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DESIGN OF SODIUM COOLED REACTOR SYSTEMS AND COMPONENTS FOR MAINTAINABILITY

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ABSTRACT

Procedures, tooling, and access requirements for maintenance must be developed and incorporated into nuclear plant designs beginning with the initial plant layout studies. If maintenance requirements are not addressed early in design, maintenance operations will be affected adversely by lack of adequate work space, access, tooling, equipment, and crane utility. Sodium coolant presents special problems associated with handling, cleaning, storage, and waste disposal. These special problems must be addressed in maintenance planning and design.

This paper discusses special maintenability problems associated with the design and operation of sodium cooled reactor plants. Some examples of both good and bad design practice are introduced from the design of the FFTF plant and other plants. Subjects include design for drainage, cleaning, decontamination, access, component removal, component disassembly and reassembly, remote tooling, jigs, fixtures, and design for minimizing radiation exposure of maintenance personnel. Check lists are included.

DESIGN OF SODIUM COOLED REACTOR SYSTEMS AND COMPONENTS FOR MAINTAINABILITY

SUMMARY AND INTRODUCTION

Nuclear power plants must be designed with maintainability as a prime criterion. Maintenance requirements must be addressed beginning with the initial plant layout studies. If maintenance aspects are not addressed until late in the design phases, maintenance operations are adversely affected by lack of adequate space, access, crane utility, storage, and other requirements for efficient maintenance. Sodium cooled reactors present unique handling, cleaning, storage, and waste disposal problems due to the properties of the coolant. These considerations must be accommodated in the maintenance planning and design.

This paper discusses plant and component design features which exert considerable influence on the maintenance of sodium cooled reactor plants. Some examples of both good and undesirable design practices are discussed. These examples are based on design of the Fast Flux Test Facility and other plants. Subjects include design for drainage, cleaning, decontamination, access, component removal, component disassembly and reassembly, remote tooling, jigs, and fixtures, and design for minimal radiation exposure of personnel.

GENERAL PLANT DESIGN CONSIDERATIONS FOR MAINTENANCE

A maintenance plan must be established very early in the design process along with an organization responsible for implementing and monitoring the plan. The plan must establish the following:

- Identification of equipment that will require maintenance
- Expected frequency, cost, and down time required for each maintenance procedure.

- Expected needs for shielding casks, tooling, personnel, transport and handling equipment
- Need for temporary supports, guides, fixtures and structural support locations for these items.
- Need for access and egress for personnel, tooling and equipment
- Needs for temporary storage and lay - down space
- Logistics of providing the necessary tooling and equipment within the Containment Building
- Need for temporary shielding for personnel within the various work areas.
- In-Service inspection requirements, including use of remote inspection equipment.

Basic plant dimensions are often established from preliminary piping diagrams, without adequate space allowance for both erection and maintenance in an effort to minimize the size, (and cost) of the building. The cost of working in the resulting confined spaces will, in many cases, far outweigh any possible savings in reduced cost of the building. Excess plant outage time, as a result of performing maintenance in confined space,is a significant plant cost. If the organization responsible for the maintenance program is not established to identify maintenance needs very early in the design process, plant design will proceed to the point at which these vital needs of the maintenance plan cannot be provided without major plant modification or excessive cost.

Piping systems in a modern sodium cooled reactor plant are exceedingly complex due to the requirement to accommodate thermal expansion and seismic motion. Installations are complicated by the need for heavy insulation and preheat systems for the sodium coolant. In contrast to water cooled plants, sodium cooled plants are high temperature, low pressure plants. Sodium piping systems comprise large diameter thin walled pipe and must be very flexible to provide for thermal expansion at the high temperatures involved. Therefore, the design of sodium piping systems can be more intricate than comparable design in a light water plant. The net result is more space required to accommodate the equipment needed to support the main piping system. Such items as pipe hangers, snubbers, guides, preheat wiring and junction boxes, insulation, cable trays instrument leads and structural supports must be accommodated. These items do not show on preliminary layouts of the main piping and equipment; but must be housed and installed. They must also be removed for each maintenance operation unless planning in design has provided adequate space. A number of photographs in the appendix show some of the complications in the Fast Flux Test Facility (FFTF) due to these factors (Figures 1 thru 6). It is not clear that we will, in fact, be able to peform adequate maintenance in some areas of the plant without literally dismantling and reassembling the plant. Space is not available in the equipment cells for temporary storage. Each item removed for maintenance must be removed from the cells for temporary storage. Much of the work of clearing obstructions for maintenance access may have to be performed remotely due to the radiation levels. To provide for some of these problems, the maintenance effort during preliminary design must predict where piping will have to be cut, what temporary supports will be necessary, and what and where special structural attachments will be required to permit this work. Adequate access platforms and ladders must be provided, requiring additional space.

