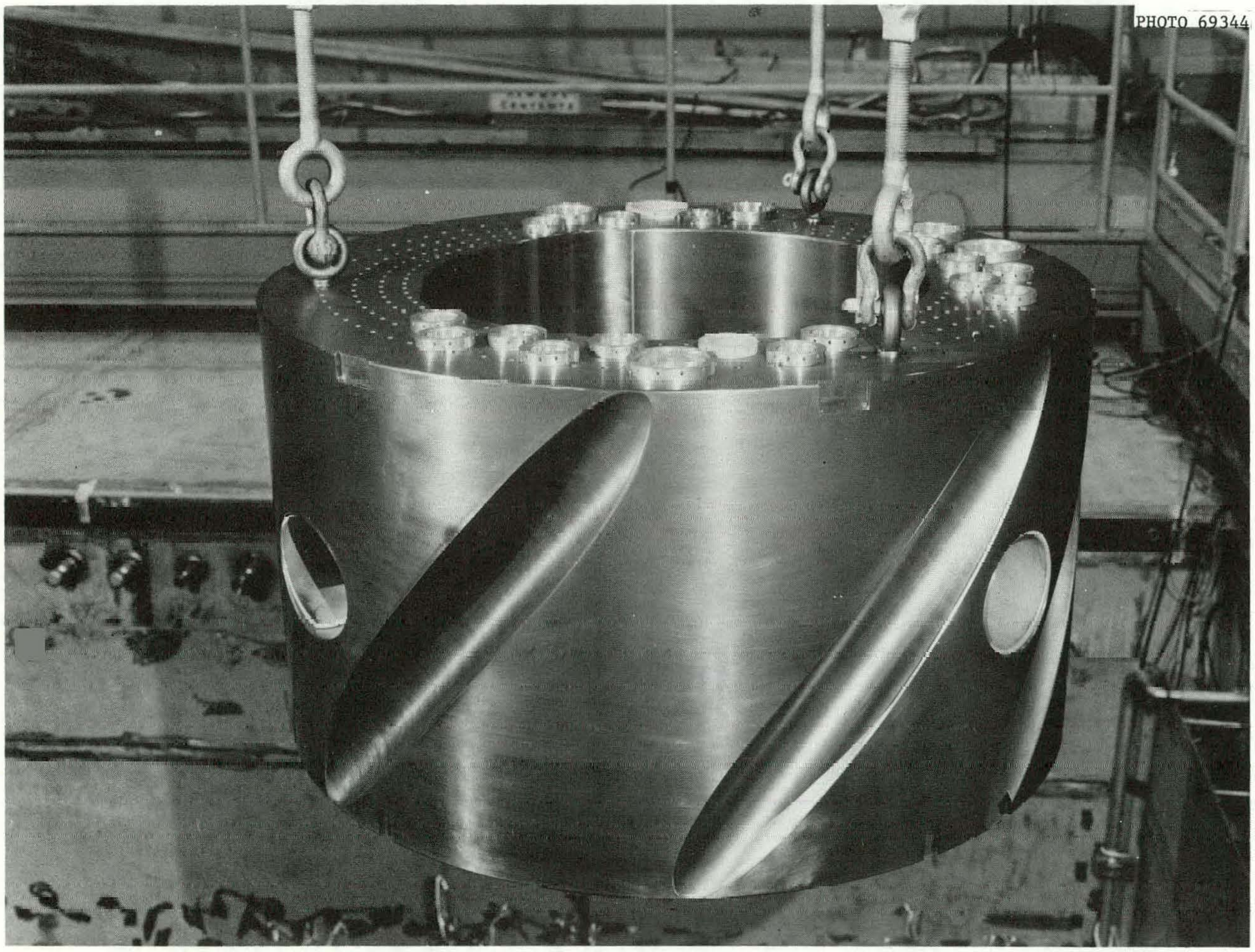

Figure 9. Permanent Reflector

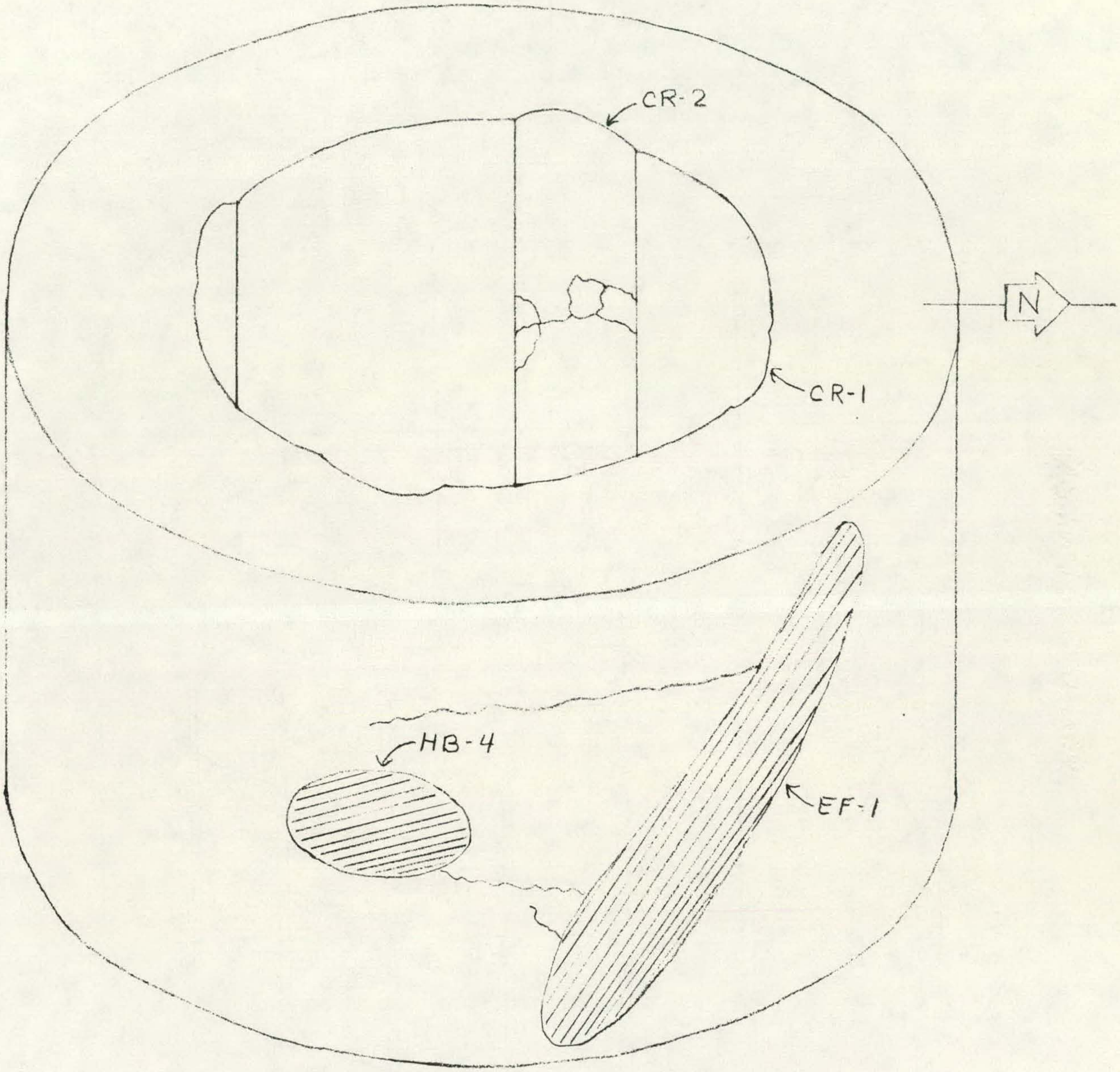

Figure 10. Cracks in the Permanent Beryllium Reflector
View 1

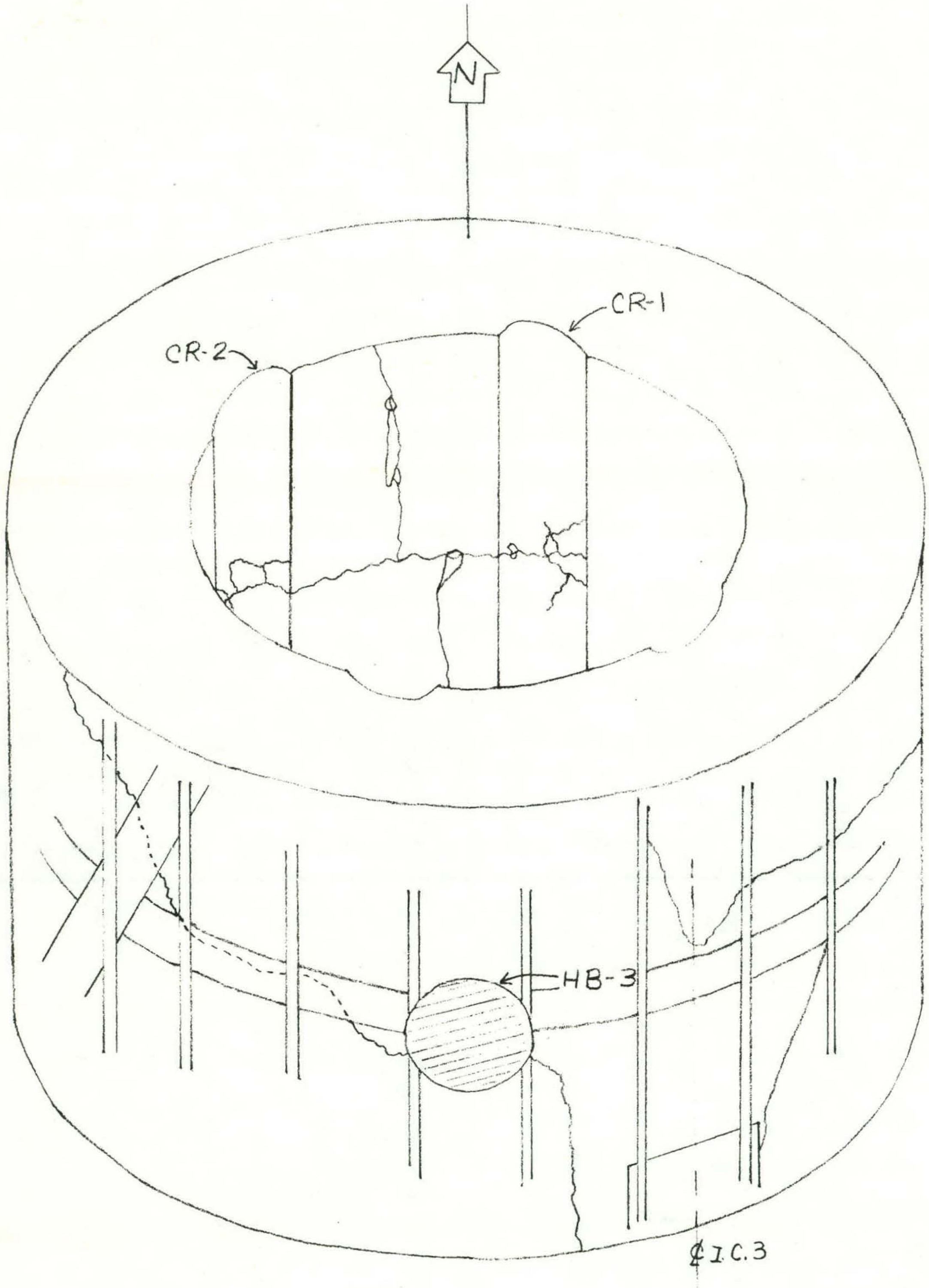

Figure 11. Cracks in the Permanent Beryllium Reflector
View 2

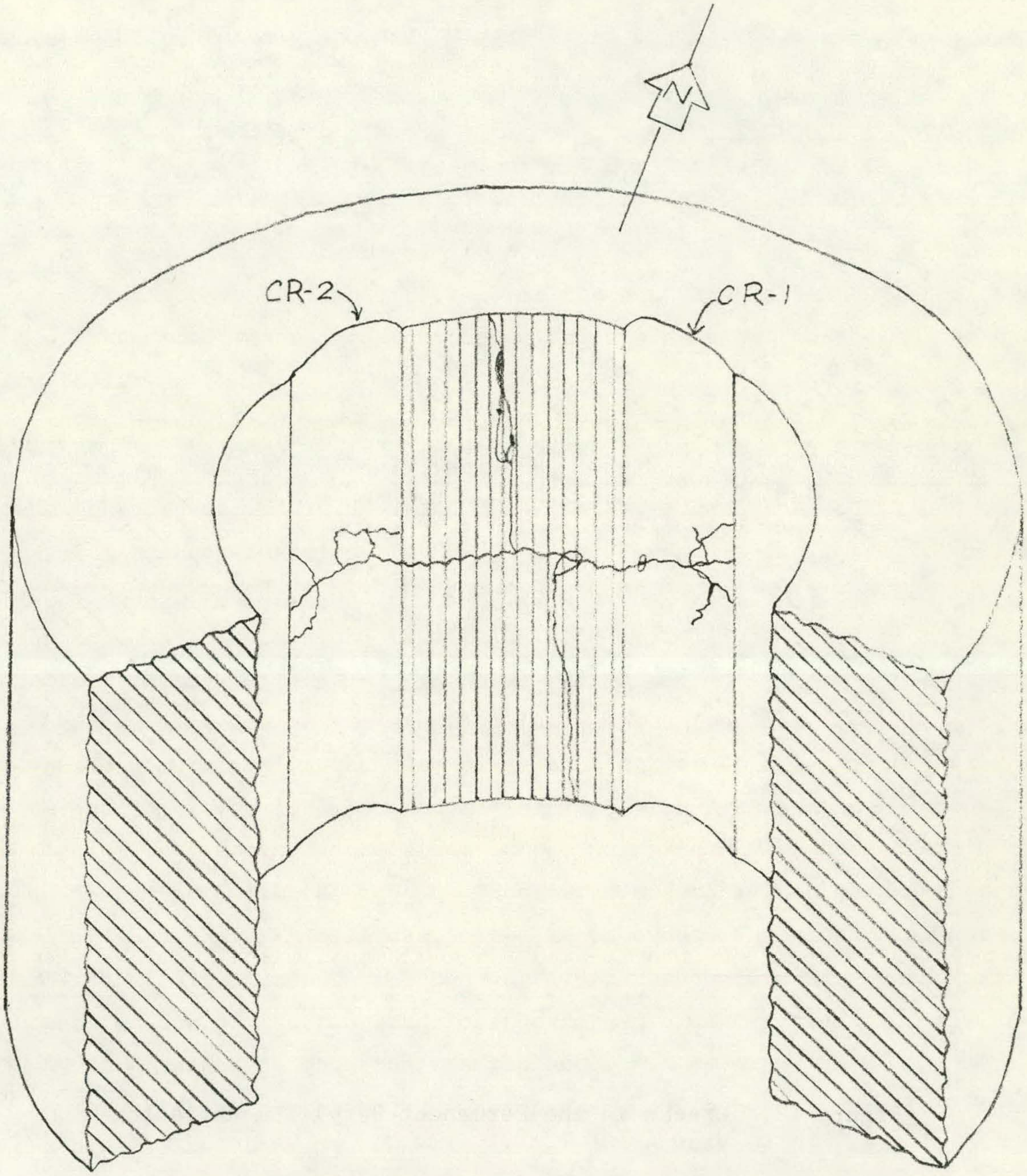

Figure 12. Cracks in the Permanent Beryllium Reflector
View 3

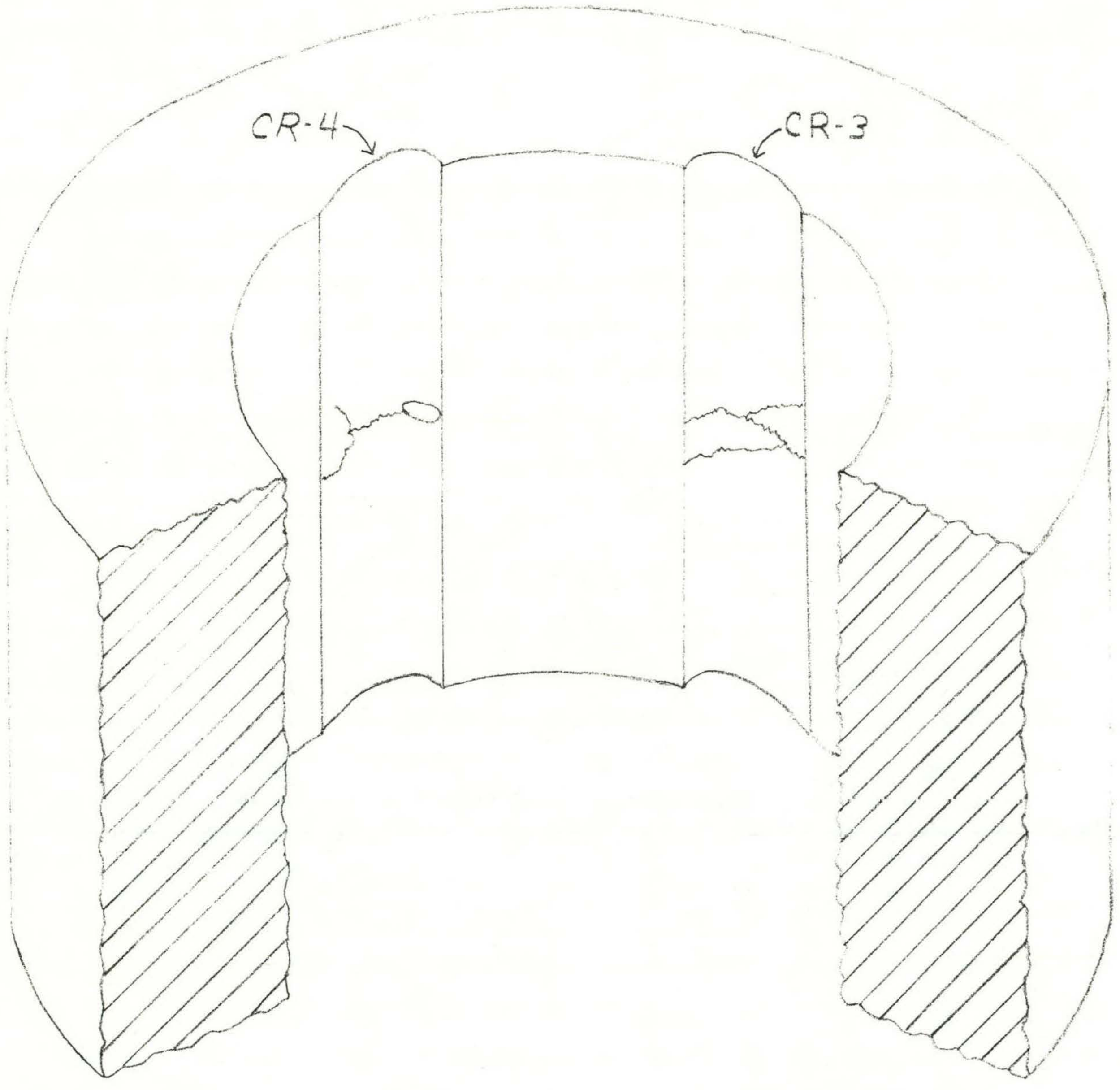

Figure 13. Cracks in the Permanent Beryllium Reflector
View 4

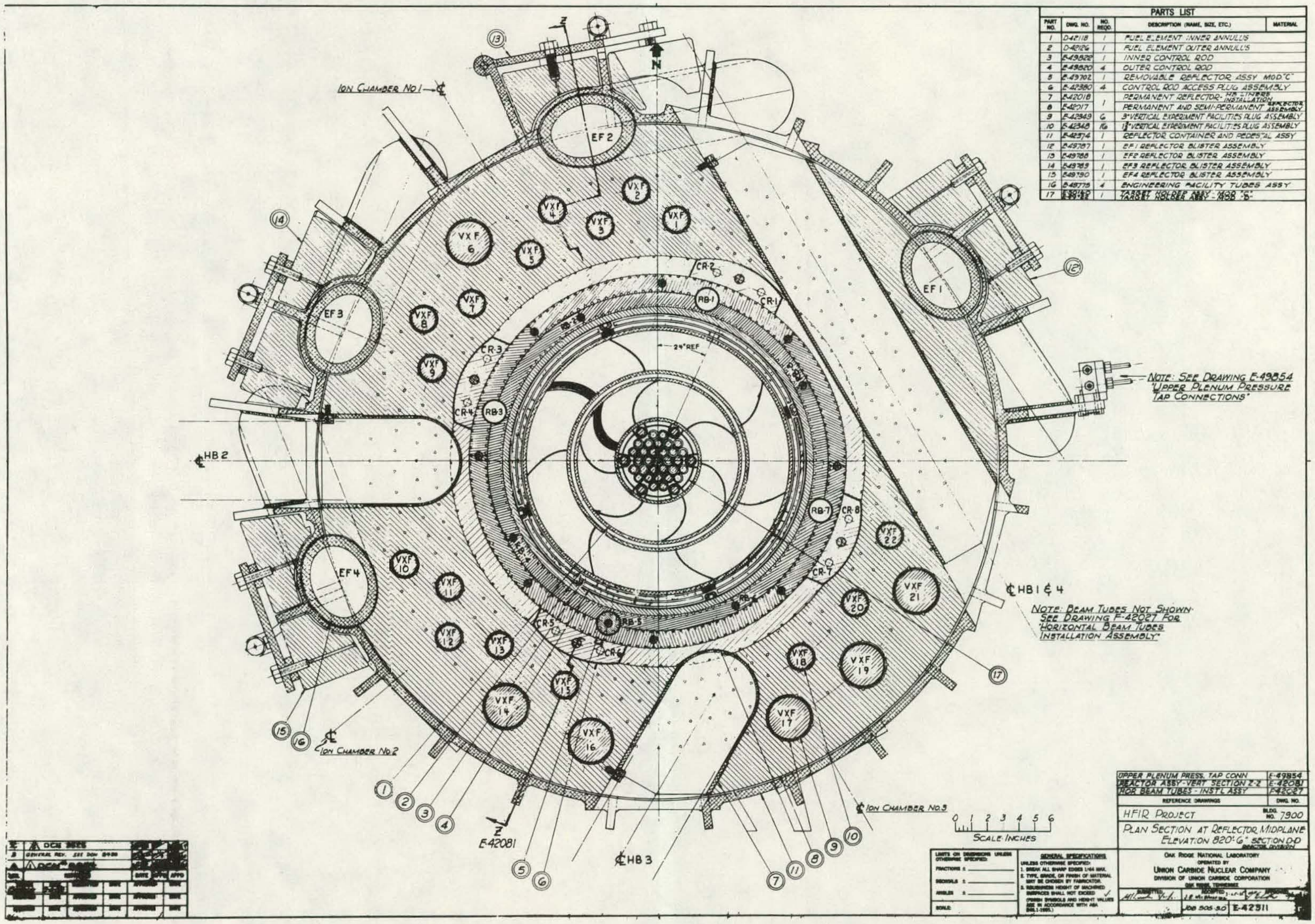

Figure 14. The HFIR Reflector (Plan at Centerline) Showing the VXF Holes, the EF Penetrations, and the HB Penetrations