Logistics of maintenance operations is a point often overlooked in preliminary planning of the reactor concept. When a plant is shut down for overhaul or repair, there is a strong incentive to expedite work to the greatest possible extent to minimize outage time. However, if the operation has not been planned for in design - if the necessary handling tools, casks, platforms and shielding are not readily available - then the entire process is delayed by logistics.

A comprehensive study of the arrangement of the items within the reactor building must be made. As a general statement, space around the reactor is valued in direct proportion to its proximity to the reactor. If an item is not required to be within the reactor hall for safety or functionability, then in many cases it should not be there. Each piece of equipment that can be located outside of the reactor hall will release additional space for the vital maintenance operations that must be performed within that confined area.

In most plants, there is only one equipment airlock into the building. Lay-down and temporary storage space within containment is seldom adequate due to the necessity to reduce the size of the building for economy. It is often necessary to move items out of containment for temporary storage. Thus, traffic through the airlock impedes maintenance operations. If the logistics problem is anticipated and analyzed early enough in design, there is a major chance to demonstrate that a larger reactor building would reduce maintenance down time sufficiently to be an economic incentive.

RADIATION CONSIDERATIONS IN PLANT DESIGN FOR MAINTENANCE

Current Federal Regulations establish outside limits on the amount of radiation exposure an individual may incur within certain time periods. In addition, it is the policy of the Federal Energy Administration that nuclear facilities be operated in a manner "to assure that radiation exposures to individuals and population groups will be as low as reasonably achievable."

Personnel may, in practice, have to enter areas where they will be exposed to small radiation exposures on a routine bases. This condition exists in areas where personnel occupancy is expected to be for short periods of time only. It is often impractical to provide adequate shielding to reduce average doses from adjacent areas to approximately background. In these cases, the maintenance design engineer can plan to limit personnel entry to some small fraction of the work day, such as two hours per day, in preference to trying to reduce radiation levels to an absolute minimum.

To account for incidences in which personnel will be exposed to small but allowable radiation doses, it is necessary early in design to determine what maintenance procedures will be necessary in each area of the plant. It is then necessary to make an estimate of the time required per incidence, and the frequency of each incidence, so that the expected annual per man exposure can be estimated. From these estimates, an allowable rate of radiation exposure can be established for the maintenance personnel. Shielding modifications may be required if the studies indicate the exposure to be excessive. Again, it is important to identify necessary modifications early in design.

Sufficient shielding to assure minimum exposure for all occassions may be prohibitively heavy; or the physical space available in the area of the reactor head may prohibit use of sufficient shielding. However, such items as maintenance casks are used frequently. At EBR II (1), space limitations prelcluded use of a handling cask with sufficient shielding to properly protect personnel. This problem was solved by designing a lightly shielded cask. In use, the cask is placed in position on the reactor head, then the component is drawn up into it. During this withdrawal procedure, only one individual is permitted in the reactor hall, along with a crane operator. These two persons remove the object from the reactor and install it in a shielded cell as quickly as possible. During the operation, they receive a measurable radiation exposure. However, it is within occupational limits, and permits the maintenance procedure to take place. The importance

(1) Lehman, J.D., and Waldo, J.B. "Maintenance of Radioactive Sodium Systems at EBR II", Nuclear Engineering Conference, Nuclear Engineering Division, ASME Palo Alto, CA., March 7-10, 1971, Paper No. 71-ME-12.

of planning such operations early in the design of the plant and equipment cannot be stressed too strongly. This experience demonstrated several principles:

- Space for maintenance casks and equipment must be provided during design of the reactor and plant itself. Otherwise, space may not be available for suitable maintenance tooling.