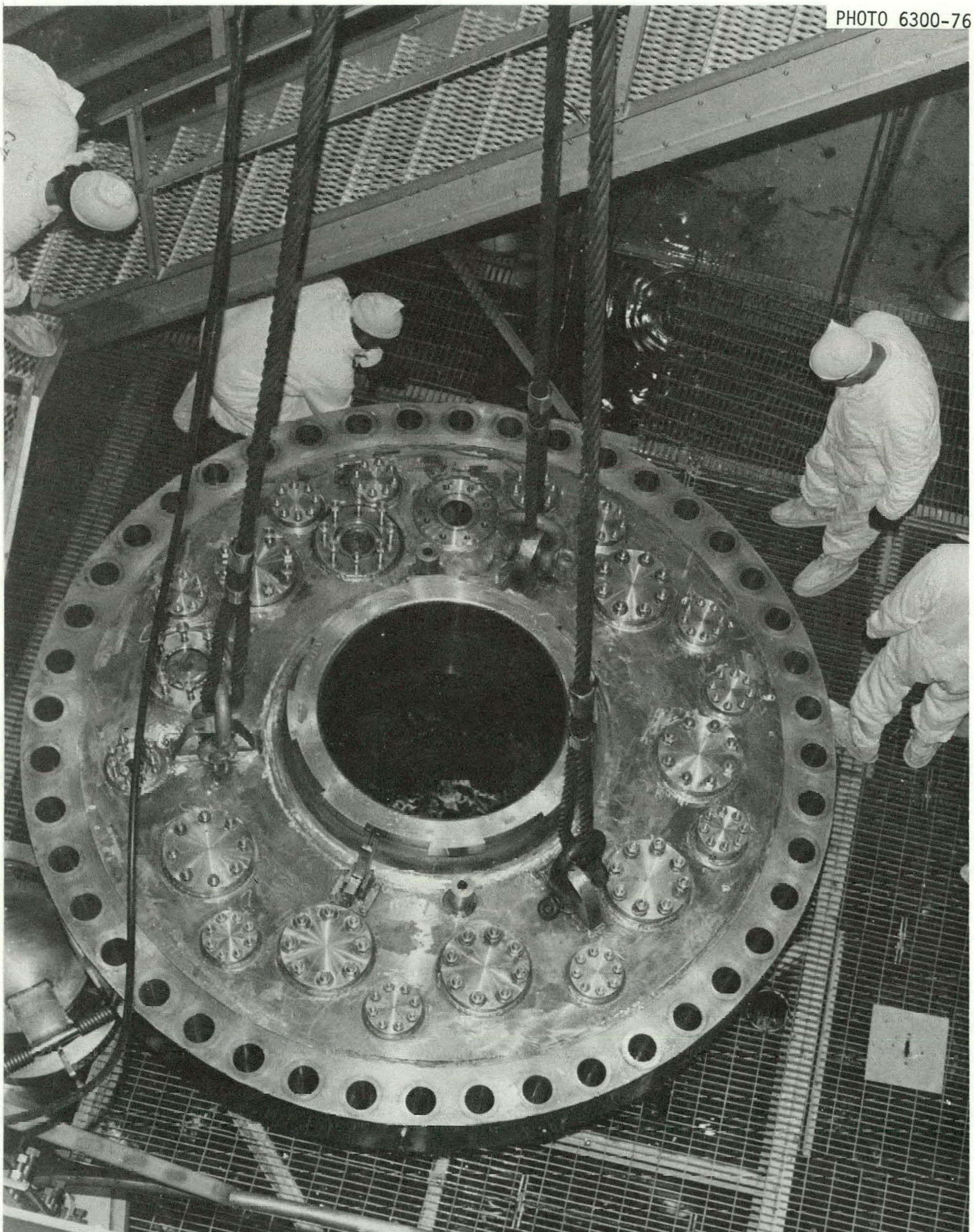

Figure 15. The Reactor Vessel Head Being Removed

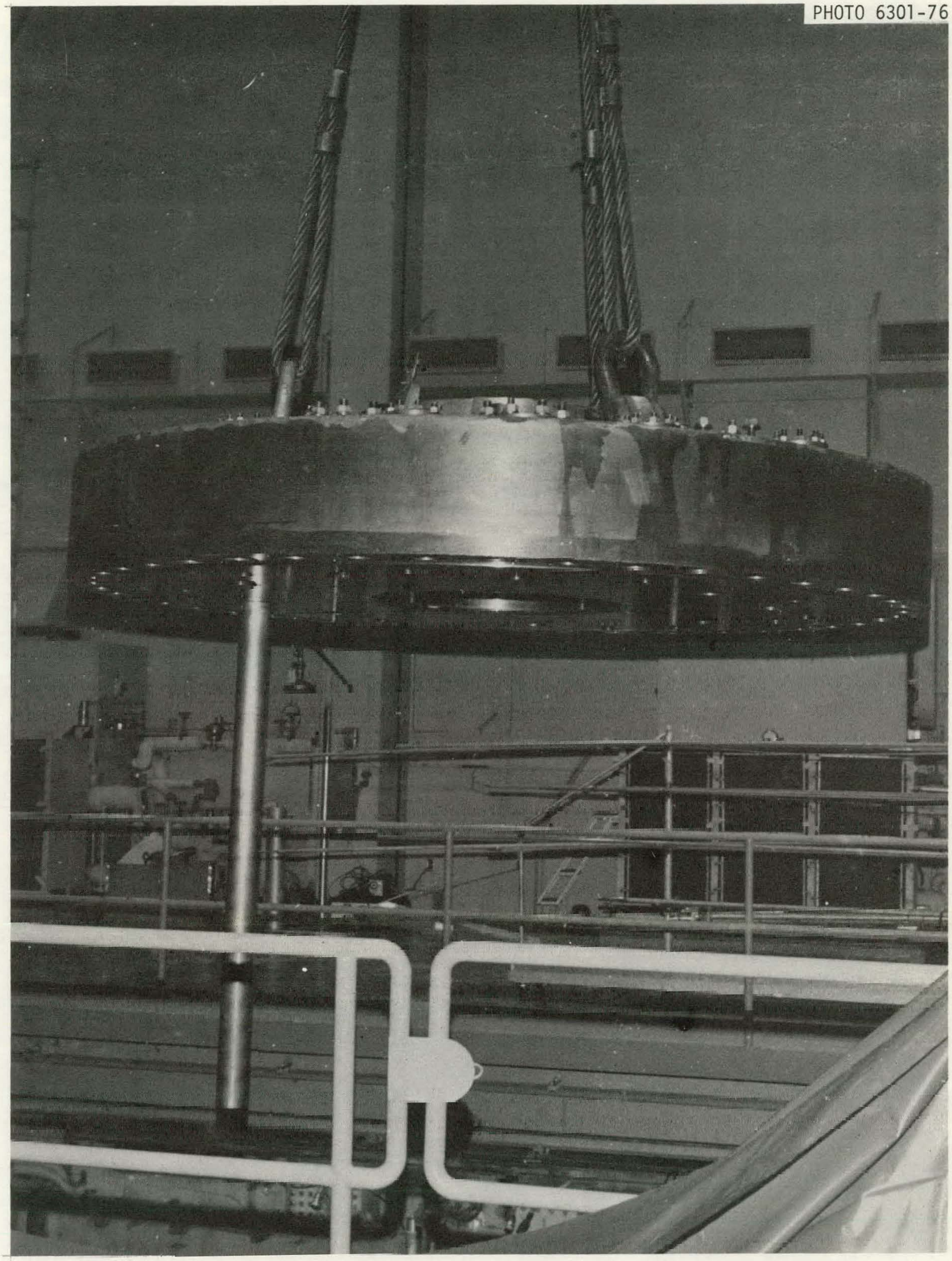

Figure 16. The Reactor Vessel Head and the Keeper Post

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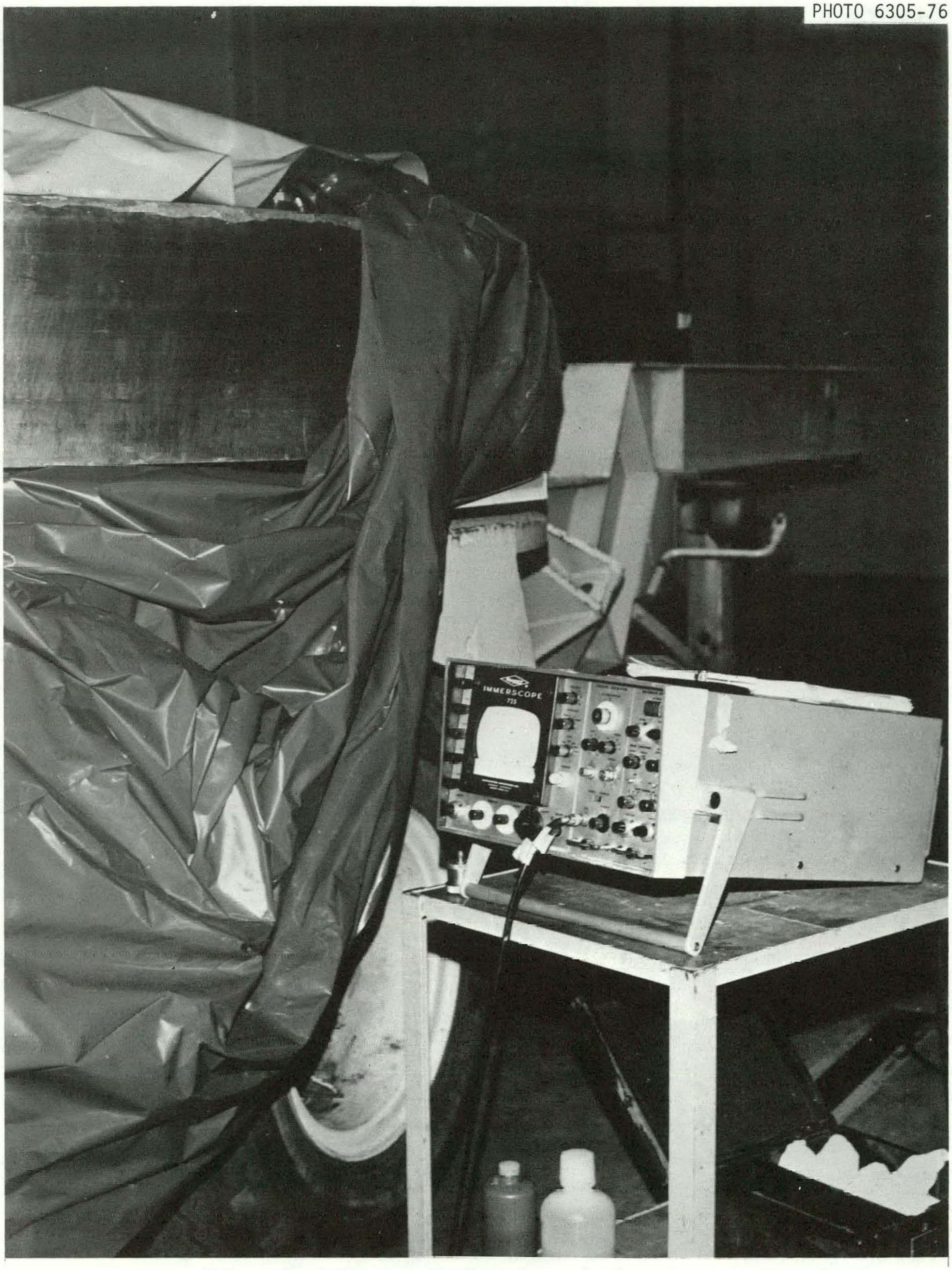

Figure 17. The Ultrasonic Testing of the Reactor Vessel Head After It Was Placed on the Truck for Storage