- For relatively rare maintenance procedures, it is quite feasible to plan for some minimal exposure for certain maintenance or supervisory personnel.

- Time scheduling of operations is an effective means of limiting exposures of maintenance personnel.

- Need for properly sized and located shielded storage cells must be anticipated, and they must be provided in design.

Appendix 1 is a tabulation of many of the points which a good design program for maintenance of sodium systems should address. It is hoped this list will be helpful in establishing the design effort in the maintenance area for future plants.

REACTOR COMPONENTS REMOVAL/REPLACEMENT

In a sodium reactor, all operations pertaining to the reactor proper are centered on the reactor head. This space contains the fuel loading machinery, the control rod drives, ports for the insertion and removal of the fuel elements, and instrumentation for control of the nuclear reaction. Cooling must be provided to the head. The head must, in addition, form a seal, and offer heavy shielding to keep radiation above the head within allowable limits. Thus space on the reactor head is critical. In design of the head and other components of the reactor system, there is often a need for dual sets of seals, the component/reactor seal, and the maintenance seal.

The component seal, for holding down and sealing the component to the reactor head, normally consists of a flange or similar joint with a sealing element. However, during component removal for repair, it is necessary to maintain a seal between the reactor cover gas space and the reactor hall. Therefore, it is necessary to seal a cask around the primary seal prior to removal of the component from the reactor. It is this second seal, together with the space necessary for shielding, that is often neglected. Maintenance Engineers must be involved in the design of the head early in the layout phases to assure that space and a suitable sealing surface are left to accommodate this requirement.

In addition to a requirement for sealing the maintenance casks to the reactor head, there is a requirement to seal the penetration after the component has been removed. This can be accomplished by inserting a new component into the reactor immediately, or by inserting a temporary maintenance seal or plug into the penetration to fulfill the functions of atmospheric seal and shielding. In some plants, maintenance casks have been devised with two barrels. After a component has been drawn up into one barrel, the barrels are rotated, to place a plug or replacement component into the penetration from the second barrel. Floor valves are also a common solution to this problem. A floor valve is sealed to the head, such that, when the component is removed from the reactor, the floor valve can be closed, and remains in place as a shield and seal until a new component or plug can be brought in and re-inserted into the reactor through the floor valve. However, floor valves require space that may not be available. At FFTF, a modification of this concept is used. The floor valve is installed above the deck covering the head compartment. A relatively light seal tube forms the gas boundary around the component and between the floor valve and reactor head (Figures 7 and 8) (2). Shielding is provided by portable shield walls placed around the work area during actual component removal.

(2) Carver, J.R. "Large Component Handling System Verification Tests", Hanford Engineering Development Laboratories Document No. TC-703 (Sept. 1976). delete

As a general statement "maintenance" of in-reactor components refers to removal and replacement of components. The components are highly activated due to neutron irradiation, and thus would be difficult and expensive to repair. "Decontamination" is impossible. The basic deficiency, is most cases, is hardening, swelling, and deformation of the material itself due to the neutron irradiation thus rendering repair, as such impractical.

Therefore, it is imperative that all in-reactor components be designed for ease of removal and replacement. The following factors must be considered:

- Easily removable assembly components such as locating pins, fasteners, etc., must be used. Screwed or threaded fasteners are not desirable.
- Swelling and bowing of the various components must be considered. Thus, there must be adequate allowance for fit up of the new replacement components.
- Each part must be analyzed to assure that it may be grasped, lifted and removed from the reactor vessel through existing access openings, usually without visibility to guide grapples.
- In general, the component should be designed to be removed without rotation or re-orientation within the reactor vessel, since space is generally not adequate for such manuevering. Handling lugs or means for attachment of lifting tools must be provided in design. Where applicable, these must be usable remotely, and often without visual assistance, as, for example, components under sodium.
- Where feasible, smaller parts are used to simplify removal and replacement. In particular, parts subject to high neutron irradiation doses will require replacement on more frequent schedules than those subject to lower irradiation doses. By designing in "radial" layers, parts can be replaced as required.

DRAINAGE

Complete system drainage is very important prior to disassembly or removal of a component for maintenance or disposal. In most maintenance processes, it is necessary to react sodium prior to beginning work. If sodium is left in very thin surface films, as it will be when drained at a suitable temperature from vertical surfaces, then the sodium removal operation is relatively simple. Conversely, if pockets of sodium with appreciable thickness remain, then the reaction becomes more complicated and time consuming. It has been estimated that a deposit of sodium 0.025 mm (1 mil) thick can be reacted in about 3 minutes. A deposit 6 mm (¼ inch) thick requires about 12.5 hours to react.(3) If water or moisture is the reactant, then excessive heat can be generated in thick sodium sections. More likely, the sodium may not be completely removed from the thick deposits. The result could be high reaction rates during rinse, or the potential for stress corrosion cracking initiated from the presence of partially reacted sodium on the surfaces for excessive lengths of time at high temperature.

Appendix 2 presents a number of rules for design of equipment for drainage. Horizontal flat surfaces, facing either up or down do not drain particularly well. Figure 9 shows the lower side of thermal baffle plates which were immersed in the gas space above a sodium system for a period of time. Slight alterations in design could have reduced the deposits without appreciable loss of effectiveness of the plates. For example, instead of being flat and horizontal, the plates could have been bent or warped and provided with drip paths such that the sodium could drip down the plates and drop back into the sodium pool. Sharp sheared edges could have been left for the sodium to drip downward. Since the plates serve only as reflective insulation, these modifications would not alter the effectiveness of the insulation appreciably.

(3) Funk, C.W. (Editor), "Sodium Removal Handbook", Hanford Engineering Development Laboratory, October 1975, Document No. MG-27.

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Figure 10 shows the upper surface of a flat plate on the in-vessel handling machine of the FFTF after a test in sodium. Note that sodium did not drain completely from the top of the flat surfaces. Draining was performed at 143°C (290°F). It is preferable to drain parts for maintenance at no less than 204°C (400°F) to assure relatively complete drainage. This plate could have had a more rounded configuration, or drain holes could have been provided. Note that this plate is not completely flat and further, it is relatively narrow. Wide flat plates are even more troublesome to drain.

Figure 11 shows a view of the FFTF instrument tree. This component comprises a box-like weldment which is to be immersed in sodium. The lower portion of this box is not completely drainable, even though some drain holes were furnished, and this will result in difficulty in the cleaning process.

Valves are expecially troublesome with respect to design for drainage. Figure 12 shows a 16 inch block valve at FFTF. Note the undrainable pocket at the bottom of the valve. For such components, sodium is not only a problem from the point of view of cleaning and drying, it is also a radiological hazard. Radioactive species, including sodium itself, can collect in this pocket. This makes handling prior to cleaning difficult, and compounds problems with disposal of cleaning solutions. In many cases, minor changes in design can eliminate such pockets.

CLEANING AND STORAGE

There are a number of means of cleaning sodium wetted components in practical use today. Probably the most universally used is the moist nitrogen process in which sodium on the surface of the objects is reacted with moisture in an inert nitrogen atmosphere. The reaction is controlled to a slow rate and particularly to a low reaction temperature, by controlling the moisture content of the nitrogen. A second cleaning procedure is use of one of the alcohols to react with free sodium. However, there is always the potential for incomplete cleaning. In particular, sodium that has been trapped behind screws or in other pockets which cannot be contacted readily by the moisture will remain, and convert to sodium hydroxide slowly for long periods of time after the cleaning procedures are complete.