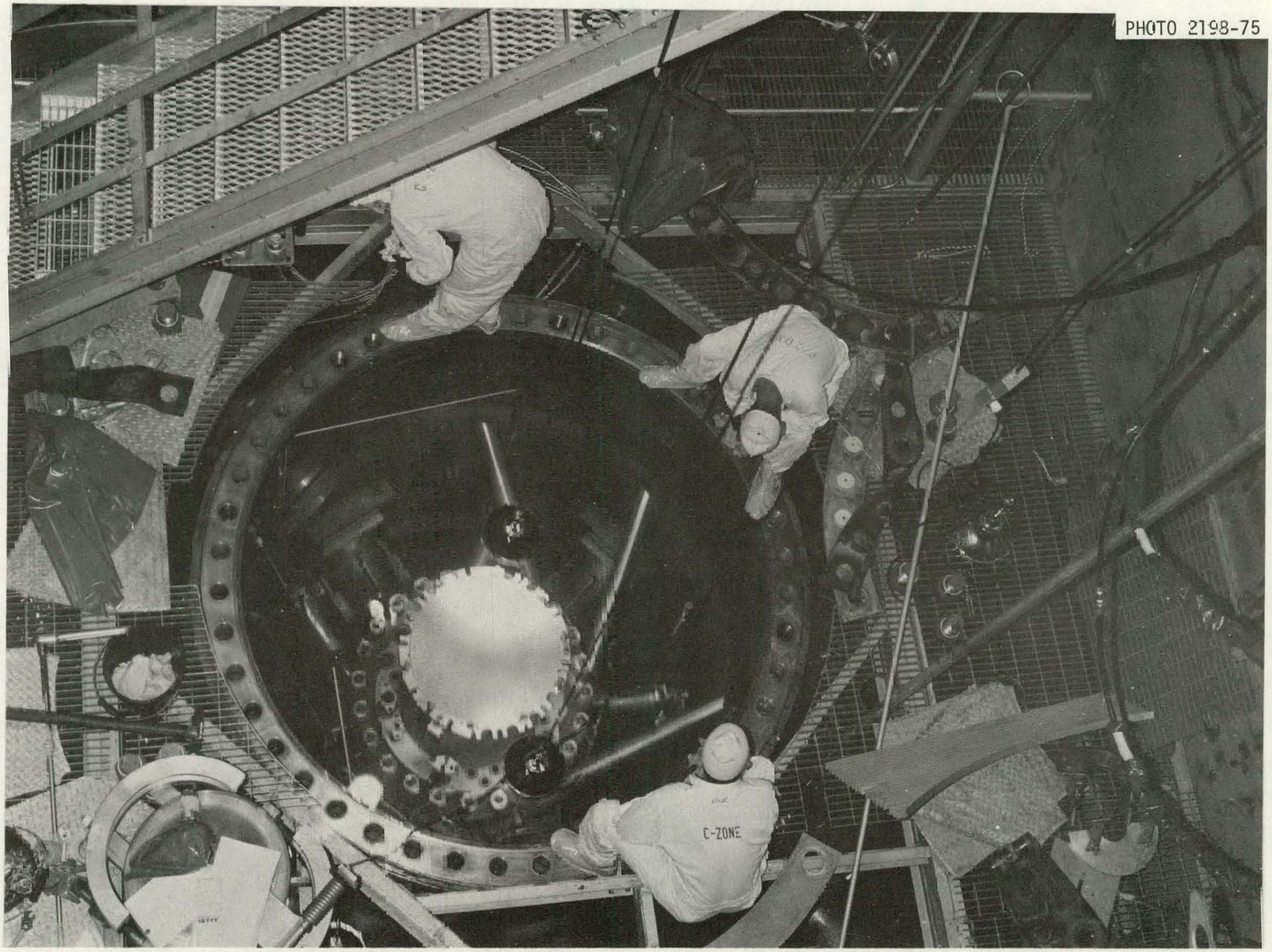

Figure 18. The Reactor Pool Without the Work Platform

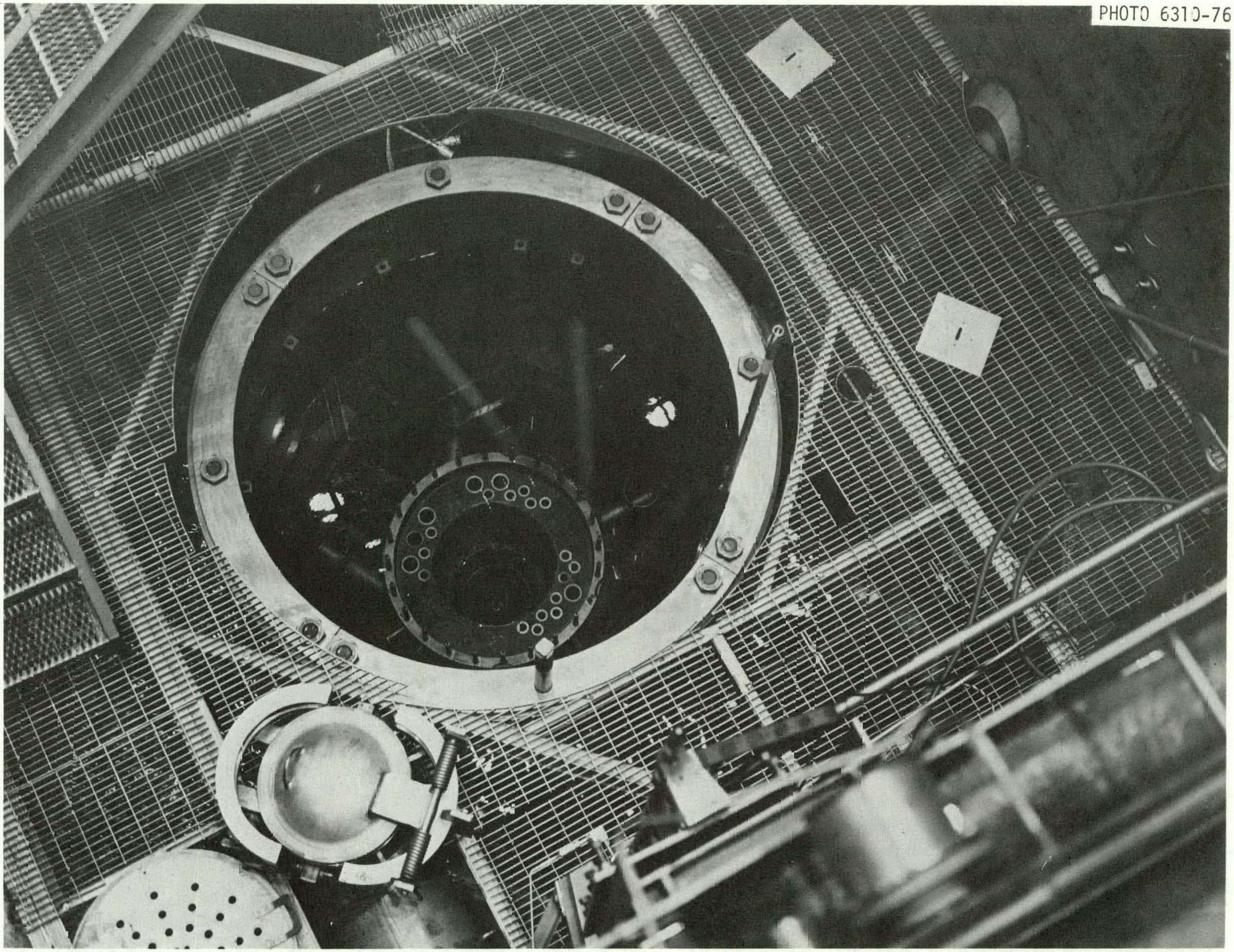

Figure 19. The Reactor Vessel with the Stud-Hole Seal Plates Installed

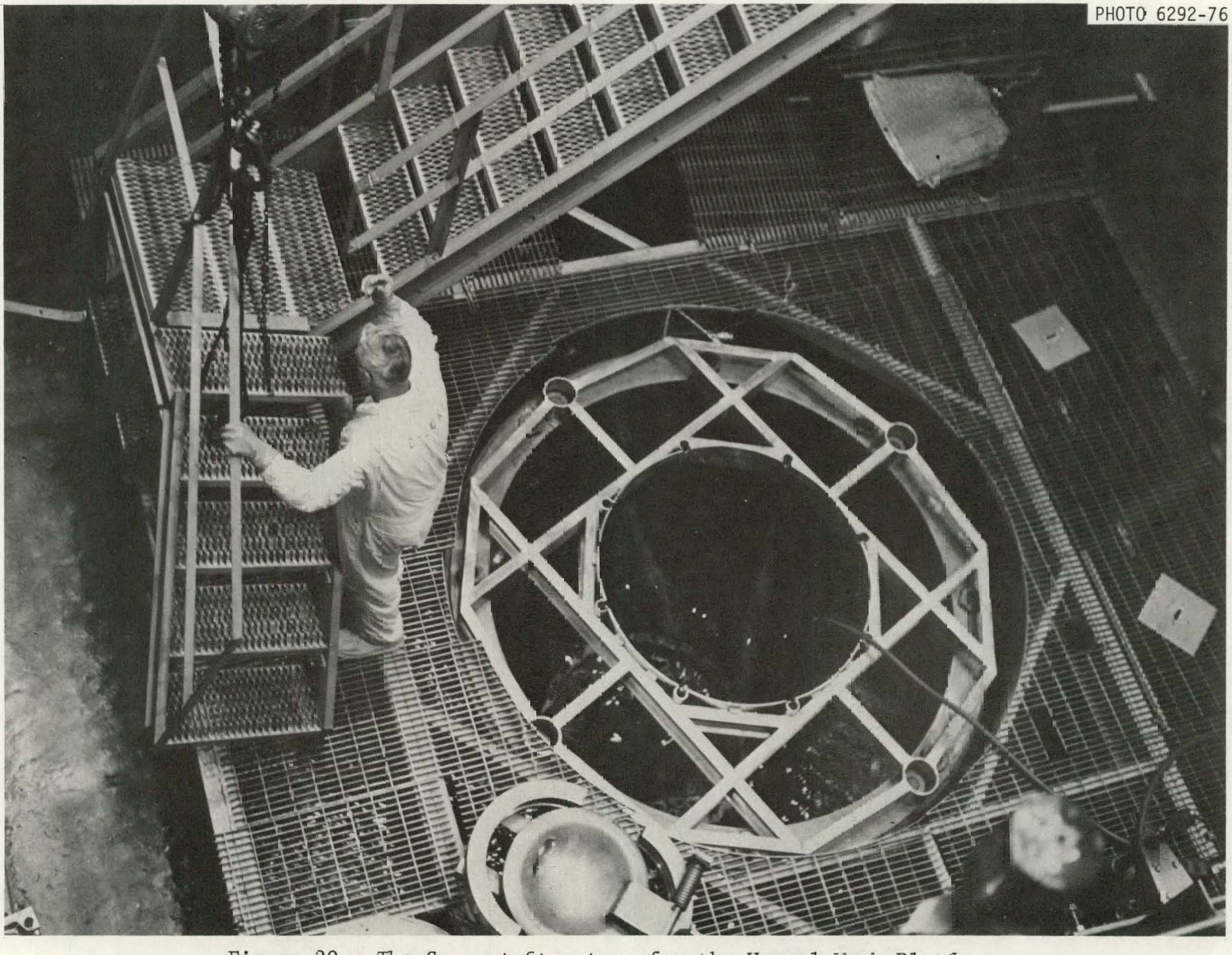

Figure 20. The Support Structure for the Vessel Work Platform

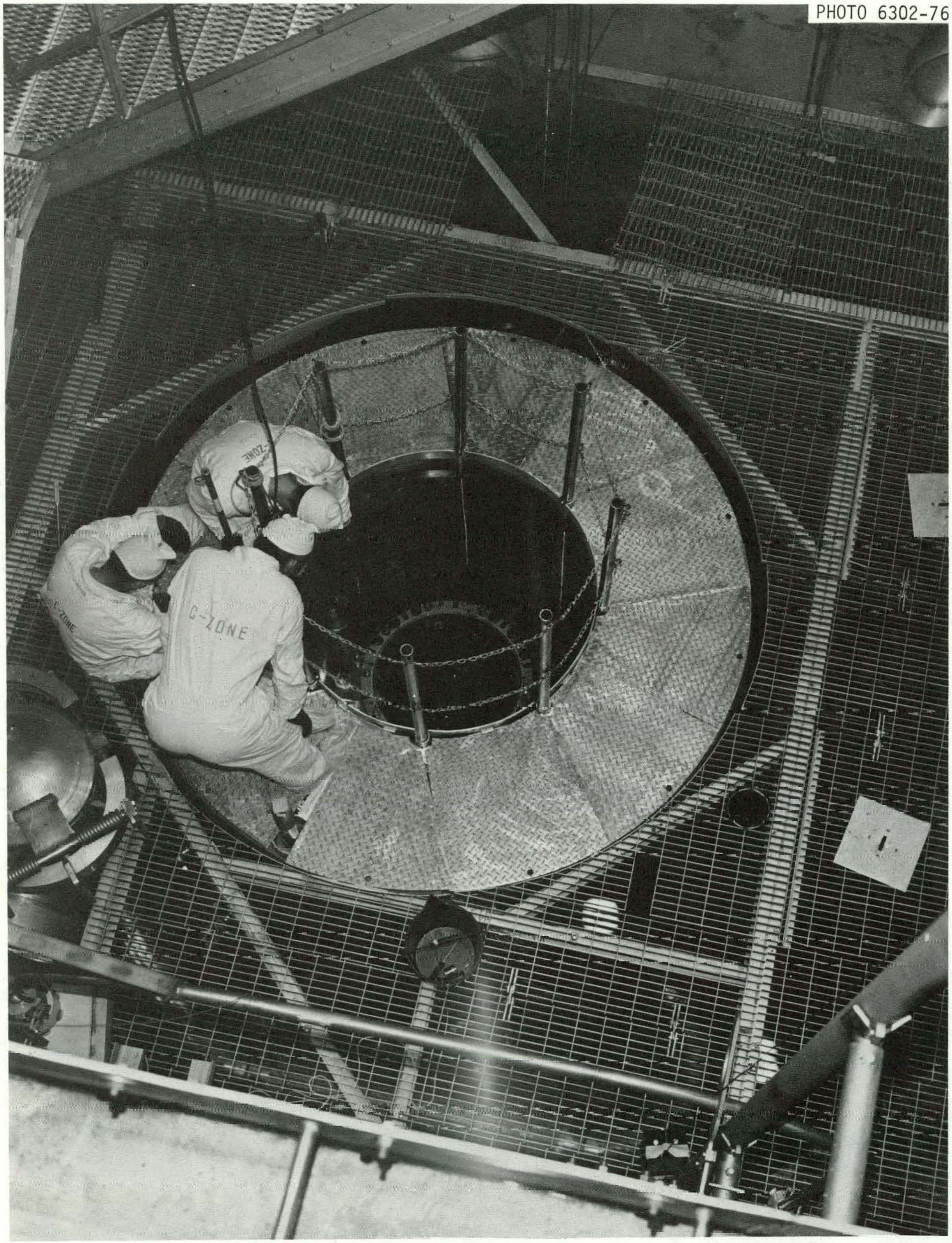

Figure 21. The Reactor Vessel with the Work Platform Installed

PHOTO 6306-76

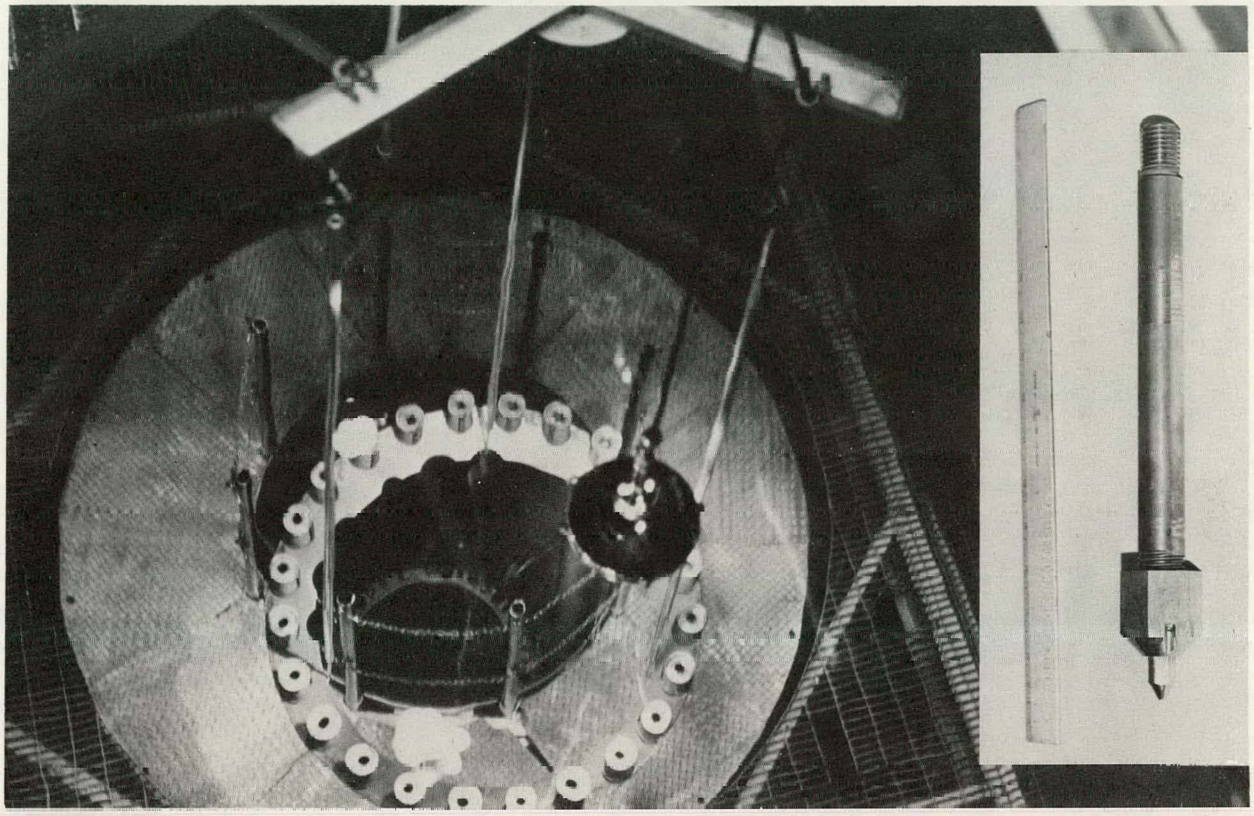

Figure 22. The Belleville Spring Being Removed
(Underwater Photograph)
(The insert shows one of the 24 studs used
to secure the Belleville spring)

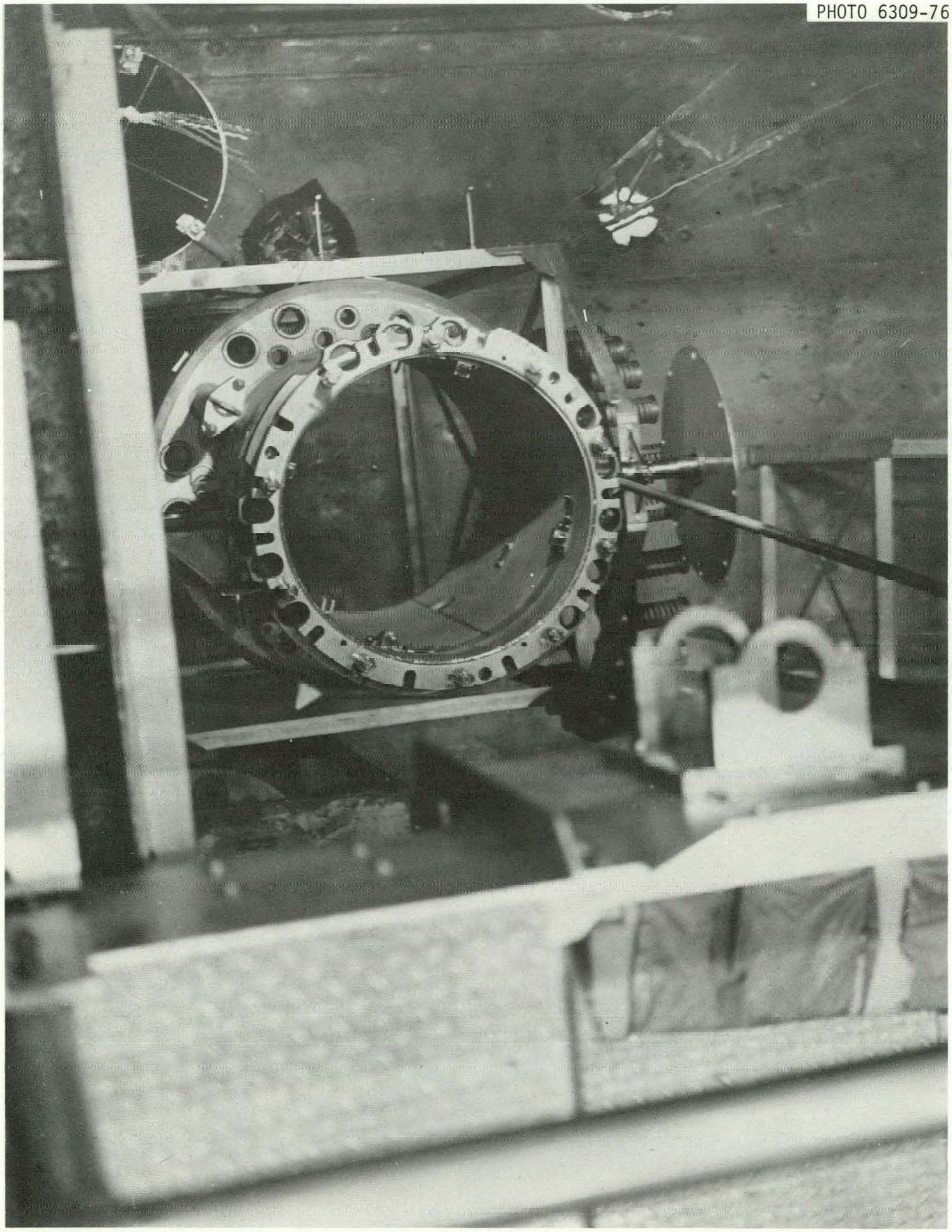

Figure 23. The Outer Shroud in the Work Platform (Underwater Photograph)

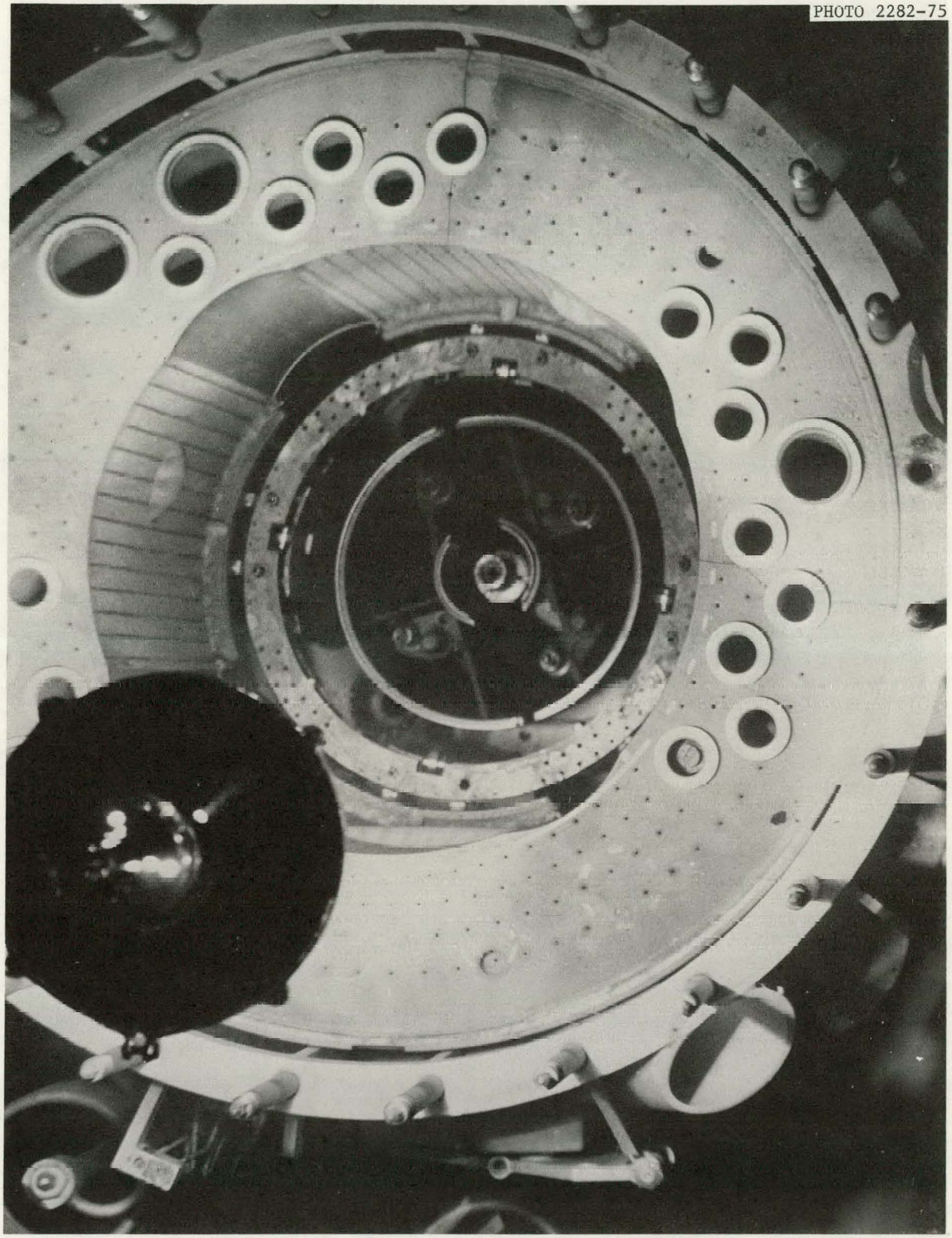

Figure 24. The Permanent Beryllium Reflector Showing the Cracks in the Surface (Underwater Photograph)

PHOTO 2201-75

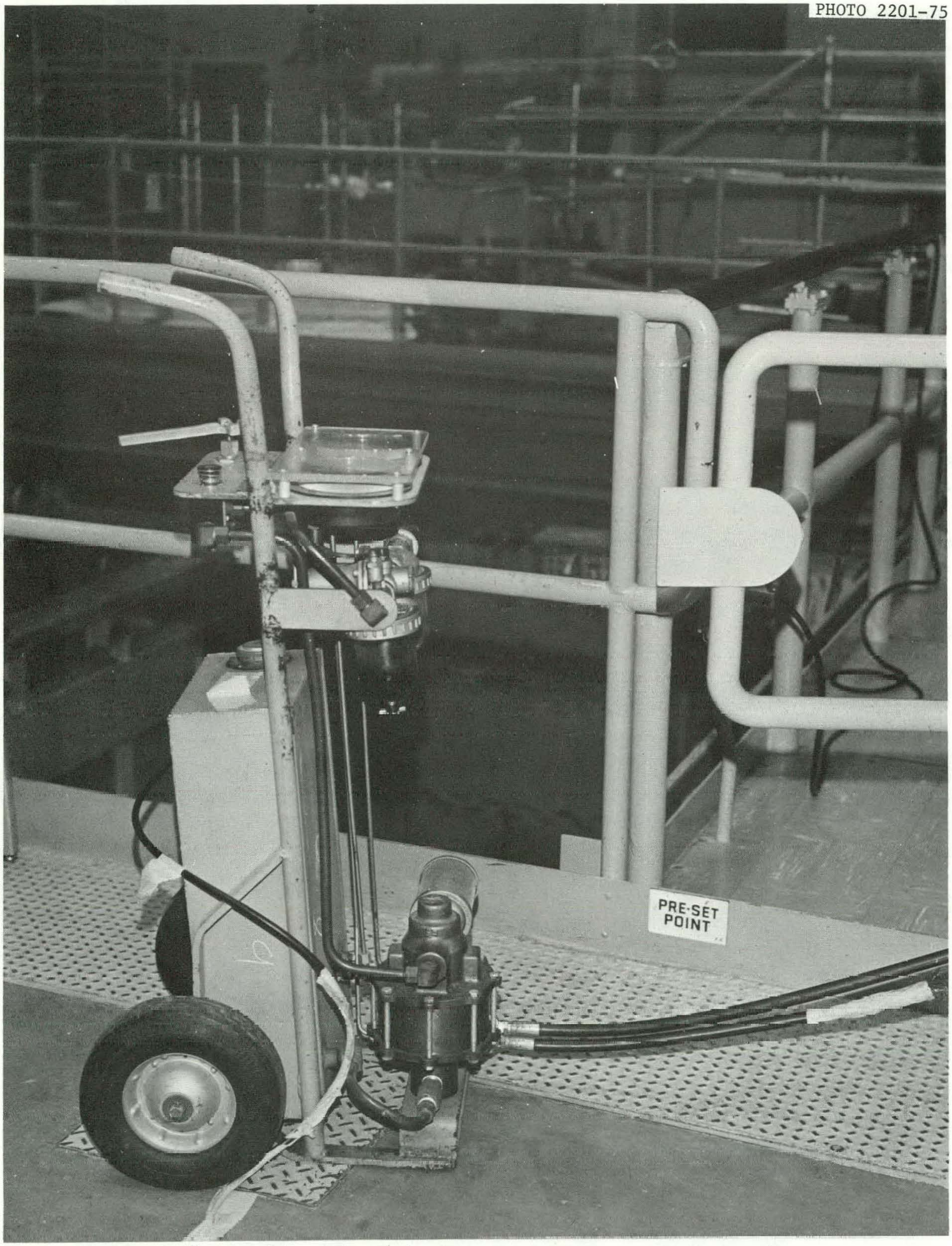

Figure 25. The Bolt-Tensioner Pneumatic Control

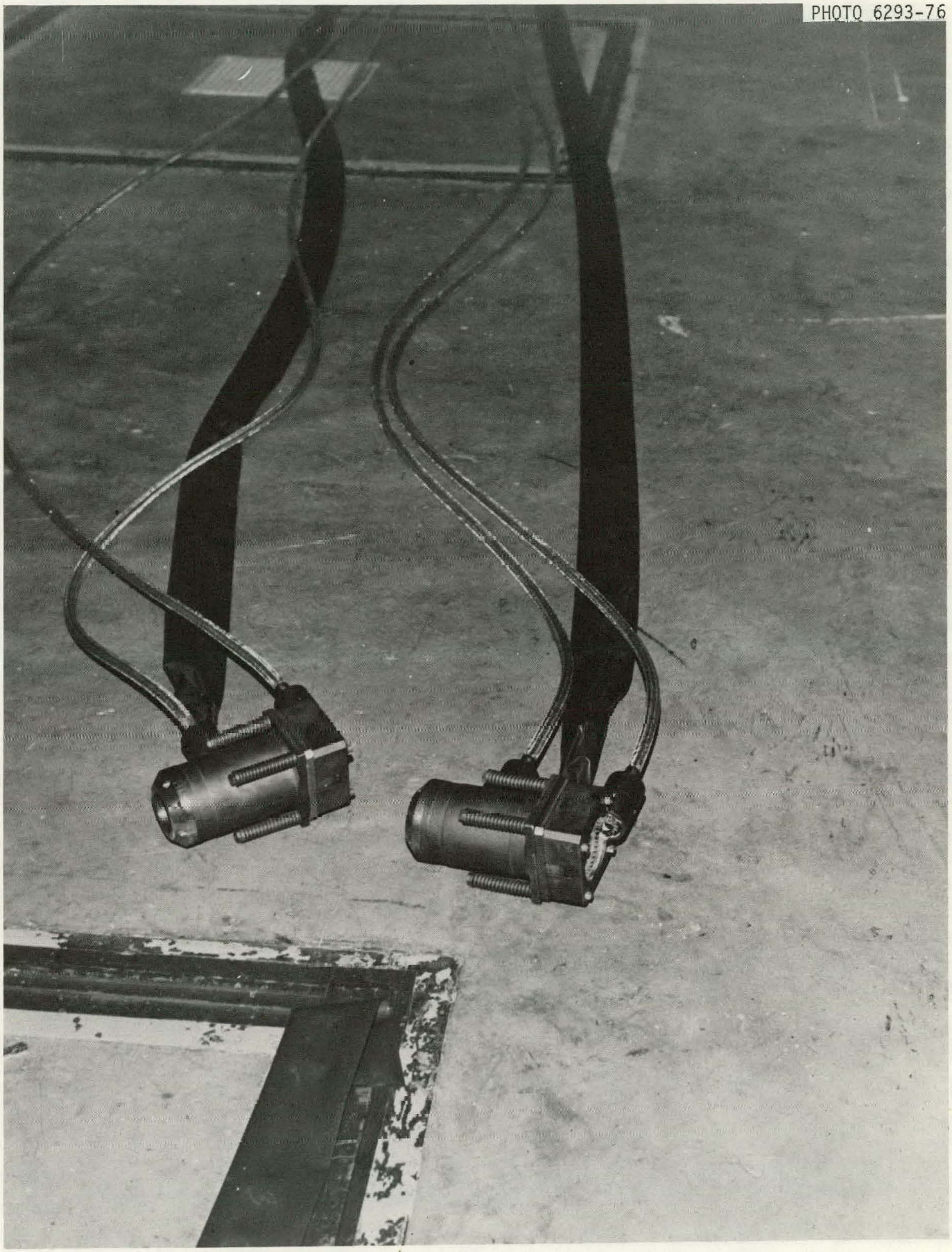

Figure 26. The Hydraulic Tensioning Units of the Bolt-Tensioning Device

PHOTO 6308-76

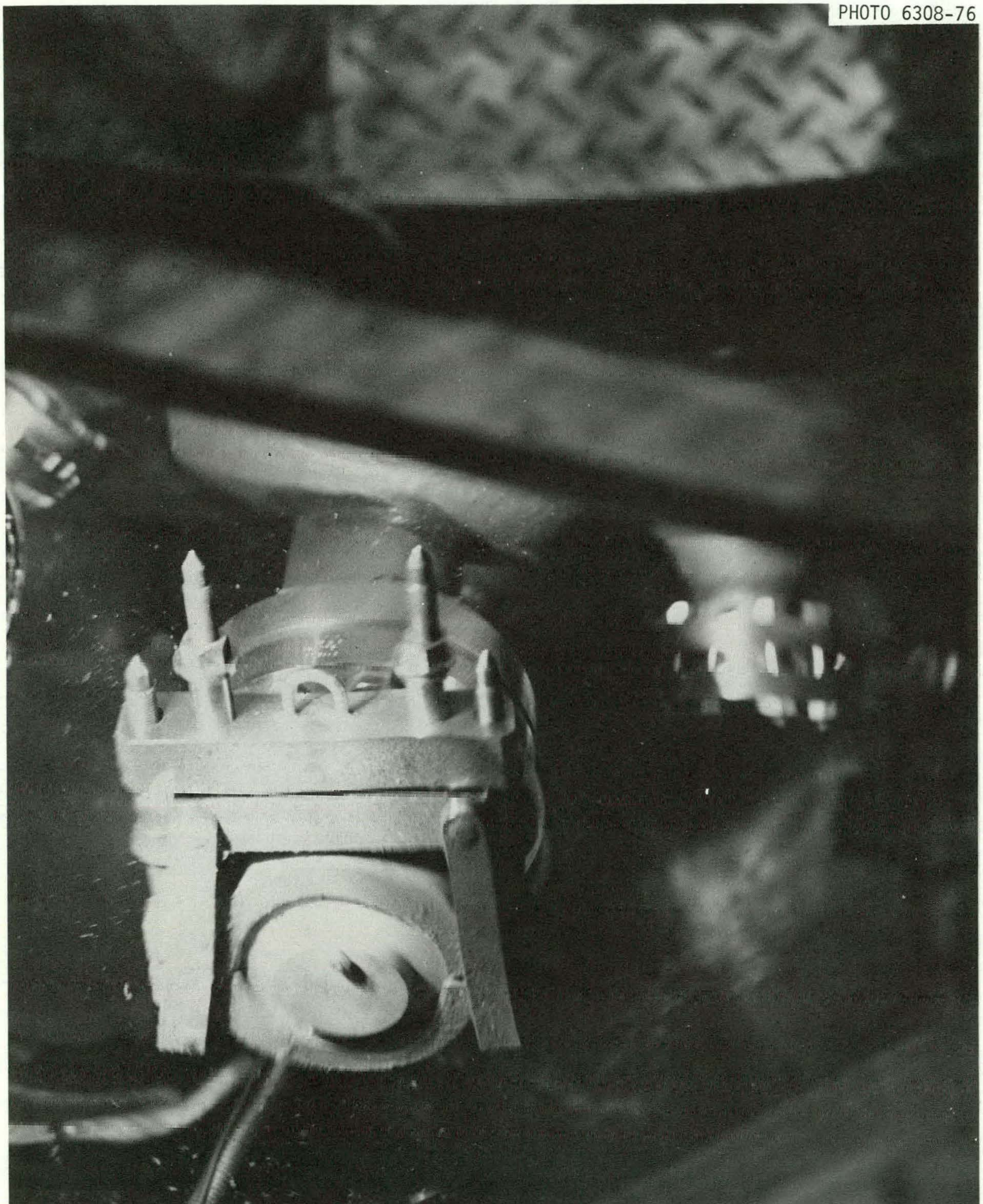

Figure 27. A Backup Clamp Installed on an Adaptor Flange (Underwater Photograph)

PHOTO 2211-75

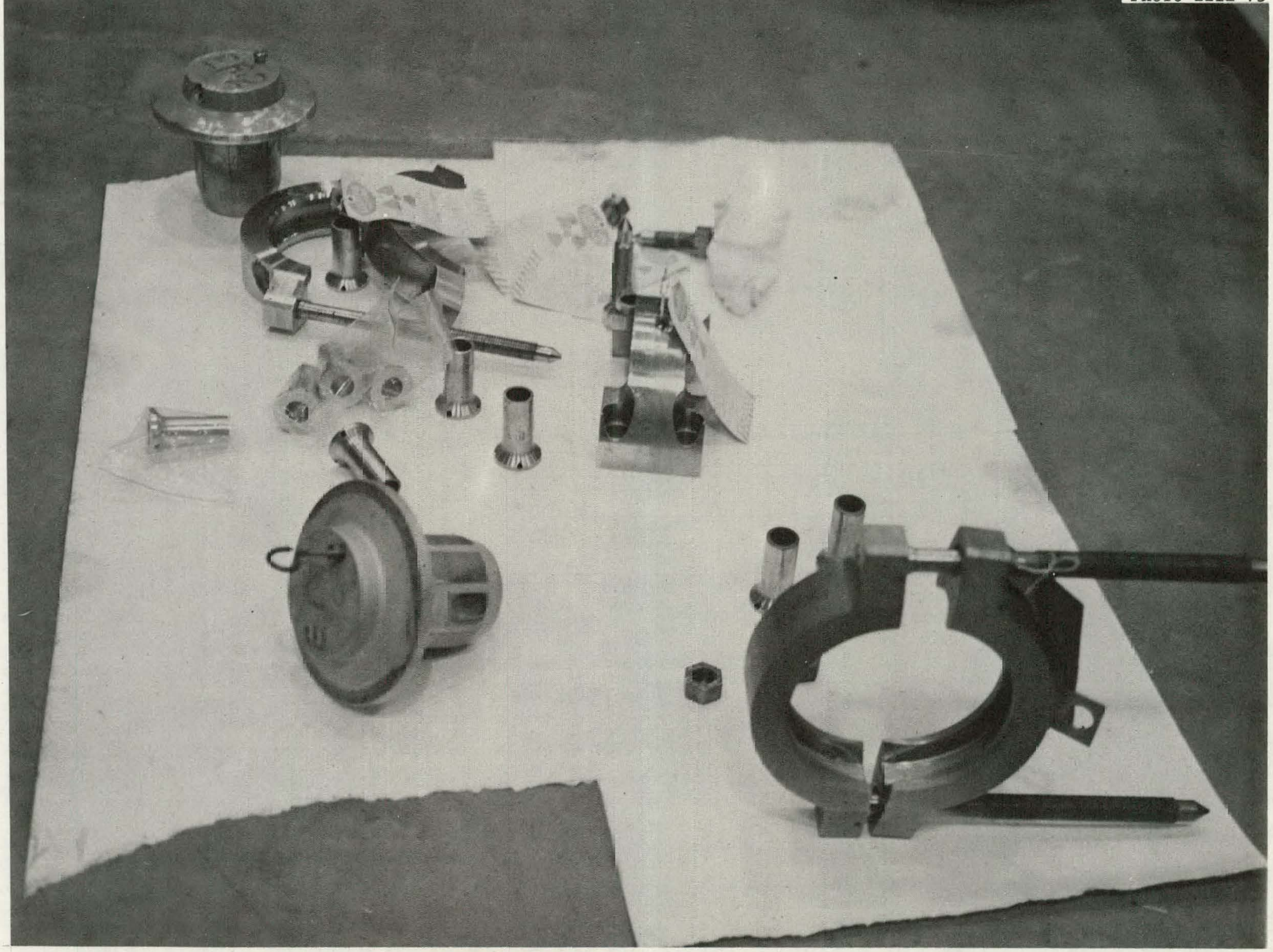

Figure 28. The Two-Bolt Variety of Marman Clamp and Adaptor Flange Plug

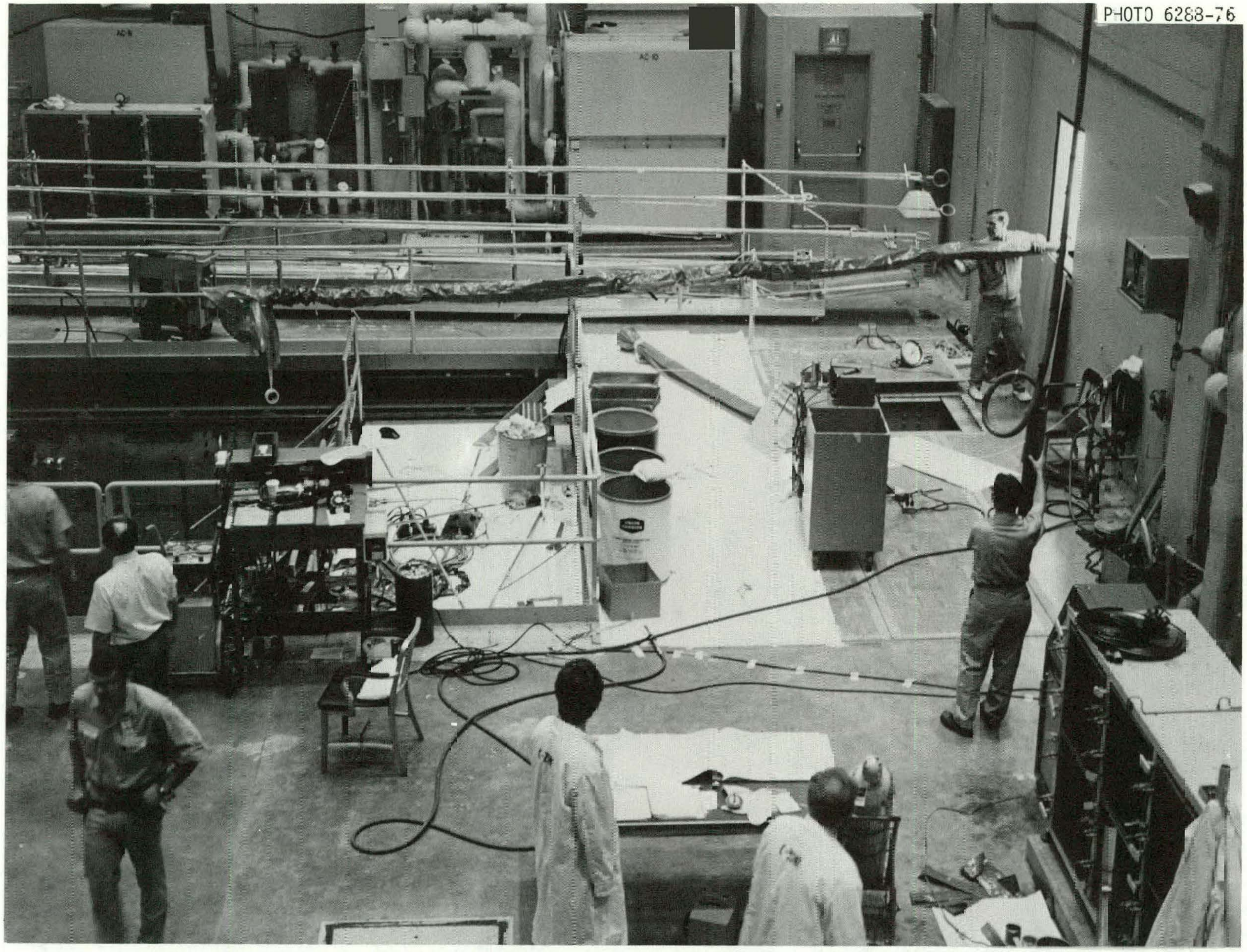

Figure 29. The EF-2 Water-Guide-Sleeve Tool Being Handled in the Reactor Bay

Figure 30. The Rig Used to Manipulate the Water-Guide-Sleeve Tool from Outside the Reactor Building

PHOTO 6303-76

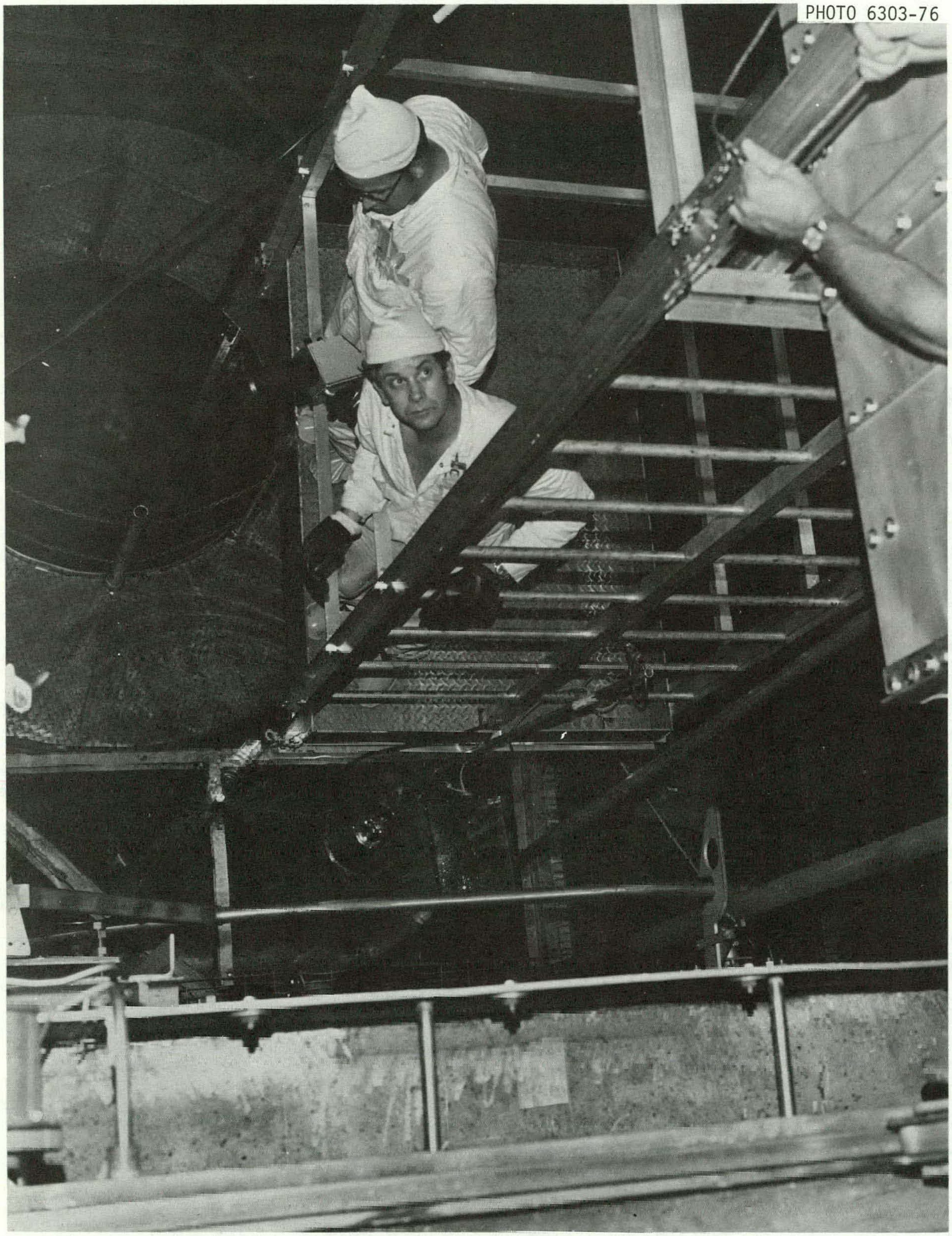

Figure 31. The Suspended, In-Pool Work Platform

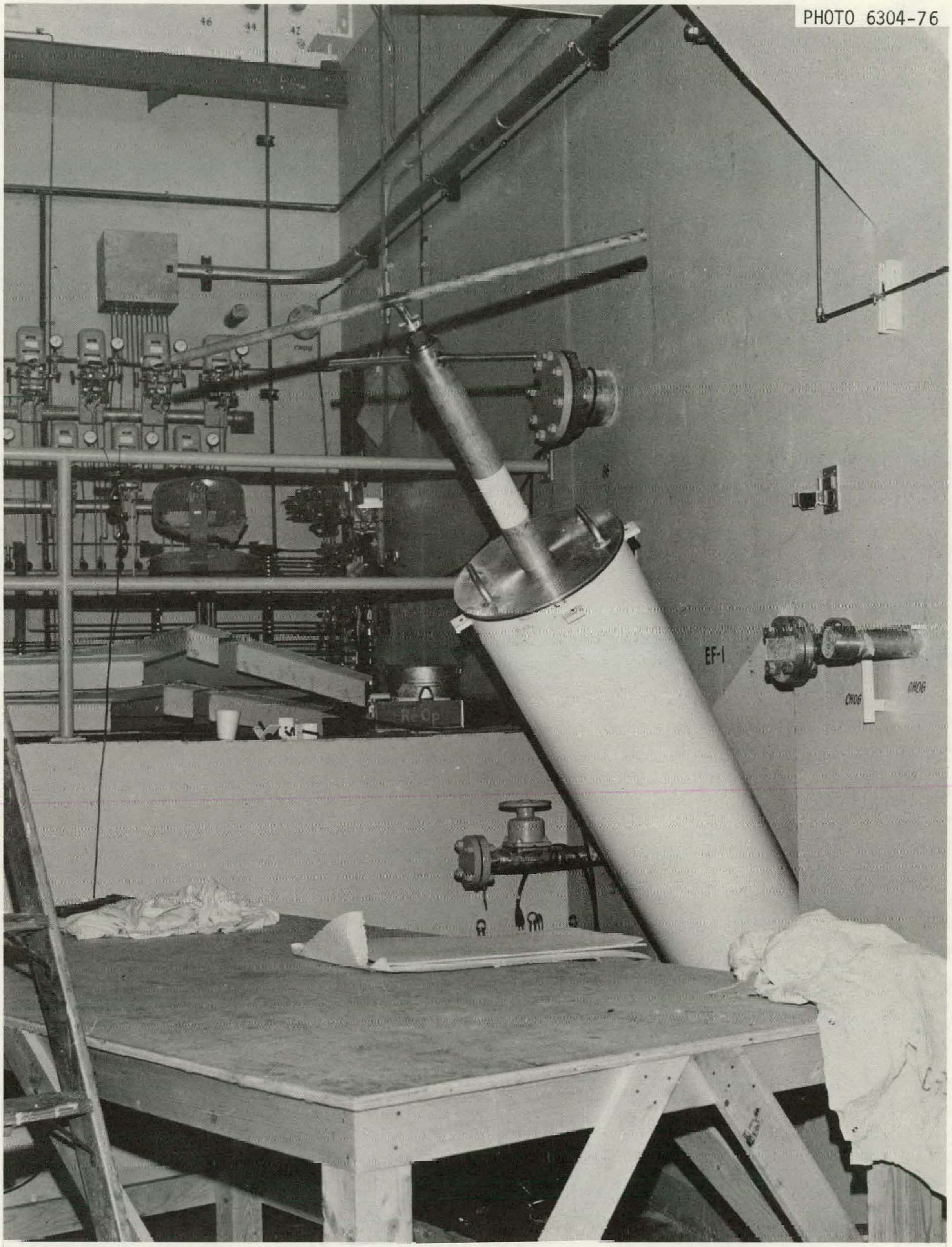

Figure 32. The Shield-Penetration Extension Tube with the Water-Guide-Sleeve Removal Tool Inserted (Used in the Disassembly of the EF Tubes in the Experiment Room)

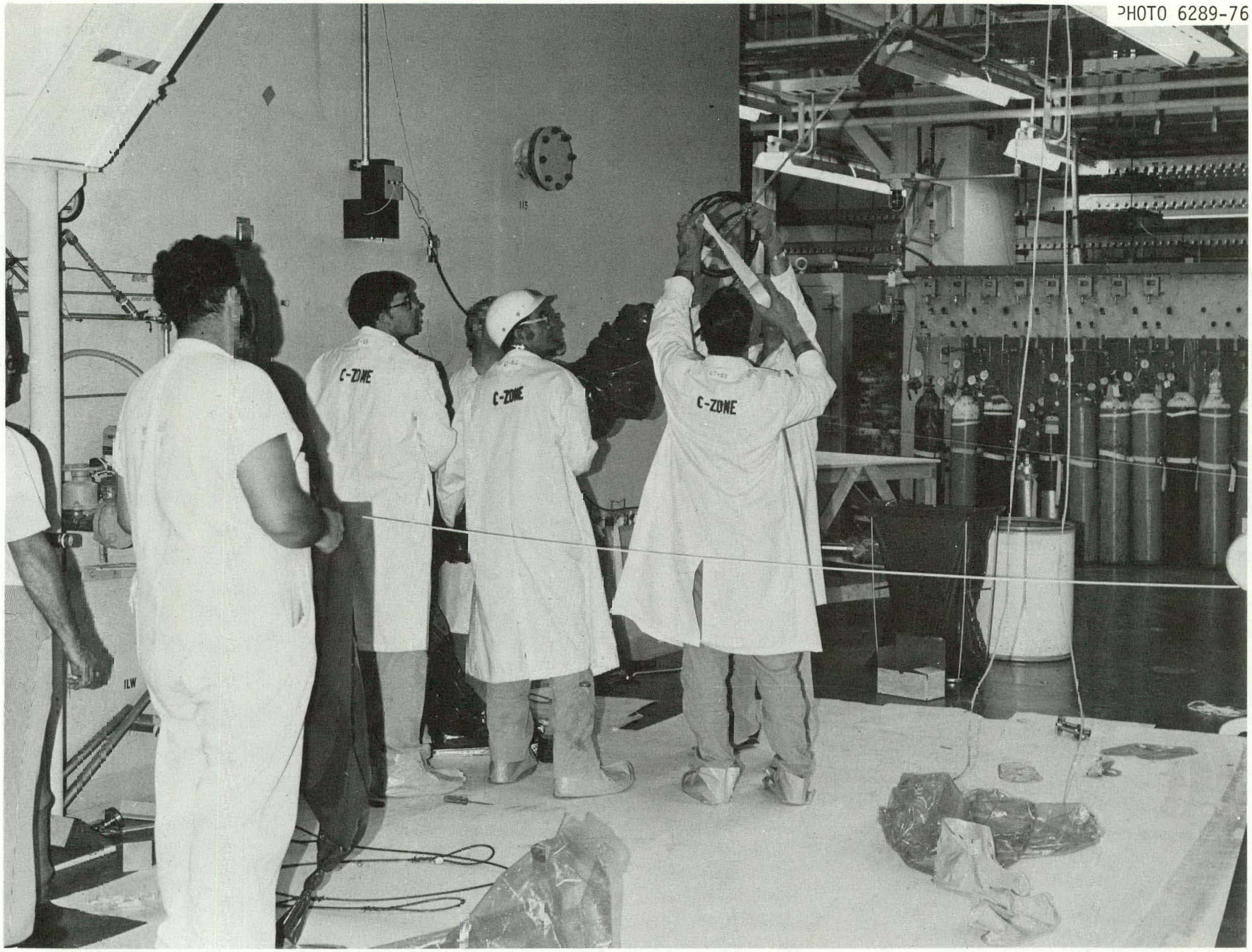

Figure 33. Removing the Ionization Chamber from the EF-2 Facility

PHOTO 6286-76

Figure 34. The EF-2 Facility Being Disassembled in the Experiment Room

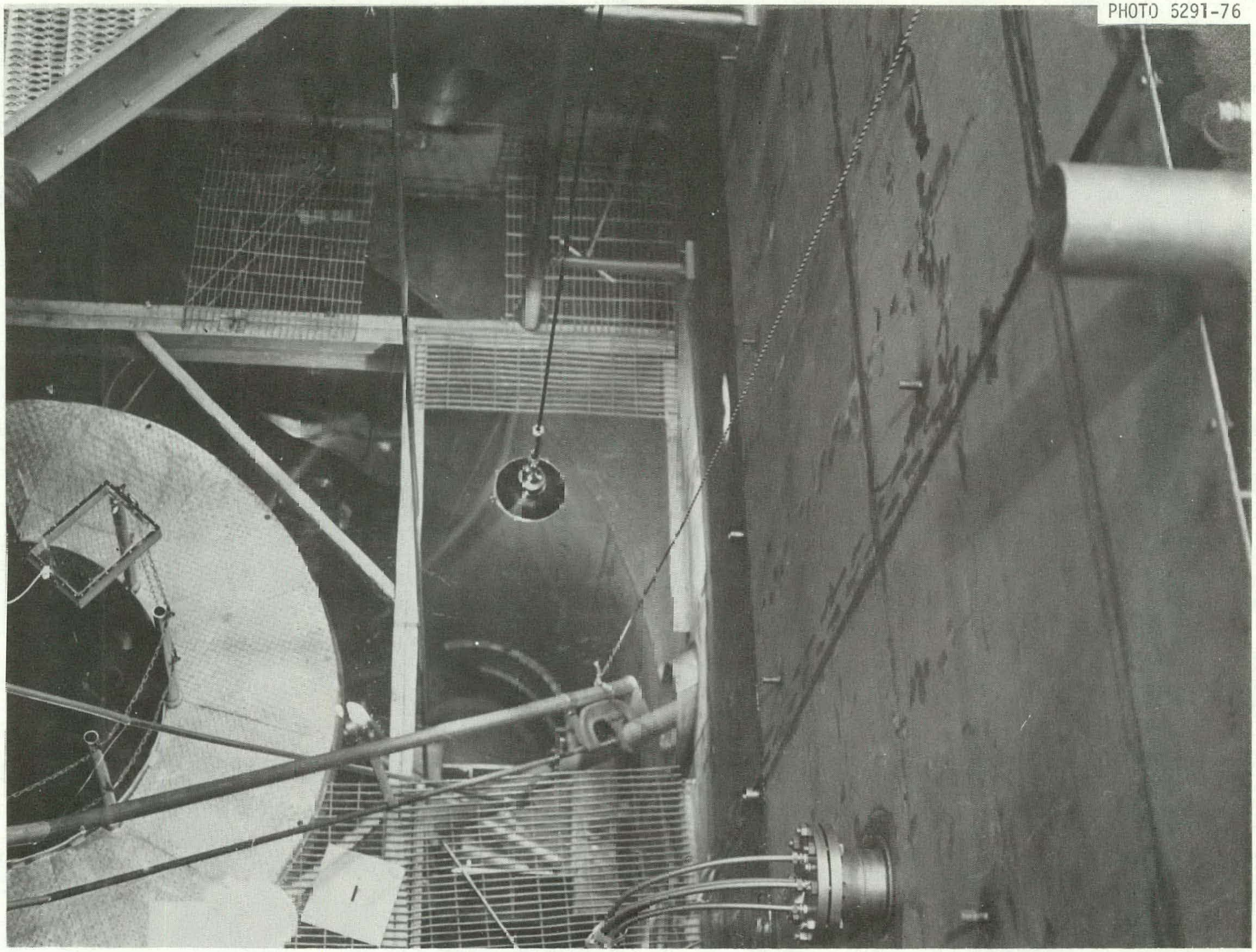

Figure 35. The EF-2 Water-Guide Sleeve Being Cut into Sections in the Reactor Pool (Underwater Photograph)