When using the cleaning procedures, it is always necessary to disassemble the component completely after the cleaning to assure that all sodium and its reaction products have been removed from hidden surfaces, such as screw holes or between close fitting elements.(4)

One problem with cleaning of components is that of access of the reactants to the surface of the sodium. For example, if there is an inverted syphon, wherein the reactant cannot penetrate due to gas blocking, a stagnant area can be formed, such that the reactant does not reach the sodium wetted surfaces. Subsequently, if the chamber is filled with rinse water, a very rapid reaction ensues. This effect was sufficient to bend certain reflective insulation plates in the In-Vessel Handling Machine (IVHM) during the rinse cycle (figure 13). To counteract this problem, there is a need to examine very carefully the configuration of objects which may require sodium removal during design. Areas where the cleaning agents cannot penetrate easily should be eliminated by providing vents or drains.

While close tolerance fits are to be avoided in components in sodium service, actual interference fits may not be a major problem. Experience at HEDL indicates that sodium does, indeed, penetrate the crevice between two plates in contact in interference fits.

(4) Crippen, M.D., "Removal of Sodium from the IVHM Orientation Plug", Hanford Engineering Development Laboratory Document No. HEDL TME 77-63, US-79 a, b, (August, 1977).

However, when such pieces are cleaned, the cleaning media does not penetrate between the components. Therefore, hydroxides are not formed within the crevice. Thus, when the component is returned to the sodium media, the surface oxide and hydroxide are taken up in the sodium and caustic stress corrosion has not proven a problem. This is not to say that the potential is not there.

Another approach is to minimize cleaning if at all possible. In many cases, repairs can be made by wiping surfaces with alcohol-wetted cloths to remove sodium from the immediate area of a maintenance operation such as a weld location. Under these conditions, it is often not necessary to clean the entire component, and problems with cleaning are minimized. Generally speaking, an article that has been exposed to sodium can be stored indefinitely in an absolutely dry inert atmosphere at room temperature without appreciable deterioration. Thus, if it is possible to accomplish the maintenance procedure without cleaning, and subsequently to store the article in an inerted cell until it is reinstalled in the sodium environment, complications are avoided.

Early is design, need for temporary storage of sodium wetted components should be identified. The size, use, and preferred location of these storage cells should be determined. The logistics of removing the components from the reactor; transferring them to the maintenance and storage areas; repairing while sodium coated; and finally returning to service, must be planned for.

GUIDES FOR SODIUM COMPONENT DESIGN

Following are several very important rules or guides for use in design of ex-reactor sodium wetted components. These rules have been developed over a number of years as a result of experience with a number of plants.

- Make the assembly as simple as possible. Maintenance of components in sodium is a difficult job at best. If intricate, close tolerance mechanisms are used, the task becomes impossible.

- Avoid threaded joints if at all possible. By its very nature, sodium will penetrate any crevice which is identifiable even by dye penetrant means. Certainly, after a period of time in hot sodium, every crevice and void in a threaded joint is filled with sodium. Furthermore, the surface oxide coating becomes reduced such that contacting surfaces are subject to such effects as self-welding and gualing which make disassembly exceedingly difficult.

- Avoid close tolerances if possible, particularly of flat surfaces. In at least on incidence at HEDL, (Figure 14), a flat plate was bolted to another plate on the bottom of a horizontal parting line. During disassembly, the bolts were removed, and the upper assembly was lifted. However, the bottom plate remained with the top assembly, much as if the sodium acted as a very strong adhesive to hold the plates together. In this instance, ordinary cleaning to remove the sodium was insufficient to release the plates from one another. To avoid this sort of problem, jack screw holes could have been provided.

- Close tolerances (on the order of 1 to 25 mils) are difficult to clean completely free of sodium. Over a period of time, sodium will penetrate crevices between two pieces of metal. Such components can be cleaned free of surface sodium. However, when the cleaning procedure is complete, it is necessary to disassemble the close tolerance fits, and to clean the surfaces by hand to remove the last traces of the caustic residue to the cleaning process. Otherwise, over a period of time, the residual sodium oxide will exude from the crevice, and coat the exterior of the object with hydroxide, providing a potential for stress corrosion cracking.

Bellows seals are highly desirable in applications such as valve stem seals, since packing glands are unsatisfactory in sodium. However, bellows seals are difficult to clean free of sodium. In almost every instance where metal bellows have been cleaned free of sodium, then re-used, the bellows have failed shortly after their return to the sodium environment. In EBR II, several control rod drive mechanisms, which have bellows seals, were cleaned. They failed uniformly after being returned to sodium environment, apparently due to surface damage to the metal by the cleaning process.(1) To rectify this problem, EBR II adopted the practice of not cleaning these components, but rather storing the sodium coated components in sealed containers in inert atmosphere. This effectively stopped the damage.