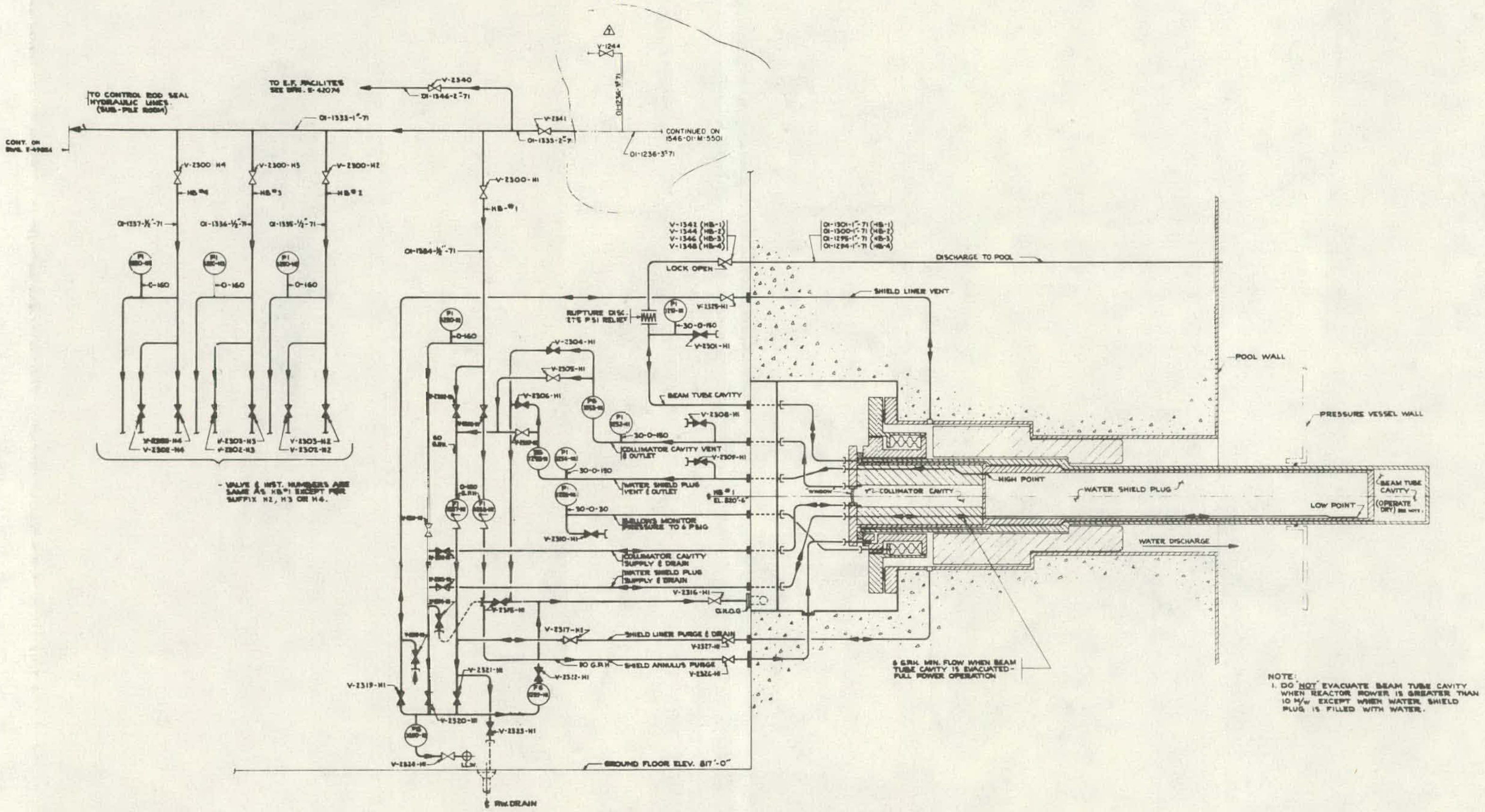

Figure 36. A Schematic of the Beam Tubes

PHOTO 2199-75

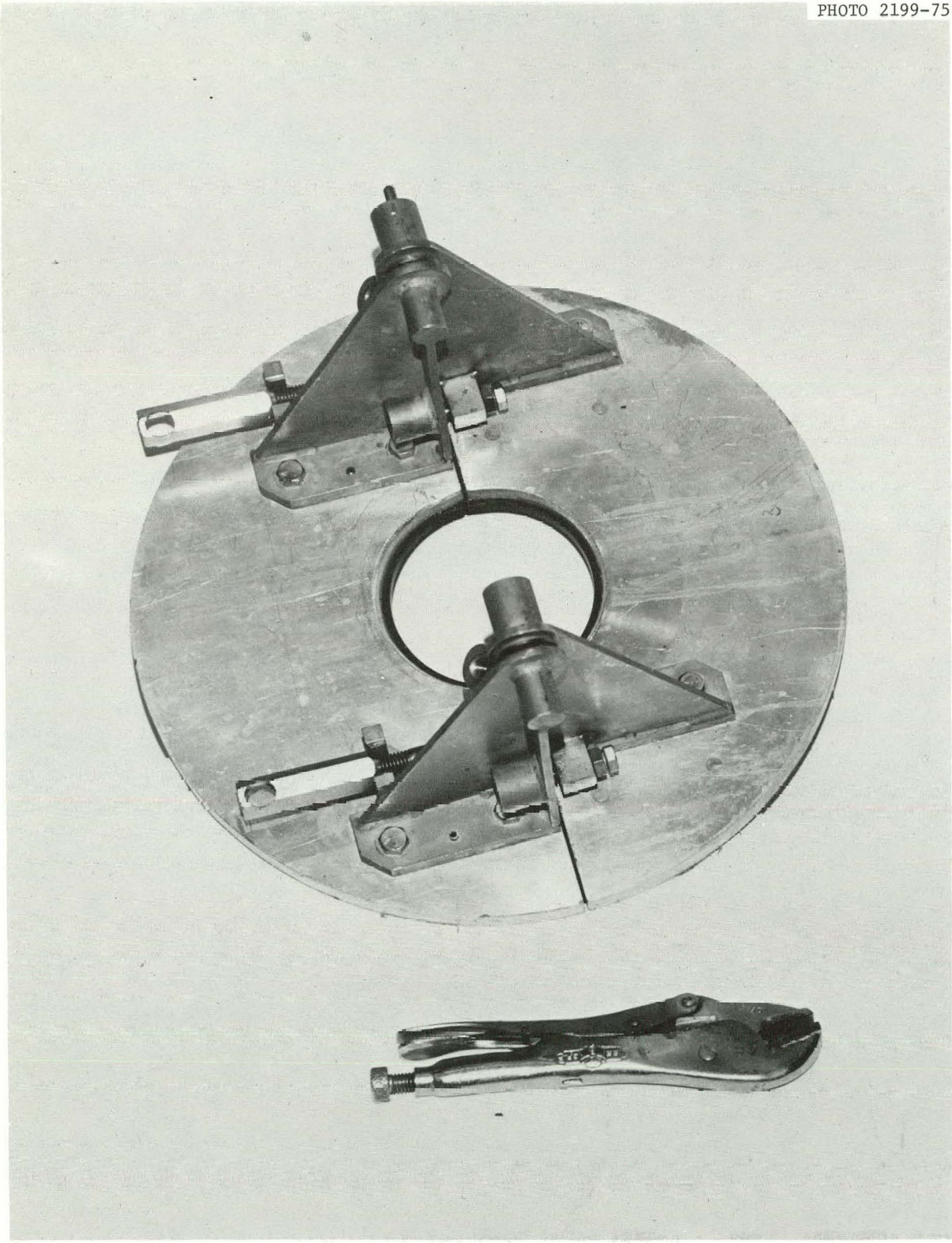

Figure 37. The Split Dam

PHOTO 2202-75

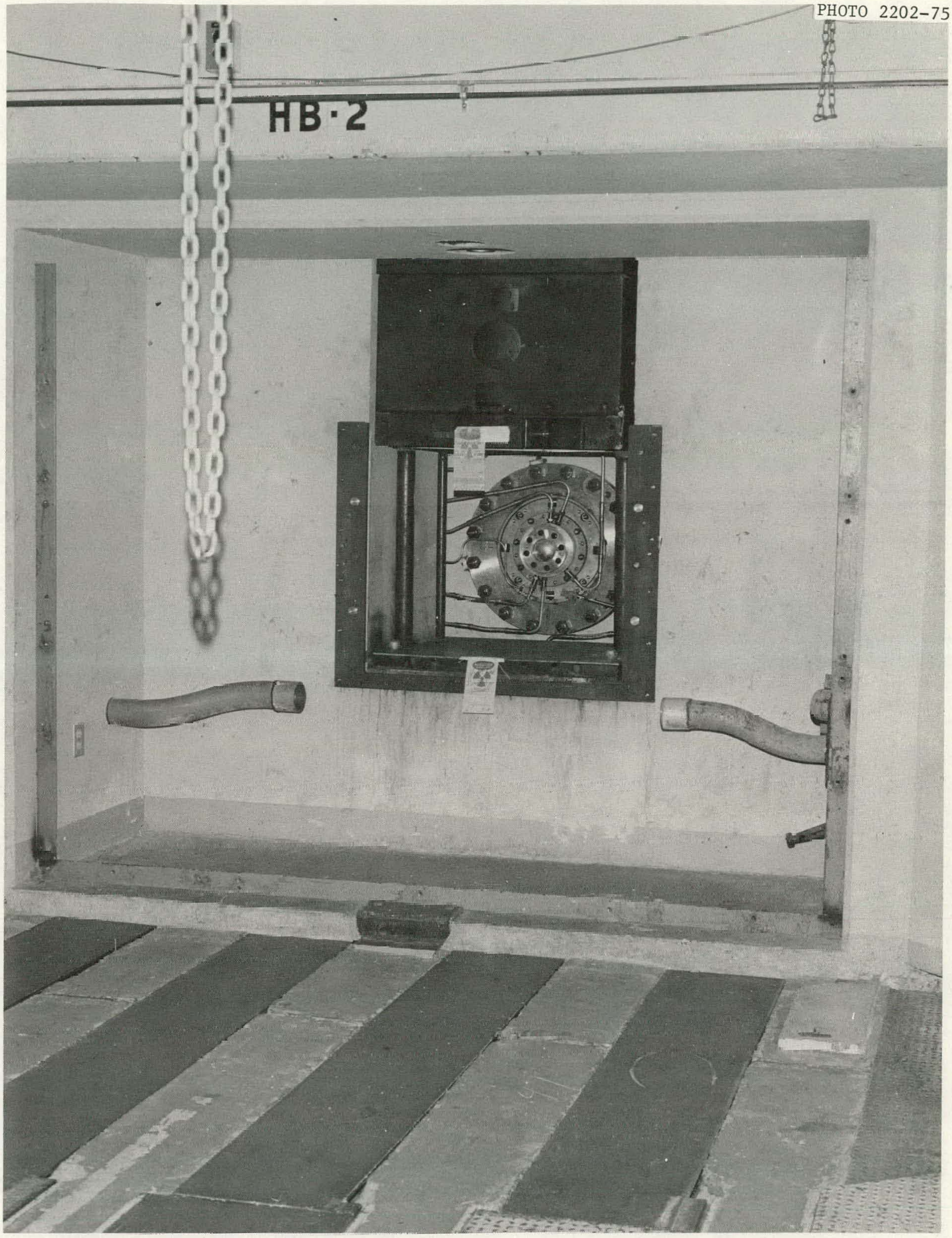

Figure 38. The HB-2 Shield Penetration Flange and the Service Piping in the Beam Room

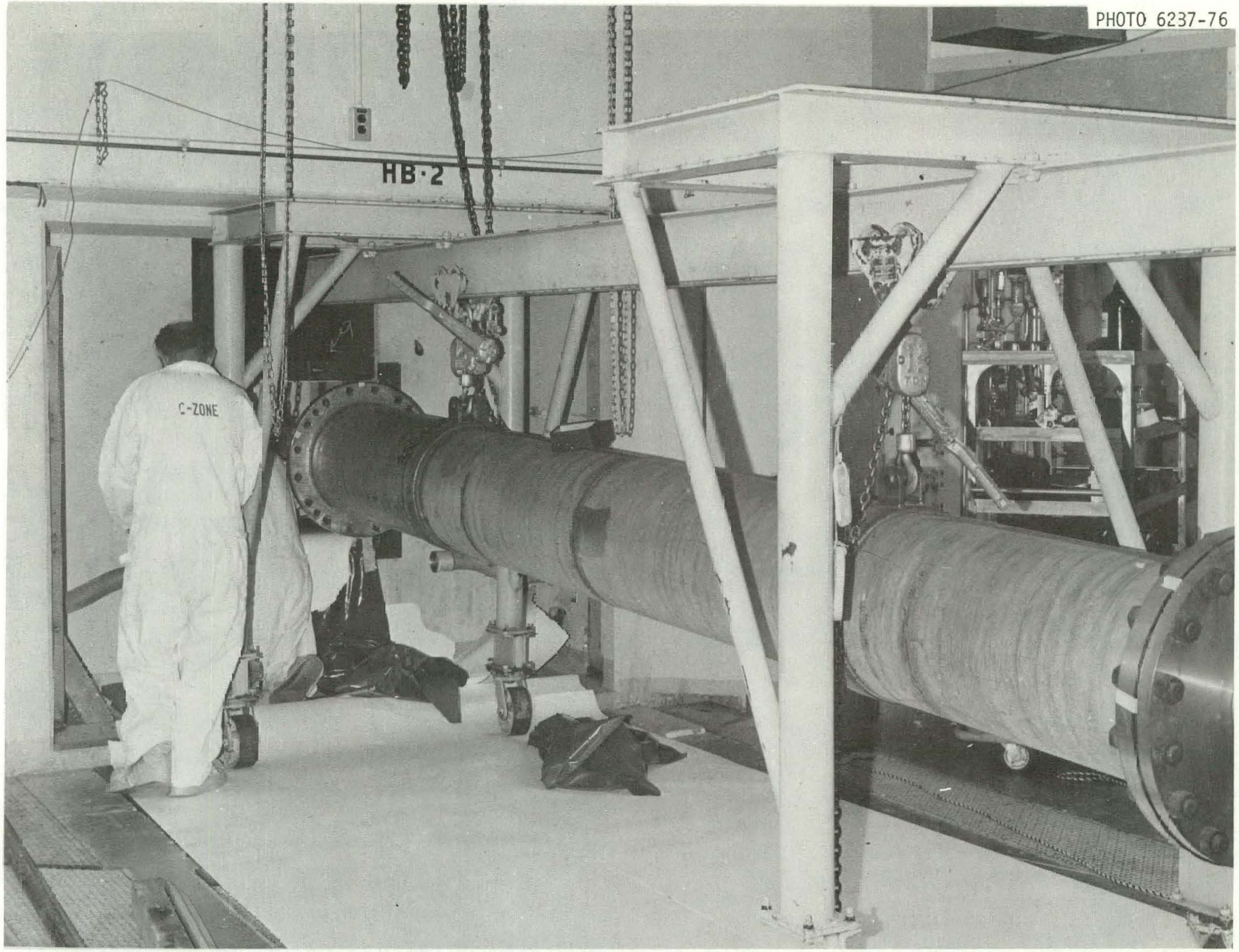

Figure 39. The Caisson Being Positioned Against the HB-2 Shield Penetration Flange in the Beam Room

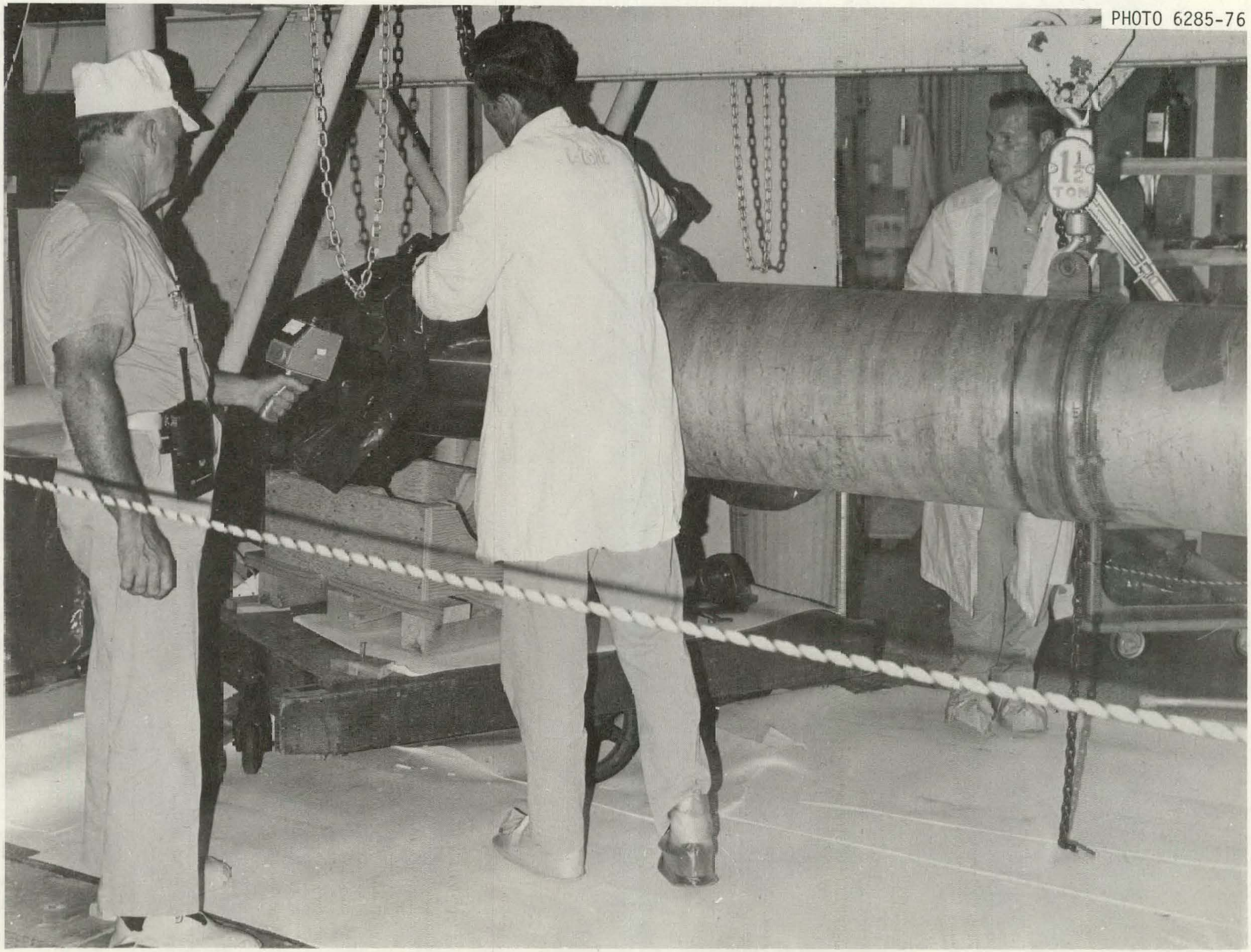

Figure 40. Removing the Removable Shield from the HB-2 Beam Tube Facility

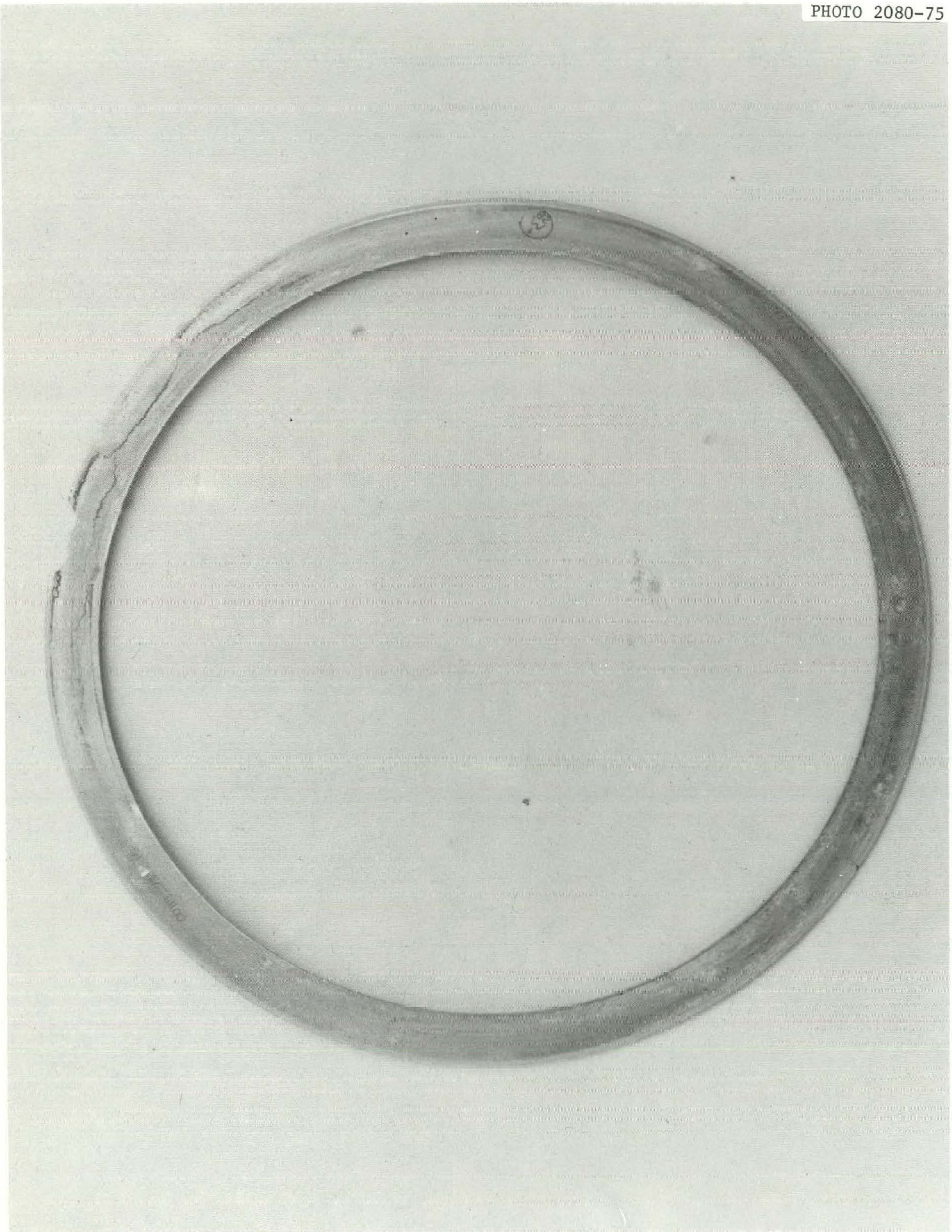

Figure 41. The Damaged Conoseal Gasket Removed from the HB-1 Adaptor Flange

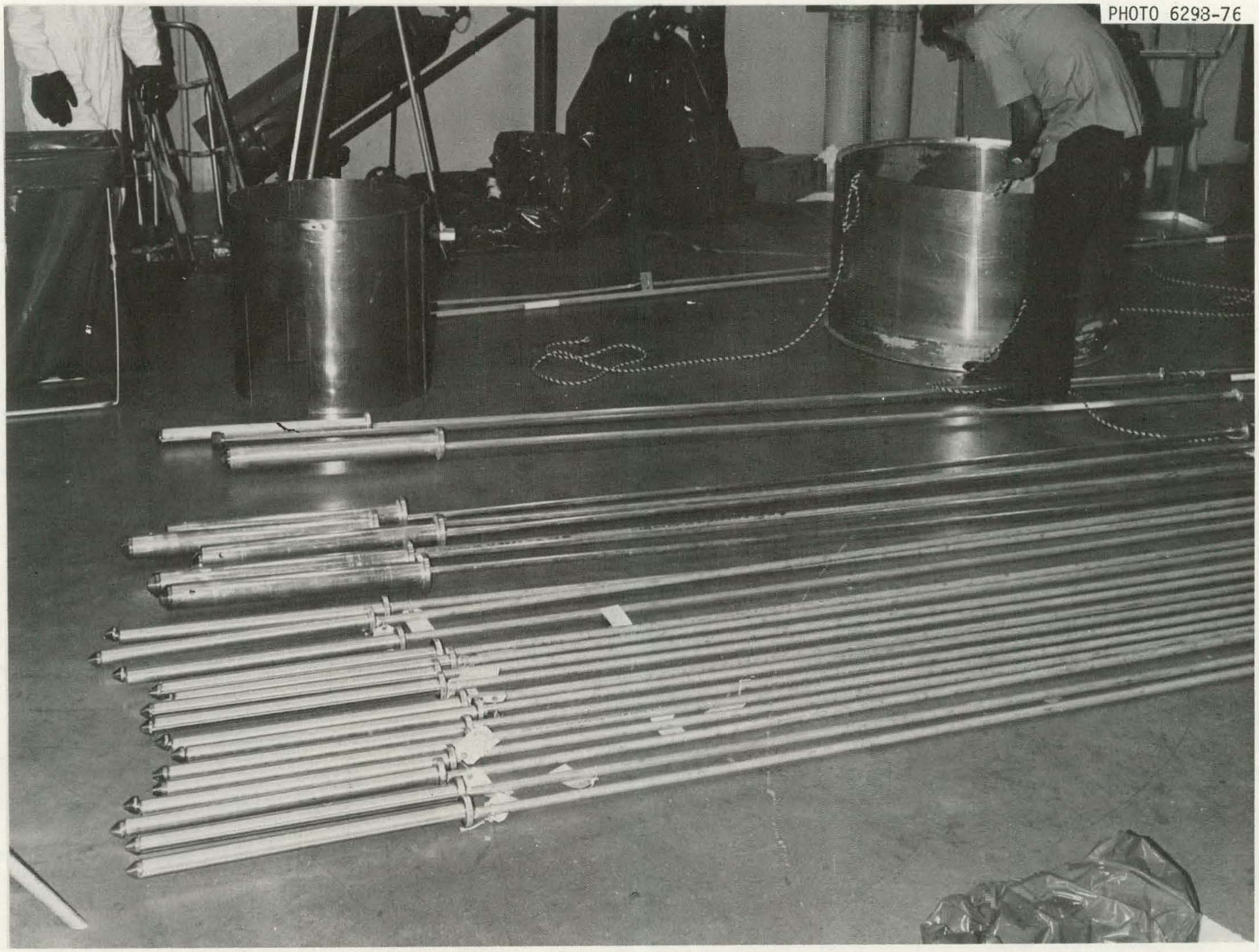

Figure 42. Some of the Special Tools Used to Remove the Cracked Beryllium
(One cylinder was placed inside the beryllium and one was placed on the outside; the long rods were placed through each of the VXF holes and comprised the main lifting scheme)

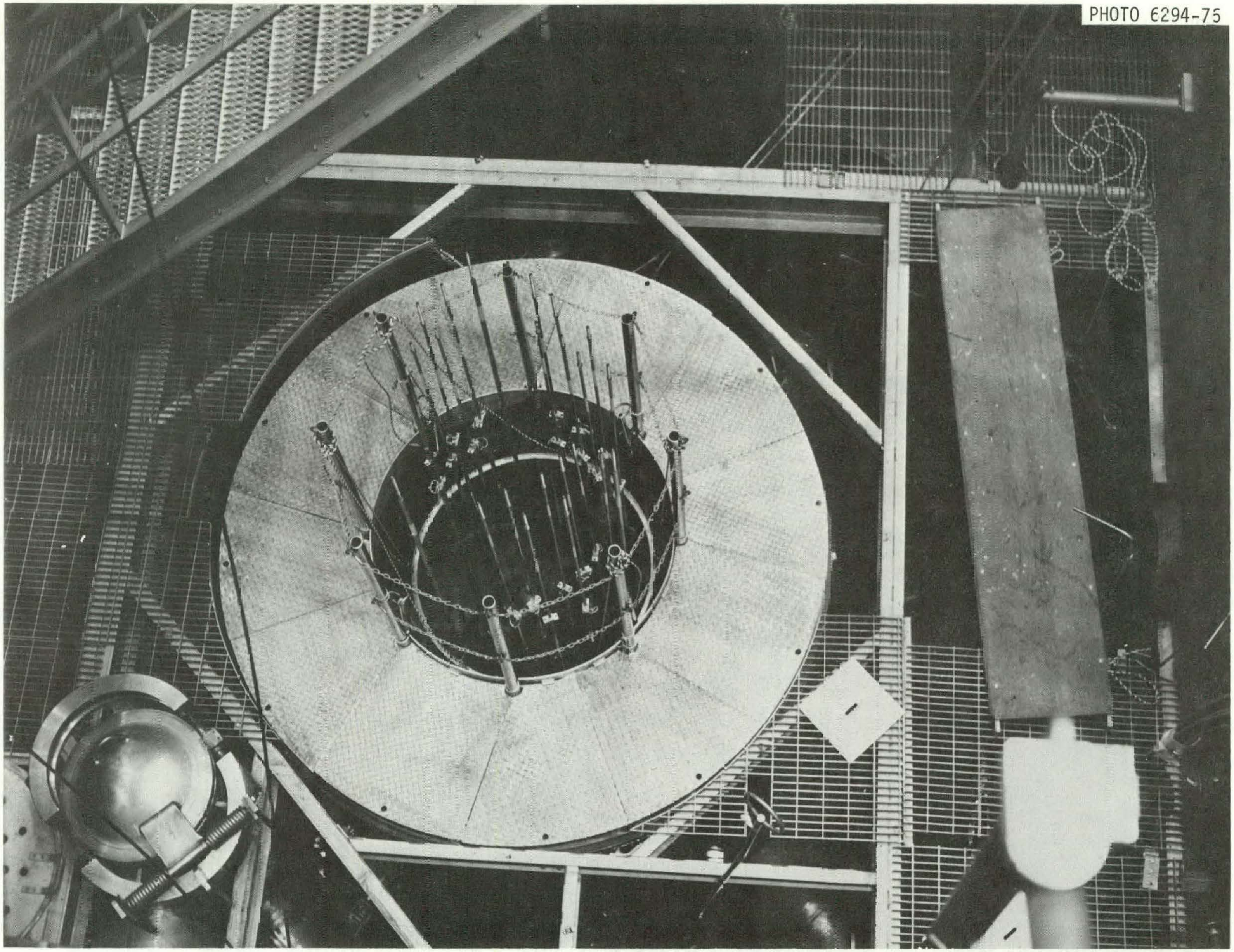

Figure 43. The Lifting Tools after Installation through the VXF Holes in the Beryllium

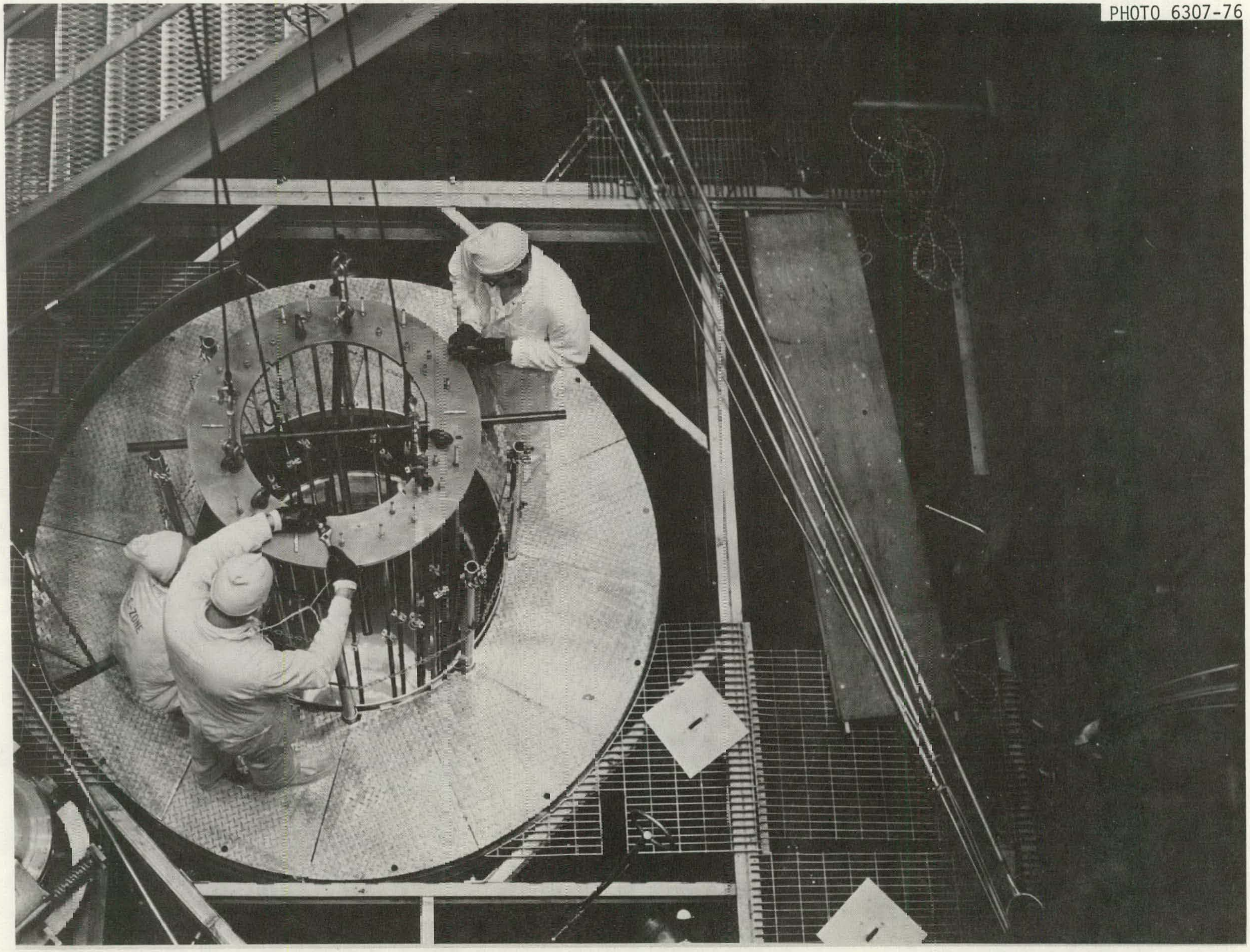

Figure 44. The Leveling Device Being Installed on the Beryllium Lifting Tools

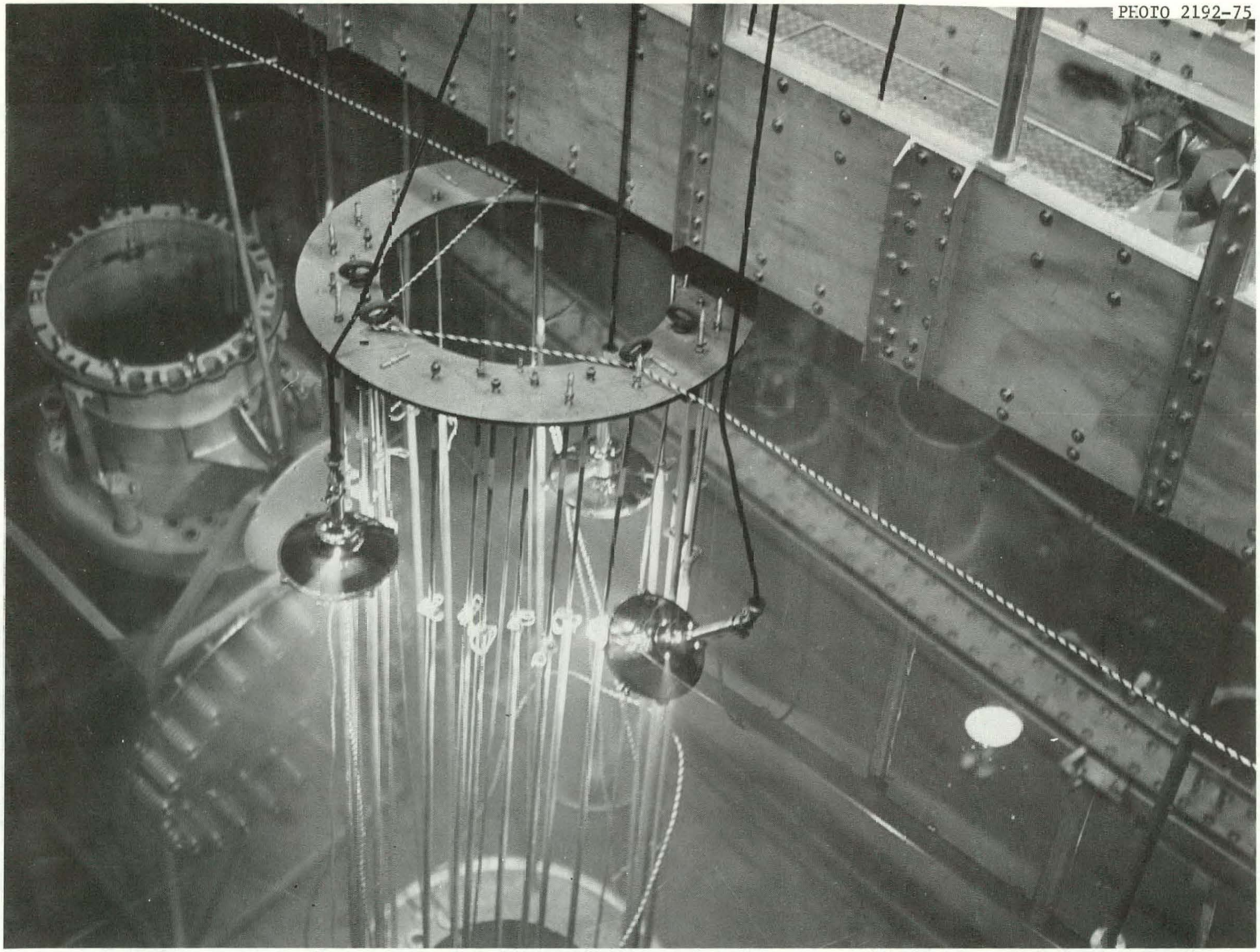

Figure 45. The Damaged Beryllium and Lifting Rig after Transfer to the East Storage Pool (Underwater Photograph) (The outer shroud and the Belleville spring may be seen in the storage rack to the left)

Figure 46. Inspection Engineering Personnel Videotaping Underwater Reactor Components

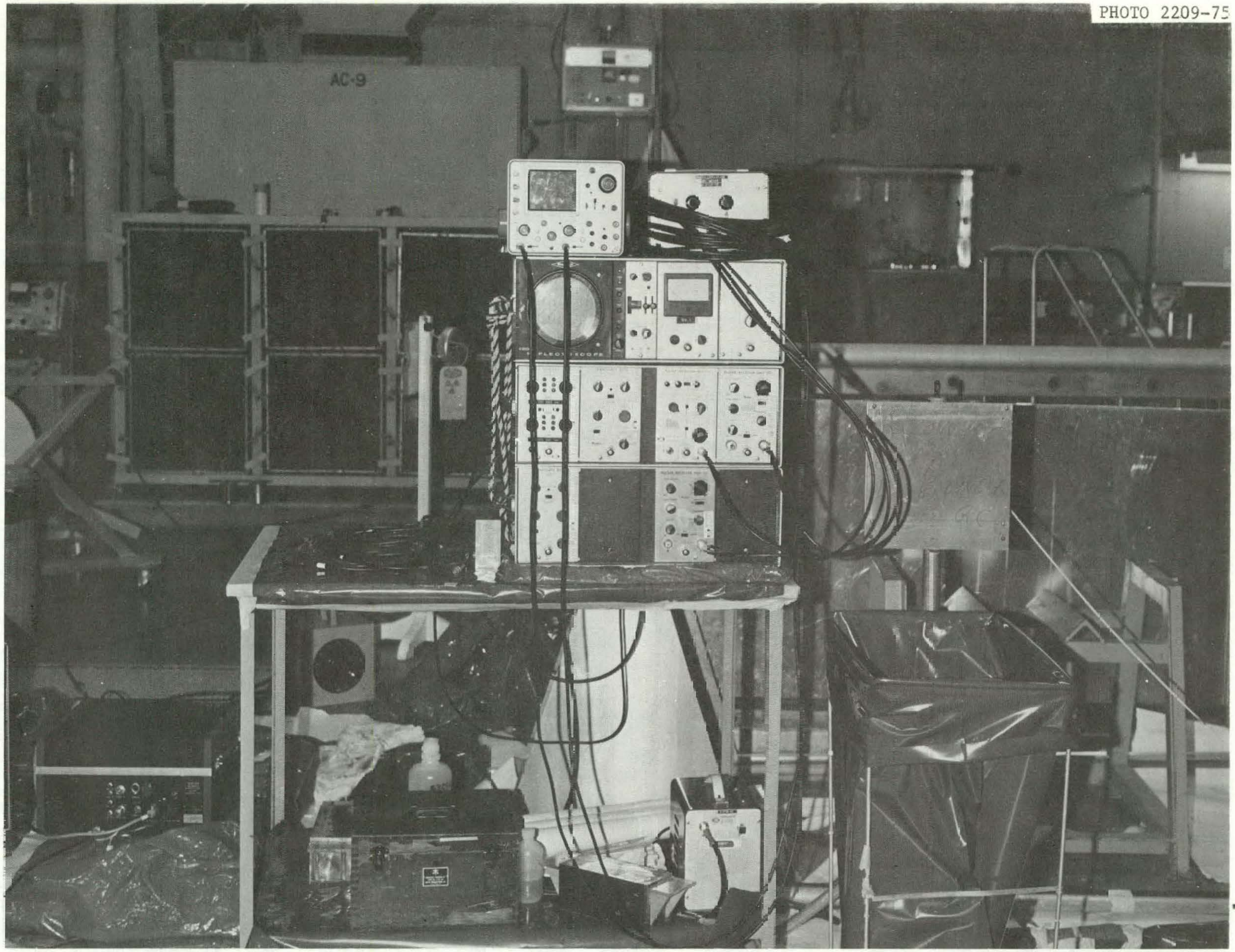

Figure 47. Some of the Electronic Test Equipment Used in Testing the Reactor Vessel and Core Components