Flanges are used in sodium only where it is mandatory that the assembly be disassembled frequently. It is usually possible to design such that the flanged joint is in the gas space rather than in sodium wetted areas of the system. Only metal gaskets are suitable for use in sodium service. The crevices in these joints are very difficult to make leak tight. During sodium removal, caustic can be left in crevices around gaskets and can result is stress corrosion cracking under certain conditions.

At FFTF, it is necessary to cut pipe to remove valves, particularly the check valves. These could have been designed with a flanged assembly in a gas space above the valve such that the valve internals could be removed without removal of the piping envelope. At the Enrico Fermi Fast Breeder Reactor, check valves were mounted within the pump casings below the pumps such that the valves were removed at the time the pumps were removed. No pipe cutting was necessary to remove and maintain the main check valves.

Component support should be considered with maintenance in mind. For example, where a component is suspended from above, it may be necessary to remove the component support before the component can be removed for maintenance. In turn, it is necessary to transfer the load to temporary supports before the component can be cut out of the piping system. This complicates the maintenance operation drastically. By supporting the component from the bottom, the additional work of transferring the load is obviated. This may be critical in a radiation zone where access time is limited.

Standardization of parts is an important item in maintenance of sodium plants. In general, it is not feasible to repair a component in place. Examples are valves, valve operators, instrument elements, etc. Rather it is necessary to remove the existing component and replace it, to expedite returning the plant to service. The replaced component can be cleaned and rehabilitated after the plant is back in service. To pursue this philosophy of replacement and later repair, it is necessary to standardize to minimize spare parts requirements. At the FFTF, the cold traps, valves, plugging meters and instruments were standardized to minimize the number of parts that must be carried in inventory. Where feasible, sizes of valves were standardized at FFTF.

One major tool for design of the reactor components for maintainability is that of the mock-up or model. A model of the item is built, and actual disassembly is demonstrated with remote tooling typical of that proposed for the plant. Such experiments demonstrate satisfactory performance of the equipment, and adequate potential for removal and replacement of the parts; or they reveal problems that may be provided for in the final design. At FFTF, a high temperature facility, the Composite Reactor Component Test Activity (CRCTA), was used to demonstrate ability to remove and re-install fuel elements, the in-vessel fuel handling machine, the instrument tree and other components.(5,6) The ex-vessel fuel handling machine which was subsequently installed in the FFTF was also proof tested in this facility. Portions of the test program were carried out in high temperature sodium to simulate the sodium and thermal environments anticipated in service. Other mock-up experiments demonstrated capability for remote change-out of primary sodium sample capsules from sodium samplers. Remote handling jigs or fixtures for removal and replacement of in-reactor components must be designed concurrently with the design of the reactor components and the access openings of the reactor itself, since it is too late to design and test such fixtures after the reactor is filled with sodium. Sufficient clearances must be provided for the passage of the component into and out of the reactor, and handling fixtures must be able to clear any openings. Again, such clearances should be demonstrated in mock-ups.

Appendix 3 presents a list of suggested rules or guides for design of components in sodium systems for maintenance.

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(5) ~~Coops, W.J., Crippen, M.D., Funk, C.W., et al., "In-Vessel Handling Machine Engineering Model - Cleaning, Disassembly/Reassembly and Requalification", Hanford Engineering Development Laboratory, May 1974, Document No. TC-633.~~ delete

(6) Crippen, M.D., "In-Vessel Handling Orientation Plug Test" Hanford Engineering Development Laboratory Document ~~No. TC-875, May 1977~~.
use TME-77-63