PHOTO 1520-75

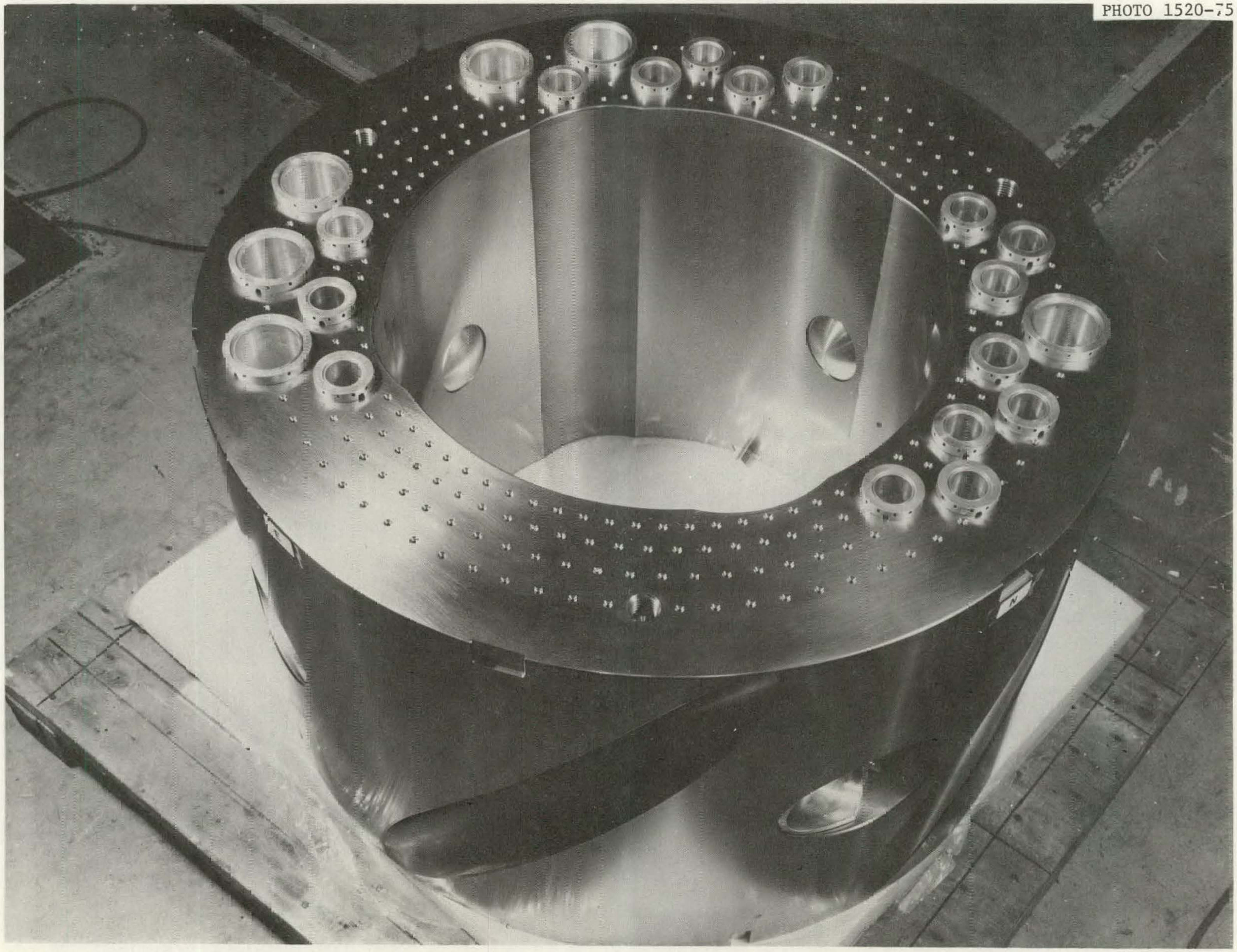

Figure 48. The New Permanent Beryllium

PHOTO 6317-76

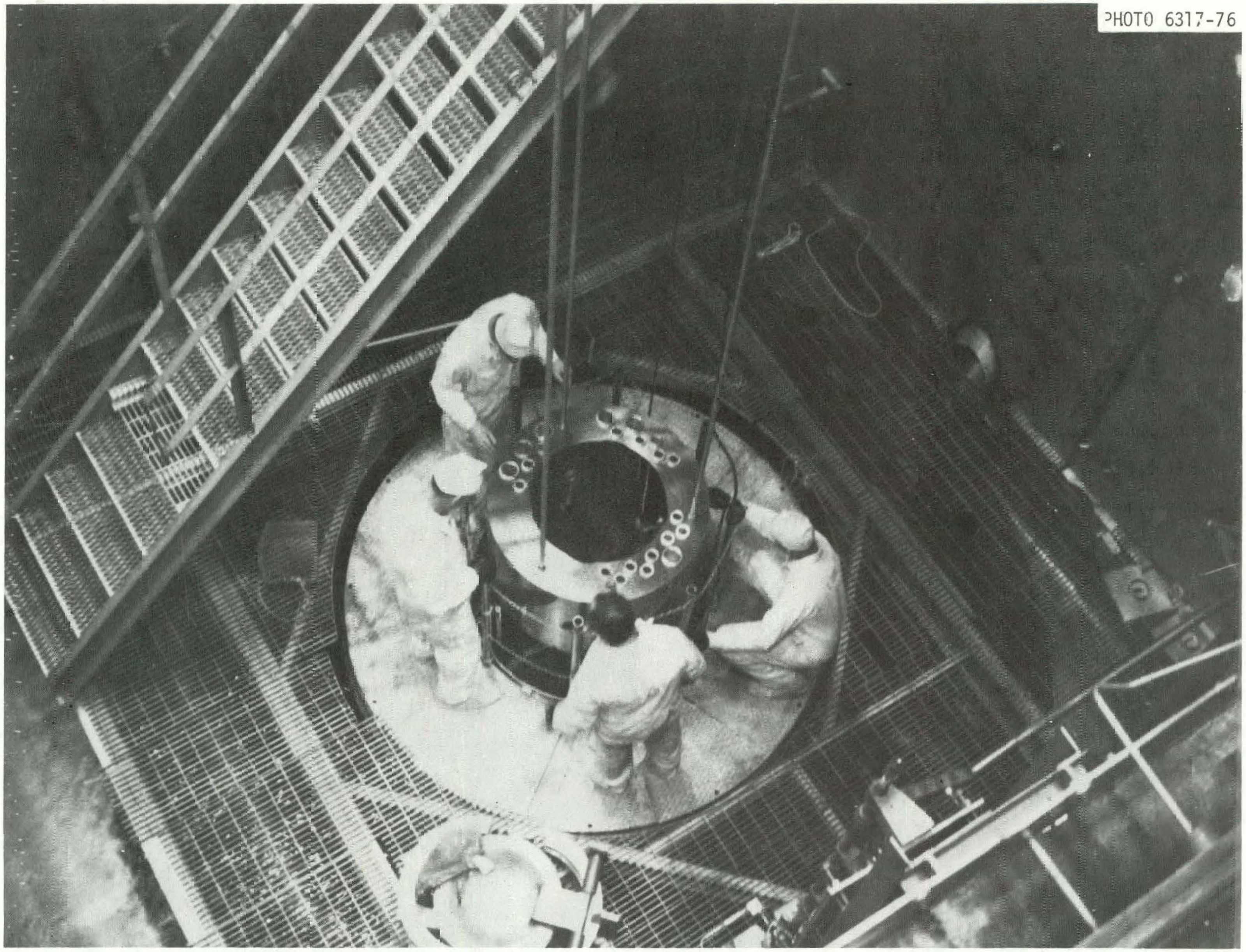

Figure 49. Installing the New Beryllium in the Reactor Vessel

PHOTO 1517-75

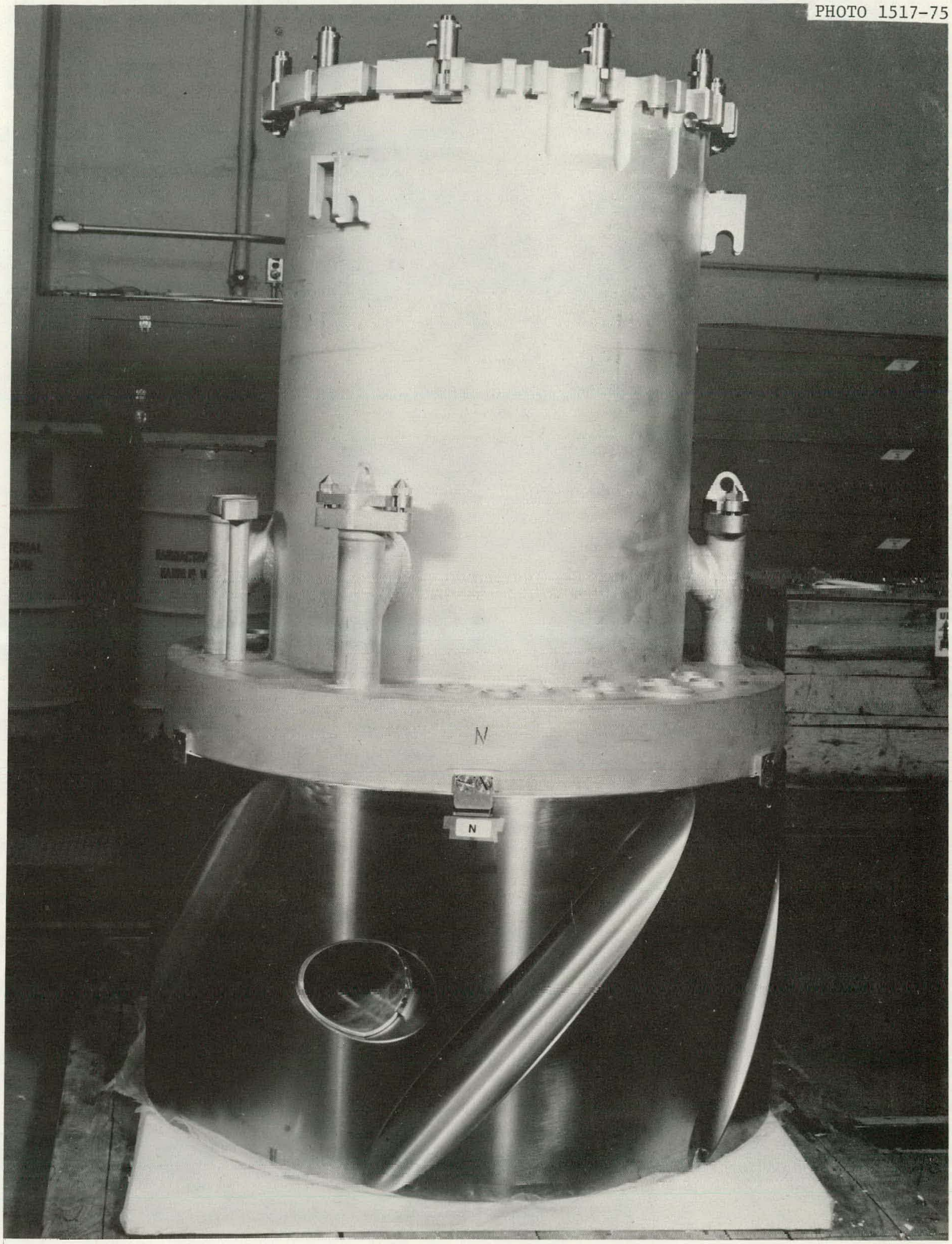

Figure 50. The Spare Outer Shroud Setting Atop the New Beryllium

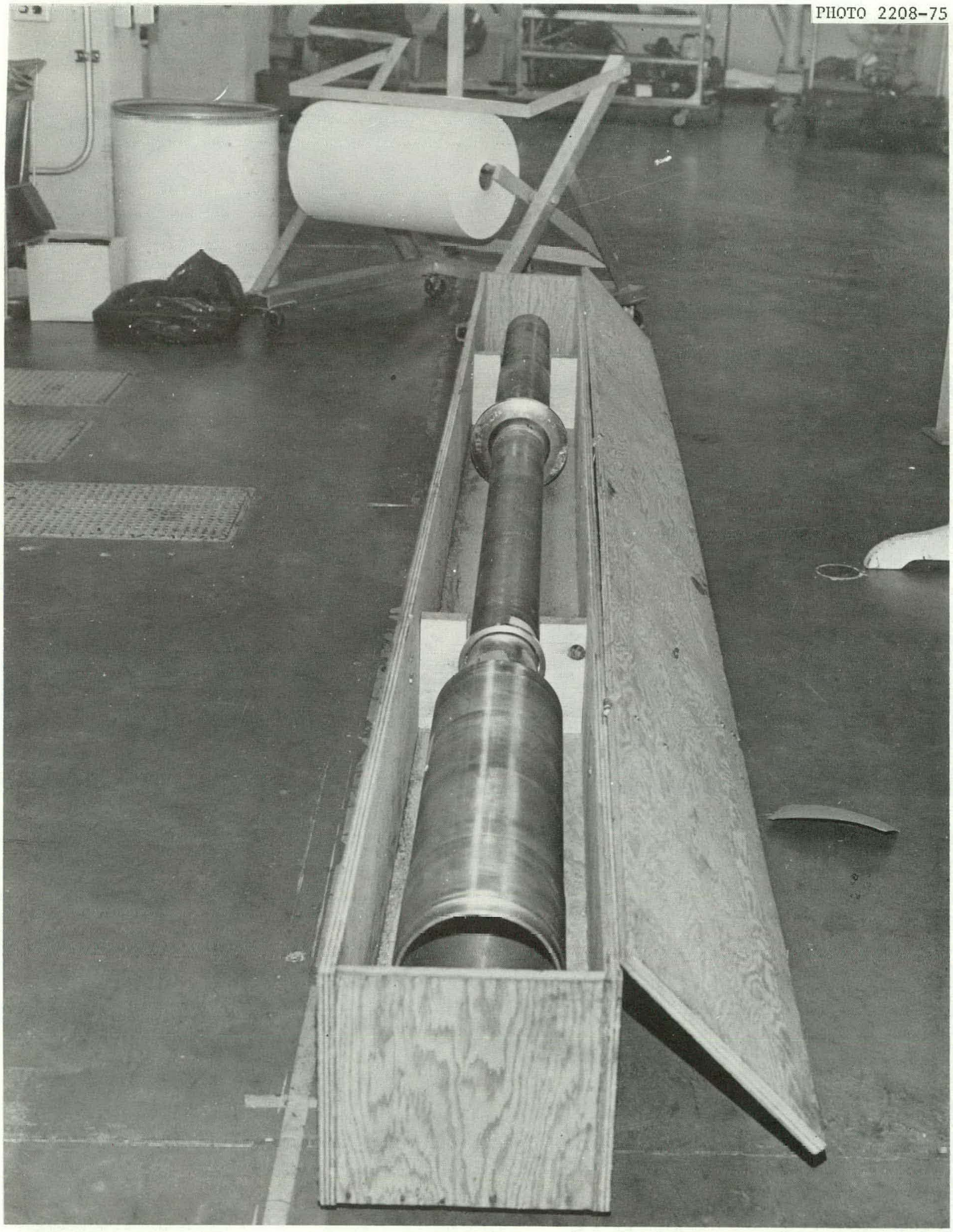

Figure 51. A New Beam Tube
(The adaptor flange is on the far end)

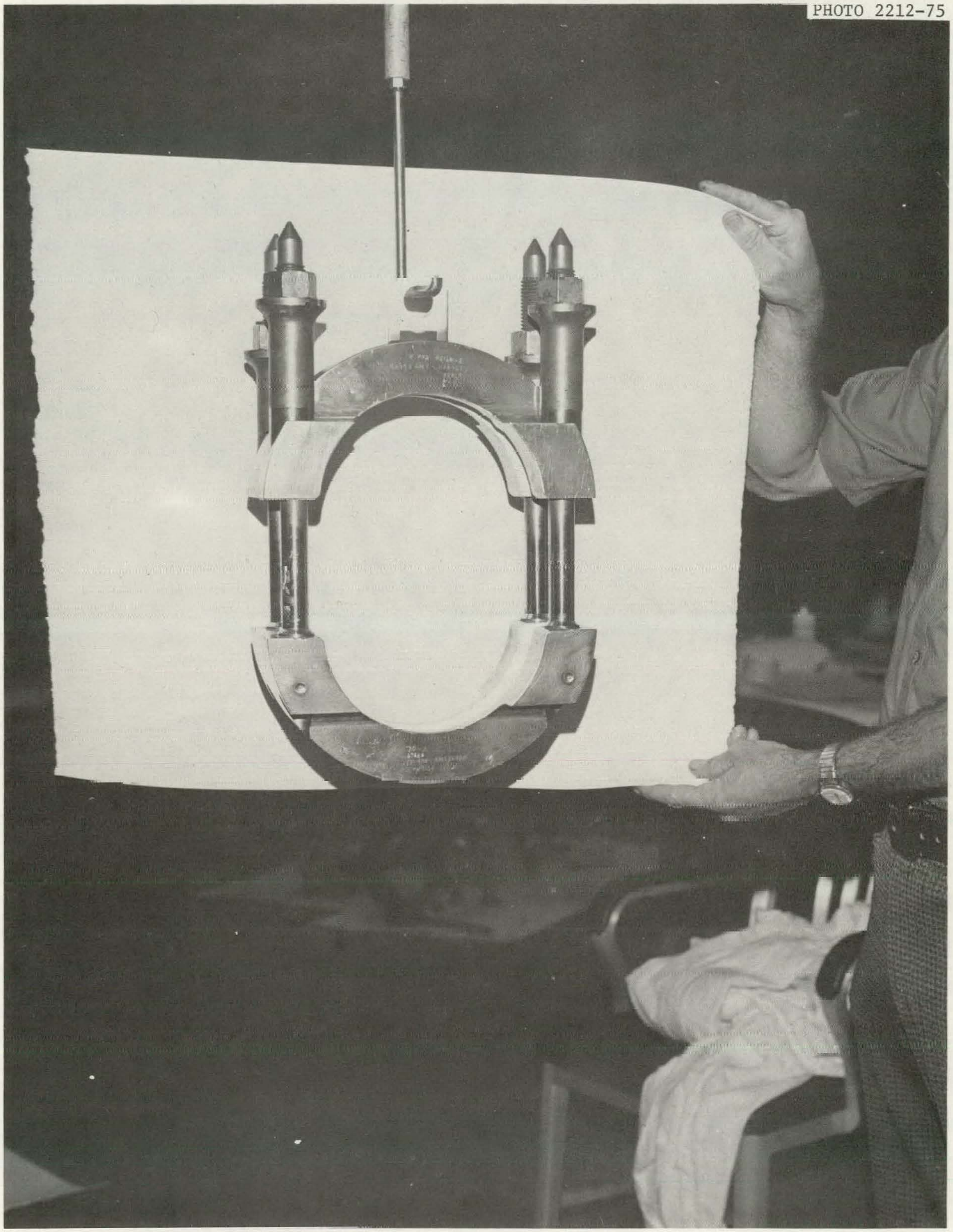

Figure 52. The Four-Bolt Variety of Marman Clamp

Figure 53. One of Two Four-Bolt Marman Clamps Used on the EF-2 Facility

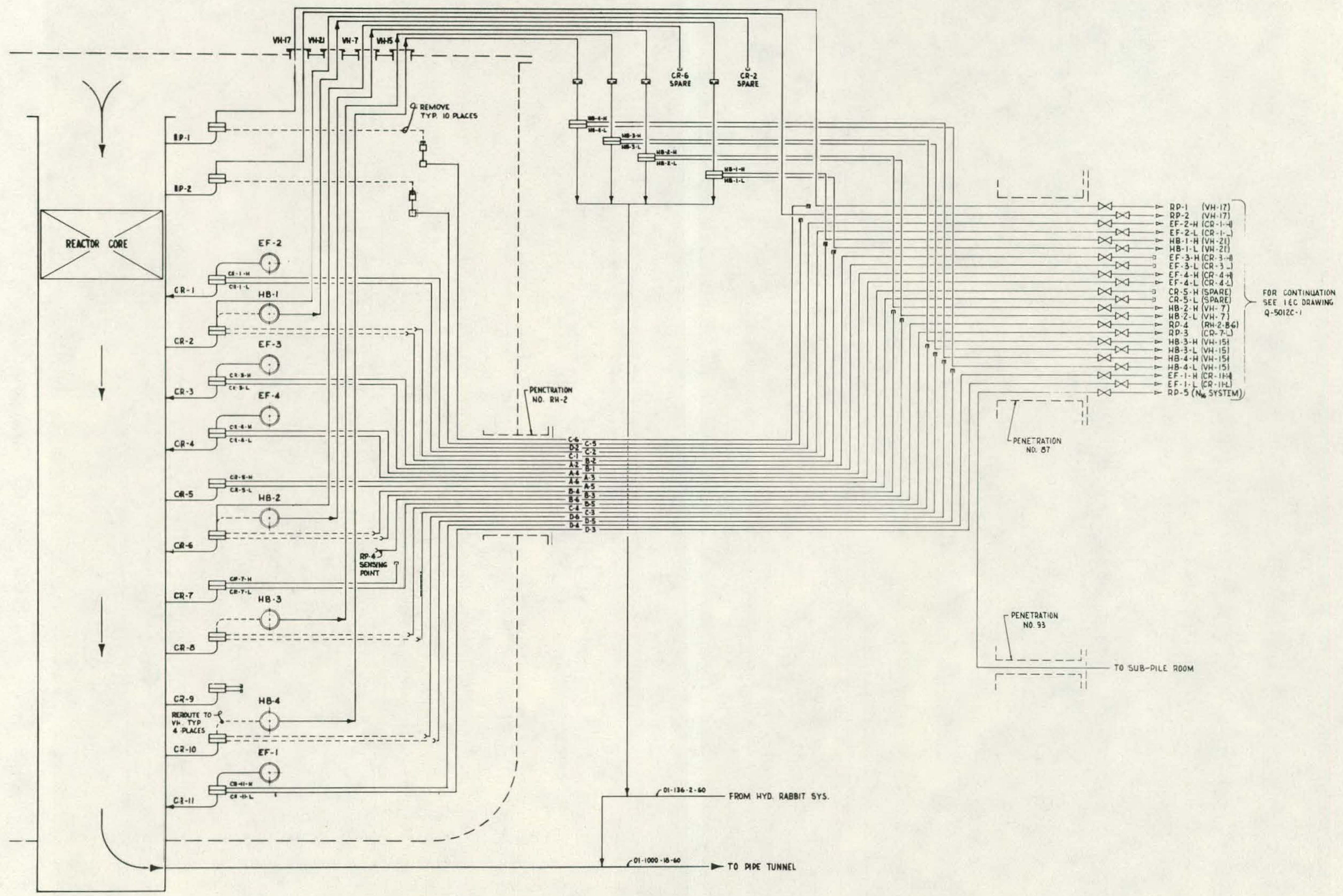

Figure 54. Schematic Diagram of the Coolant-Return Lines from the Water-Collector Clamps

PHOTO 2278-75

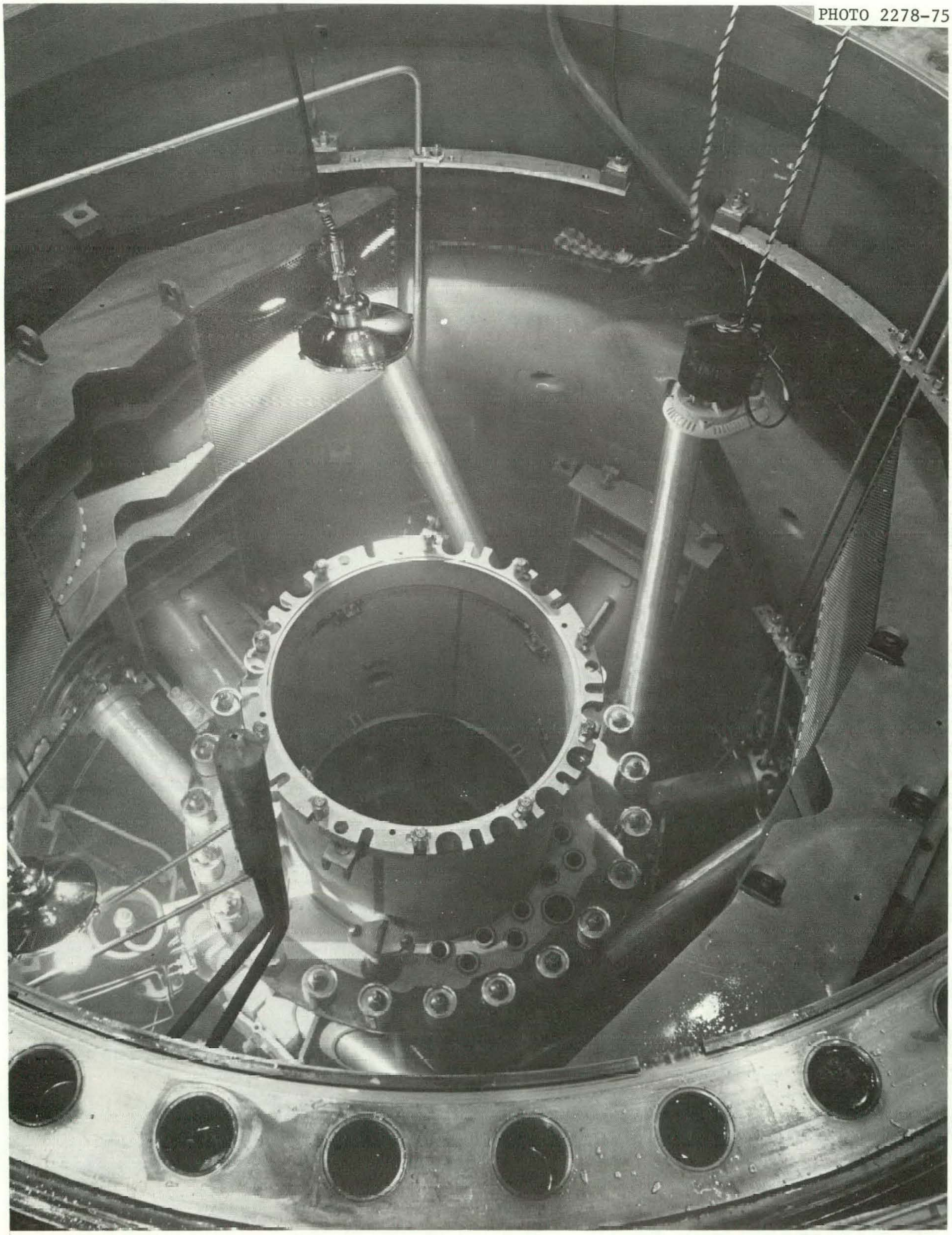

Figure 55. Reactor Vessel Components after Major Reassembly Work (Underwater Photograph)