DESIGN OF LMFBR PLANTS FOR IN-SERVICE INSPECTION

Section III of the Code outlines rules for in-service inspection of nuclear power plants to provide a continuing assurance that they are safe. Division 3 of this section of the Code will cover in-service inspection of sodium cooled power plants. The basic emphasis of in-service inspection in LMFBR systems is placed on early leak detection and visual inspection. However, other means of non-destructive inspection, such as ultrasonic inspection or radiograph, will also be used as applicable and feasible. Provisions for in-service inspection must be made in preliminary and final design to assure that adequate space and capability are available. Provisions that must be identified and accommodated include access walkways and ladders, lighting, easily removable insulation packages, space for access, and possibly additional shadow shielding, either permanently installed or removable. Where the radiation levels will be such as to preclude direct man access, provision must be made for remotely operated non-destructive inspection and testing equipment. Some test equipment may be affected adversely by residual radiation levels anticipated in the sodium cooled plants. This residual radiation is primarily due to corrosion products deposited on the inner walls of the pipe and equipment of the primary sodium system or to induced radiation in the reactor cavity. The anticipated radiation levels must be estimated and checked against the proposed means of non-destructive testing for compatability. Appendix 4 presents some rules for use in design of sodium cooled reactor plants to assure adequate in-service inspection capability.

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APPENDIX 1

Check list of General Plant Design Considerations for Maintenance:

1. Provide space and routing for access, removal and replacement of maintainable components. Provide access,routing and space for manuevering remote handling equipment needed for removal of maintainable equipment.

2. Provide overhead crane service or other transport capability including hatches to permit moving components into and out of position within the plant.

3. Prepare a complete logistics plan for each maintenance task anticipated, including at least:

   ° An itemized list of all detailed sub-tasks, with estimated time to accomplish each task.

   ° An itemized list of each tool required.

   ° A study to demonstrate suitable clearances for access, installation, operation, and removal including remote handling tooling and capability if required.

   ° An estimate of expected frequency of each task.

4. Make compensation in plant layout for space and access requirements for minor components including pipe supports, insulation, snubbers, structural equipment supports, wiring, instrument leads, tooling clearances and access platforms and ladders.

5. Provide structural attachments and/or support locations for temporary fixtures, jigs and tooling which will be required for identified maintenance procedures.

6. Verify that adequate lay-down space and temporary storage are available for plugs and components removed for access during maintenance; or include their removal from containment in the logistics planning for maintenance.

7. Verify that adequate shielding is provided between shielded cells to permit entry into an isolated cell; or make provision for temporary shielding, shielded access or remote maintenance operations.

8. Demonstrate plans and equipment capability for disposing of replaced components, such as cleaning, storing, and repair or ultimate disposal.

9. Provide modular removable insulation/preheat packages at locations where its removal is expected during maintenance operations.

10. Pneumatically actuated equipment is generally preferred to electrical equipment since the force exerted by the pneumatic equipment is limited. Manual equipment is often preferred to automatic equipment for the same reason.

11. Review component location for absolute need to be close to the reactor.

12. Maintenance tooling and casks should be designed concurrently with the plant to assure clearance and accessibility requirements are identified and met.

13. Flanges are, generally, unsatisfactory in sodium wetted applications. Install maintenance components with flanged joints in the gas space over the sodium if possible.

14. Sodium heat transfer equipment should be easily accessible and maintainable at minimum expense. Due to size and weight, it is preferable to carry out repair work in situ if possible.

APPENDIX 2

Check List for Design of Sodium Cooled Systems for Drainage, Venting and Isolation

1. Slope all horizontal sodium lines at least 1/16" per foot toward suitable tanks or drain lines. 1/8" per foot is preferable.

2. Avoid un-drained low points in systems and components.

3. Warp or bend horizontal plates and provide drain holes in horizontal plates if possible.

4. Avoid inverted pockets without vents. Provide adequately sized running vents where feasible to facilitate venting during fill, operation and cleaning procedures.

5. Specify maximum permissible shrinkage of welds in horizontal piping to minimize sodium hold-up behind welds.

6. Install valves in the vertical or take other feasible precautions to minimize sodium hold-up in valves.

7. Avoid "shrouded" structures where feasible. Provide vent holes through such structures wherever possible to facilitate venting, drainage and access for cleaning media.