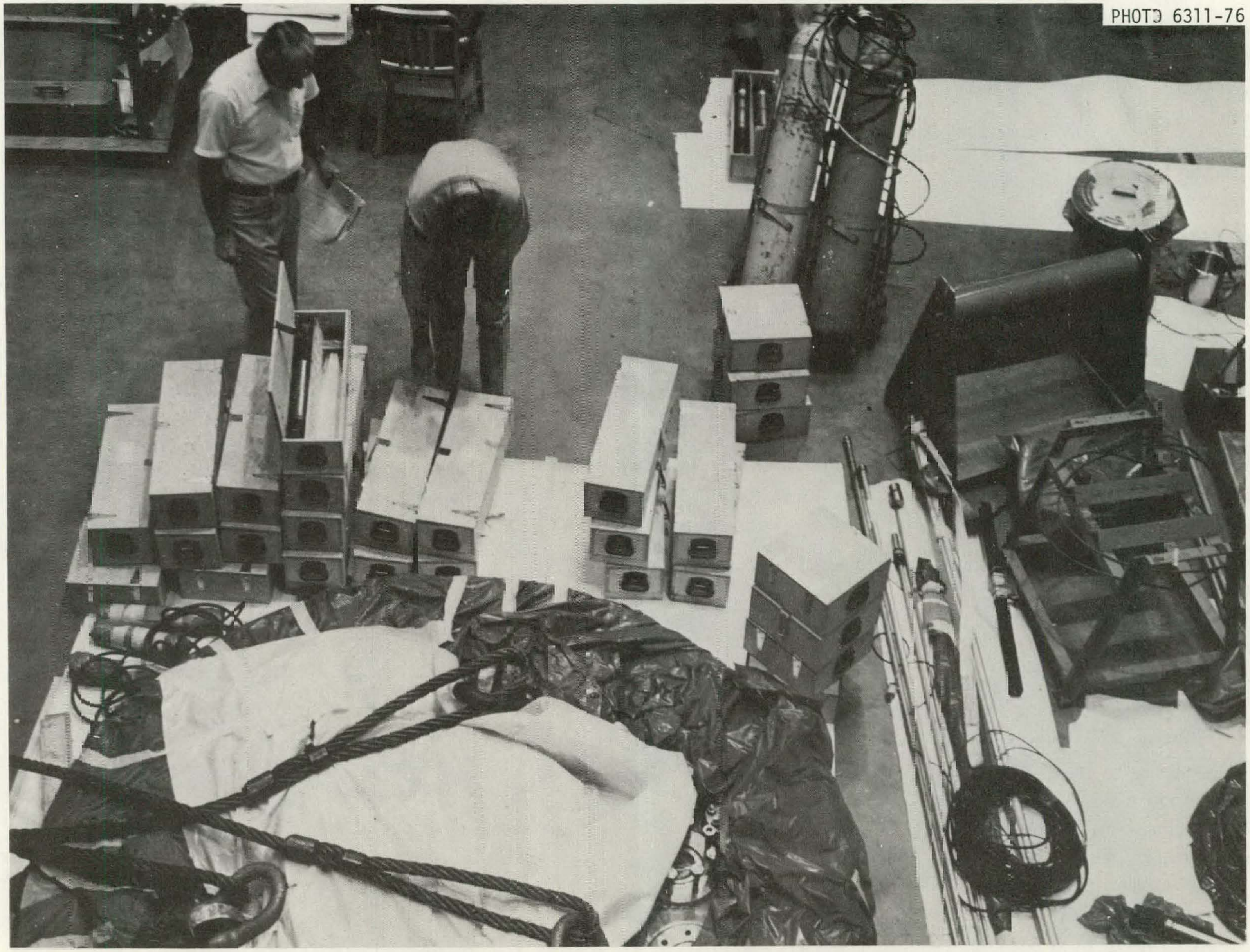

Figure 56. Inspecting the Studs for the Reactor Vessel Head

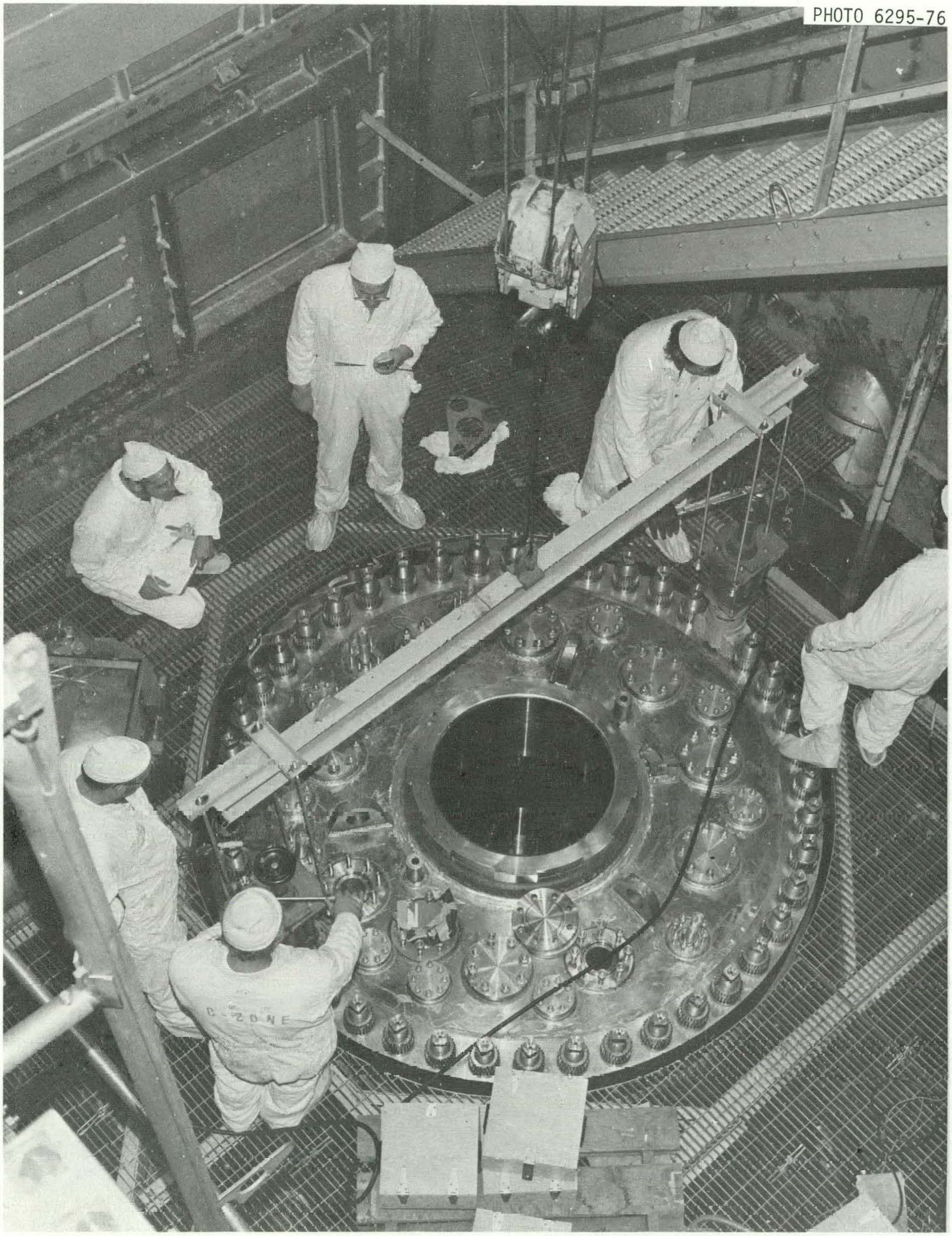

Figure 57. Installing the Reactor Vessel Head Studs

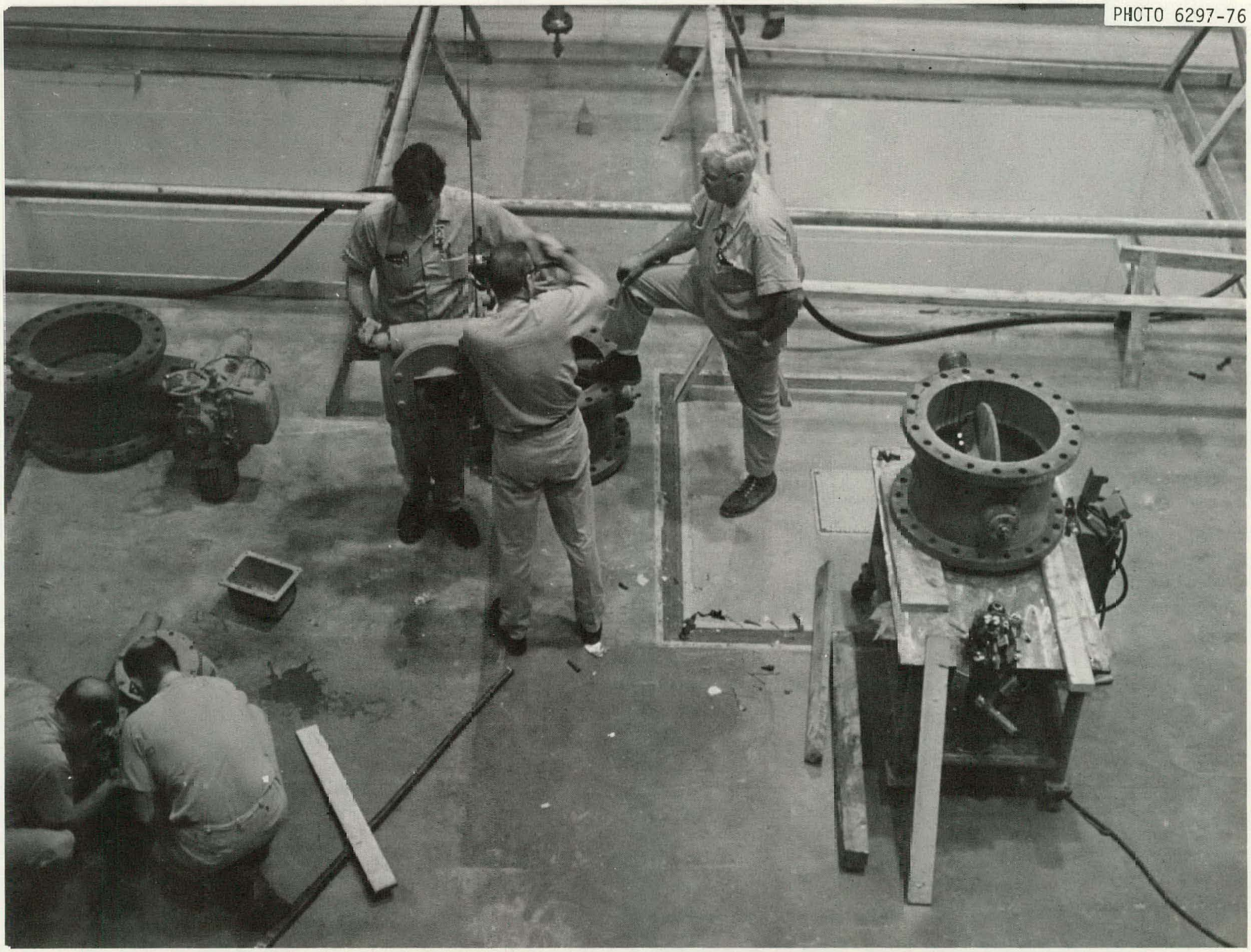

Figure 58. Overhauling of the Heat Exchanger's Secondary-Water Control Valves

Figure 59. Construction of an Addition to the HFIR Building

PHOTO 2999-75

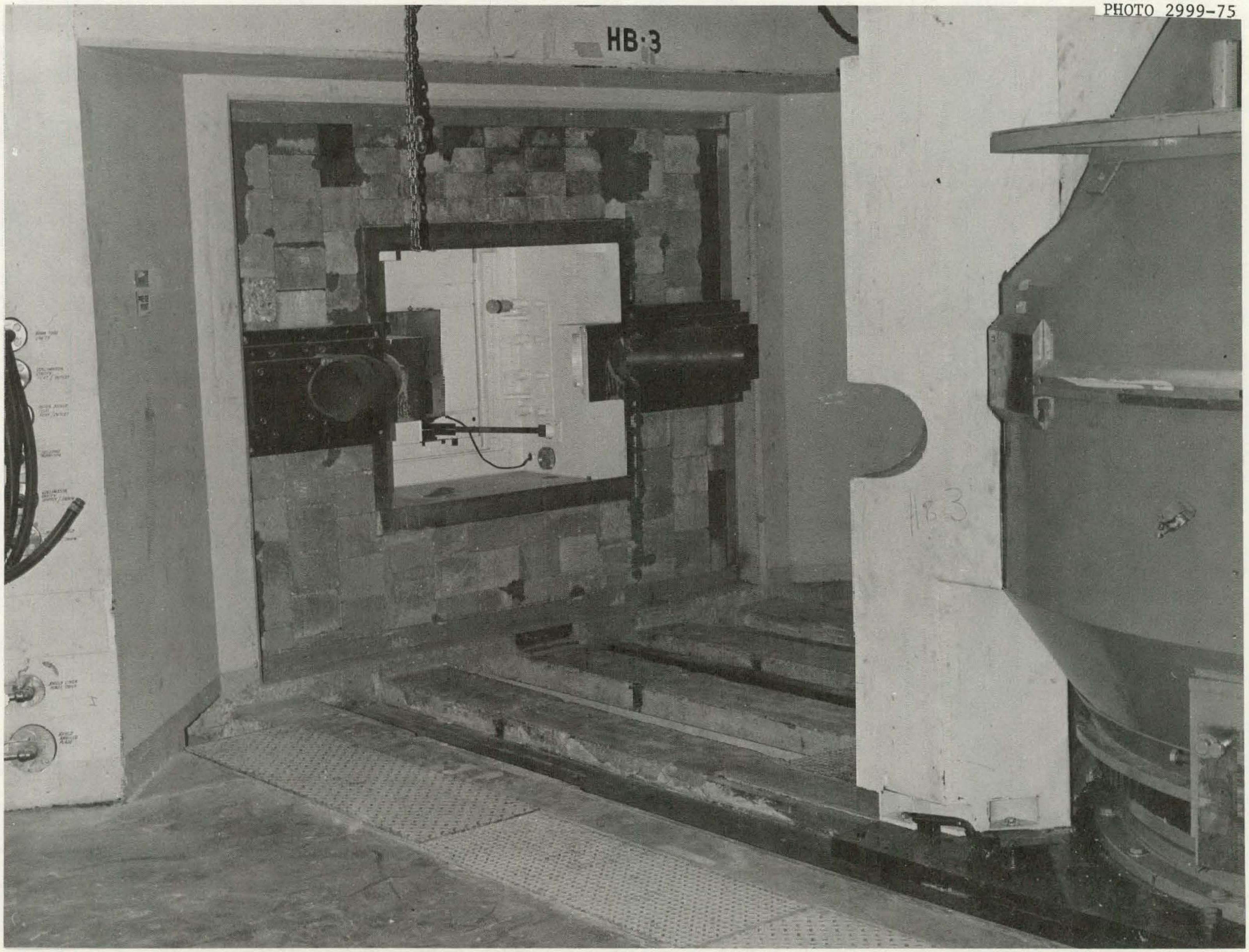

Figure 60. Beam Tube Prior to Shutter and Shield Installation

Figure 61. Shielding Blocks for Beam Tube Facility

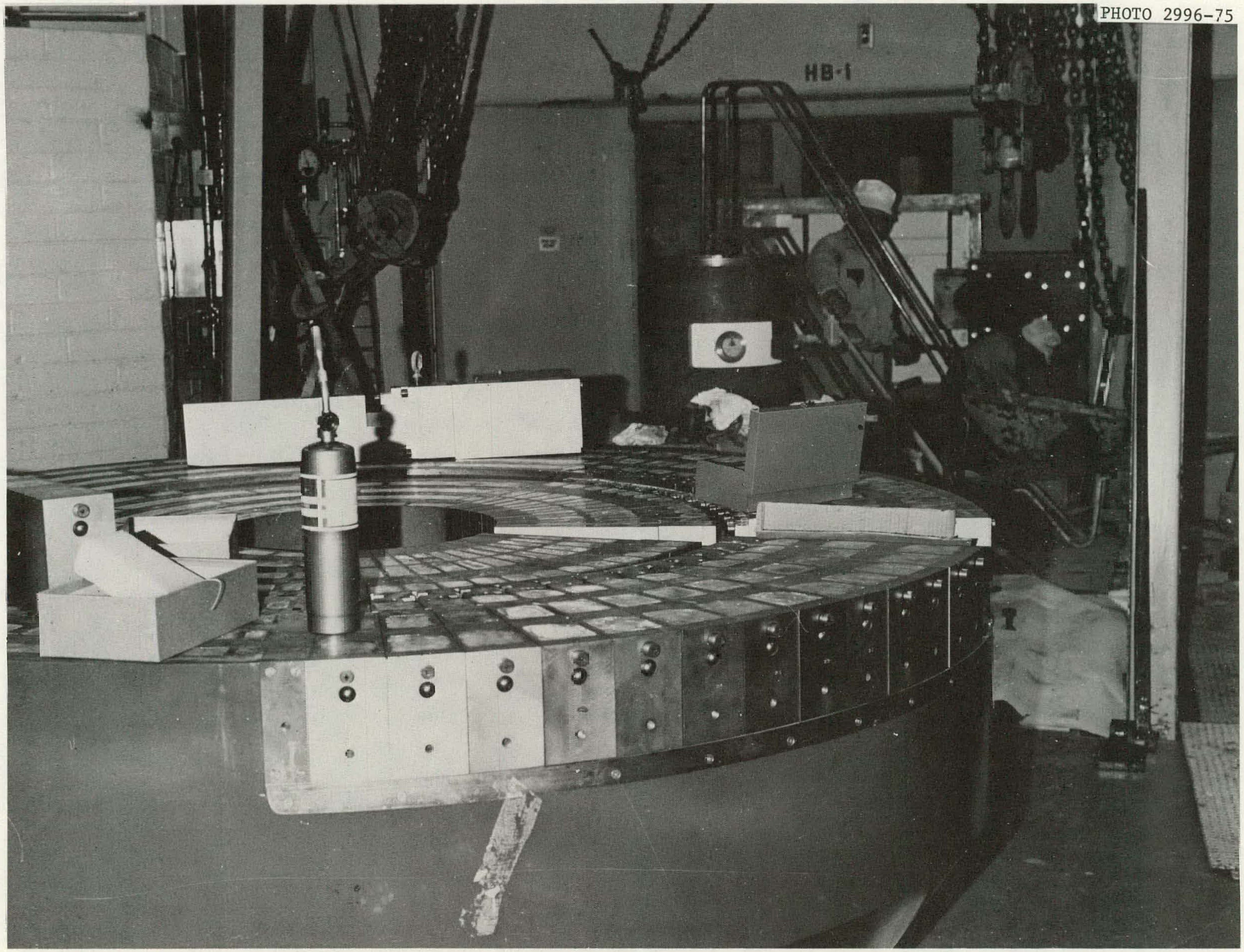

Figure 62. Rotating Shutter for Beam Tube Facility

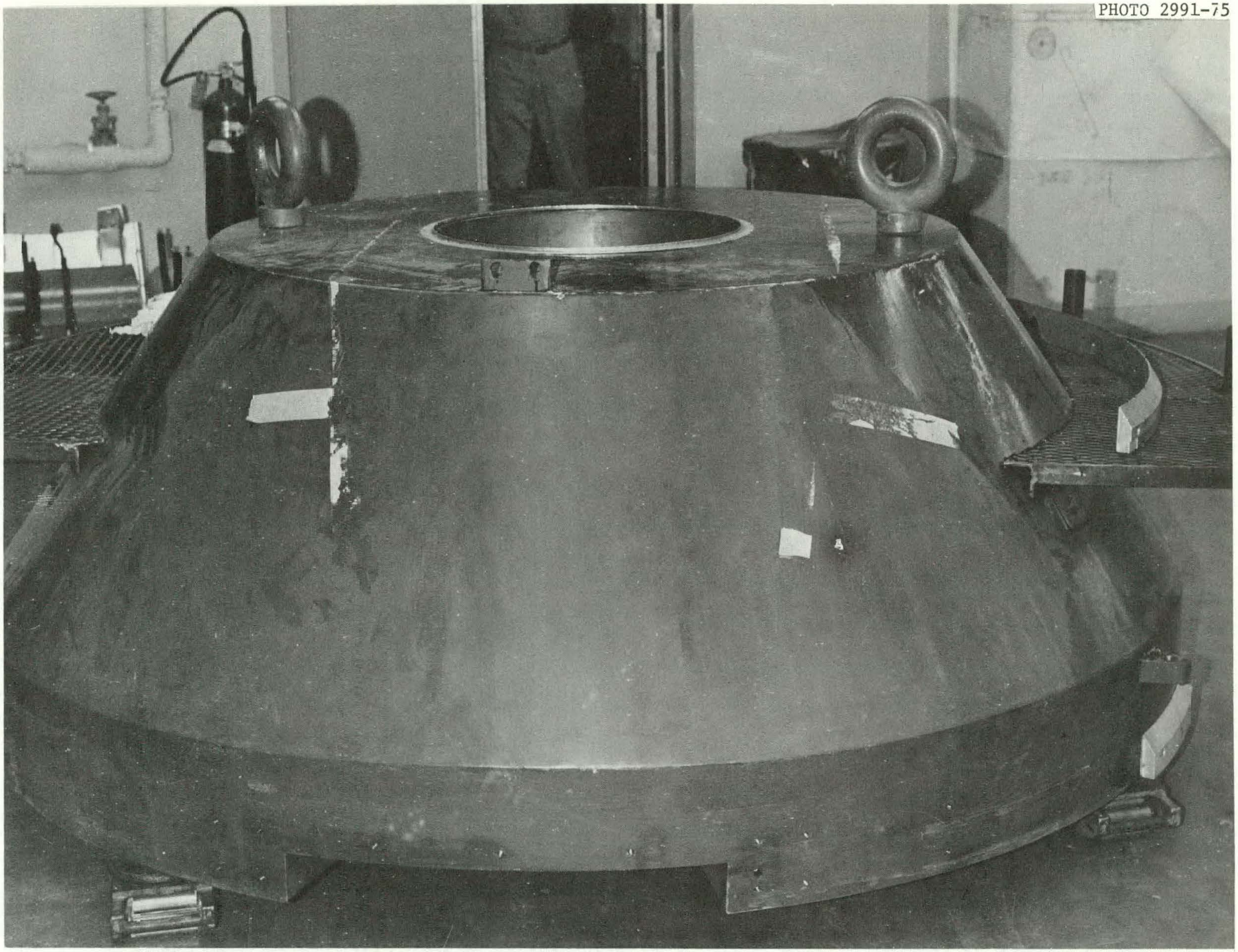

Figure 63. Shielding for Beam Tube

PHOTO 2993-75

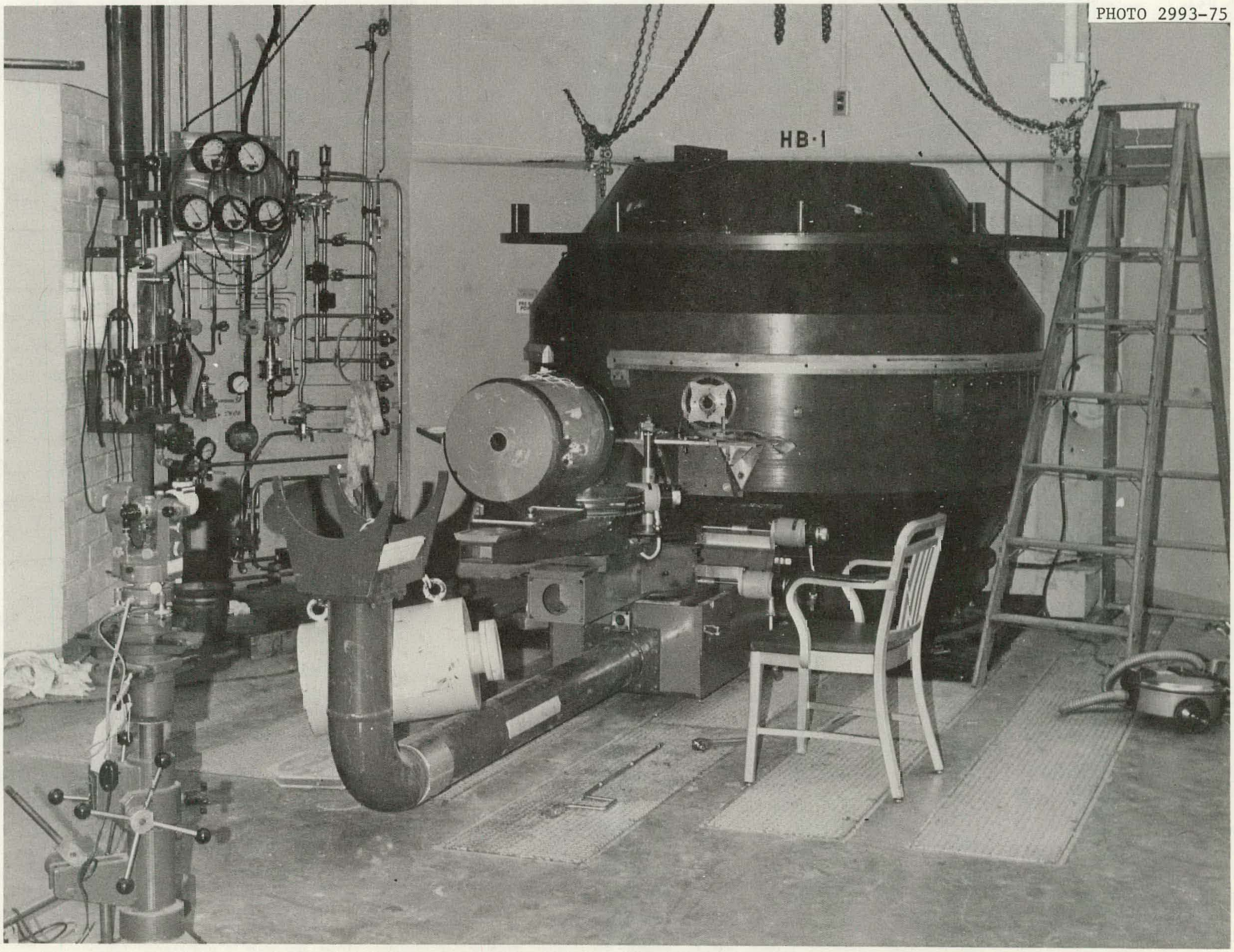

Figure 64. Completion of Beam Tube Shutter Installation

APPENDIX B

MAINTENANCE AND OTHER WORK PERFORMED DURING THE BERYLLIUM-REPLACEMENT SHUTDOWN

1. Removal of deposits from the secondary side of the four heat exchangers.

2. Installation of viewing ports in the shell side of heat exchangers B, C, and D.

3. Removal, overhauling, and reinsertion of all the flow-control valves in the secondary side of the four heat exchangers.

4. Installation of a manually operated valve in the bypass line around the cooling tower.

5. Construction of an addition to the HFIR building for the benefit of the experimenters.

6. Overhaul of the level-control valves for the deaerators and HCV-1024.

7. Inspection, repair, and painting of the cooling tower and flushing of the flow distributors.

8. Replacement of the primary system's pressure-safety valves with tested valves.

9. Replacement of pressure-safety valves on the secondary side of the primary heat exchangers.

10. Removal, cleaning, and replacement of all primary pump-seal water filters.

11. Cleaning of the pressurizer pump strainers.

12. Replacement of diaphragms in the cleanup-system valves.

13. Cleaning and lubricating couplings on PU-9A and PU-2A pumps.

14. Checking and adjusting the asymmetry setback switches.

15. Inspection and repairs of all four pony motors.

16. Replacement of the PU-1D pump seals.

17. Calibration of all primary pump-seal water-inlet and outlet flow meters and the installation of glass covers.

18. Repairs of pump PU-14.

19. Installation of a bypass around LCV-202.

20. Removal, recalibration, and replacement of new letdown valve from heat exchanger cell No. 110.

21. Flushing out of the decay header in the pipe tunnel.

22. Calibration of all inlet and exit temperature sensors for the core.

23. Checking and repair of the electrical circuits on the pressurizer pumps.

24. Draining and flushing of the pressure balance system and replacement of rubber components.

25. Draining and cleaning of the sulfuric-acid tank and lines.

26. Inspection, cleaning, and repairs of all relay contacts, connections, etc., in the auxiliary control room.

27. Cleaning of all battery systems.

28. Locating and repairing a ground fault in substation--Transformer No. 1.

29. Checking and testing the electrical distribution system.

30. Cleaning all servo motors; installing new brushes, as needed.

31. Overhauling of all three fission chamber drives.

32. Replacement of the inner control-rod-drive seal bearing and drive rod.

33. Installation of a new pneumatic tube in-core piece.

34. Vacuum cleaning the reactor pool floor.

35. Performing the poison-injection-system test.

36. Performing the radiation-block-valve test.

37. Performing the primary-check-valve test.

APPENDIX C

ITEMS WITH WHICH GALLING PROBLEMS WERE ENCOUNTERED

1. One of the bolts used to secure one of the peripheral sealing plates for the reactor vessel.
2. One of the 24 Belleville washer studs, during removal.
3. The EF-3 Marman clamp (removal).
4. One of the studs on the RP-1 flange.
5. One of the bolts on the HB-1 split shield.
6. One of the Belleville washer studs, during installation.
7. All four nuts on the HB-4 Marman clamp, during installation.
8. The nuts on the EF-2 Marman clamp, during installation.
9. The nuts on the EF-3 Marman clamp, during installation.
10. One of the bolts on the inlet strainer.

APPENDIX D

A SUMMARY OF RADIATION EXPOSURES RECEIVED BY PERSONNEL PARTICIPATING IN THE BERYLLIUM-REPLACEMENT SHUTDOWN

Accumulated Radiation Dose (in mrem)

Operations Division Personnel

	Pocket Meters	In-Pool Dosimeter	Film Badge
A	300	146	240
B	20	20	---
C	415	479	260
D	285	400	240
E	195	271	---
F	60	0	---
G	60	34	---
H	205	407	370
I	215	416	250
J	430	681	370
K	395	277	280
L	170	221	---
M	70	44	---
N	190	275	250
O	240	718	260
P	340	351	290
Q	55	217	---

Accumulated Radiation Dose (in mrem)

Plant and Equipment Division Personnel

	Pocket Meters	In-Pool Dosimeter	Film Badge
A	320	---	370
B	465	316	346
C	50	---	---
D	30	11	---
E	580	---	---
F	450	---	---
G	330	21	---
H	230	---	---
I	30	---	---
J	370	---	---
K	30	---	---
L	20	---	---
M	70	---	---
N	70	---	---
O	355	---	---
P	40	---	---
Q	250	35	---
R	45	---	---
S	90	70	---
T	80	---	---

Accumulated Radiation Dose (in mrem)

Inspection Engineering Department Personnel

	Pocket Meters	In-Pool Dosimeter	Film Badge
A	165	240	---
B	50	148	---
C	35	48	---
D	40	---	---
E	70	25	---
F	65	65	---
G	110	196	---
H	40	---	---
I	40	---	---
J	35	33	---

Health Physics Division Personnel

	Pocket Meters	In-Pool Dosimeter	Film Badge
A	45	---	---
B	125	---	---
C	20	---	---

Reactor Division Personnel

	Pocket Meters	In-Pool Dosimeter	Film Badge
A	20	8	---
B	65	---	---

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