8. Provide for removal of components from sodium (for drainage) at temperatures above 200°C where possible.

9. Analyze valves in high temperature sodium systems for absolute need. Frozen pipes sections, complete drainage or freeze vents are often preferred.

10. Review the systems to assure against inadvertent syphoning action or draining due to pressure changes during maintenance procedures.

APPENDIX 3

Design Check List for Design of Sodium Cooled Plant Components for Maintenance

1. Design of components in sodium must be simple with a minimum number of parts and adequate clearances.

2. Avoid threaded connections if possible. Where their use is necessary, avoid blind holes. Use vent holes through studs as applicable to vent blind holes.

3. Avoid flat horizontal plates. Where they must be used, either in gas or liquid, provide drain holes or cant plates for better drainage where possible.

4. Provide for complete drainage both in the sodium system boundary, and also in internals. Where complete drainage is not possible, provide drain holes at the bottoms of pockets where possible. Use of running drains is often acceptable.

5. Avoid unvented high points in components and system boundaries where possible. Use running vents if necessary to avoid these problems.

6. Check location of all studs and nuts, and other fasteners to assure clearance for insertion and removal including clearance for wrenches, sockets, impact tools, and remote handling tooling.

7. Avoid close tolerance assembly of both flat plates and rotary parts if possible. Provide guide pins and lead-in shoulders with liberal clearances to assure ease of assembly and disassembly, both when covered with sodium, and when utilizing remote handling equipment. Provide jack screws or other devices to separate flat plates.

8. Review all assemblies to assure that, after reaction of sodium, all parts can be removed and disassembled (remotely if applicable) even though the sodium reaction may not be entirely complete. In particular, ascertain that all fasteners, can be removed by remote tooling.

APPENDIX 3 (cont'd)

9. Where applicable, build mock-ups of the maintenance area and expected tooling to demonstrate that the necessary maintenance steps can be performed.

10. Support components such that they can be removed for maintenance without requiring transfer of weight to temporary supports (generally support from below where feasible).

11. Standardize parts where feasible to minimize spare inventory and to facilitate repair of components and return to inventory.

12. Where appropriate, use flanged-in components with flanges in the gas space to facilitate component removal for maintenance.

13. Avoid close tolerance and interference fits where possible to minimize problems with cleaning, differential expansion and creep.

14. Avoid crevices. Use full penetration welds. Avoid socket-welds and rolled tubes which comprise crevices.

15. Smooth surface finishes including weld finishes are favored over "as rolled" or "as welded" finishes for ease of decontamination and freedom from laps and pores.

16. In design of heat exchangers, both ends of tubes should be accessible for tube plugging if possible.

APPENDIX 4

DESIGN OF LMFBRS FOR IN-SERVICE INSPECTION

1. Identify areas of high stress and select areas to be inspected periodically for long term changes in condition. The means of inspection (whether contact or remote) and the specific NDT test applicable (radiograph, visual, ultrasonic, or other) must be selected. Check design of the weld or other feature being inspected for compatability with the test selected.

2. Access routes, ladders, work platforms, temporary or permanent shadow shielding, lighting, power, and communications must be provided the work sites for contact in-service inspection. Provide easily removable insulation packages at the inspection site.

3. When applicable,provide hoists,hatches or other equipment necessary to handle or remove structural components, insulating blocks, or other items preparatory to in-service inspection procedures.

4. When remote in-service inspection procedures are mandatory, provisions must be made in design for entry and positioning of the inspection equipment, and for remote removal of the insulation. Compatability of the inspection equipment with the expected radiation field or fluence must be checked.

5. Radiation calculations must be made for the areas where contact inspection is contemplated to assure that working conditions will be acceptable after extended periods of reactor operation.

6. When required, special means of illumination of the surfaces to be inspected must be provided.

7. Means must be provided for cleaning of the surfaces to be inspected, either before or after the inspection, or both as applicable.

8. Make pre-service measurements of the areas or features to be monitored during service life to establish a base from which to judge changes in condition. These measurements should, if possible, be made with the actual equipment, and in the same manner as will subsequent measurements to assure comparability.

9. Make provision for maintenance, testing, and repair or replacement of leak detectors.

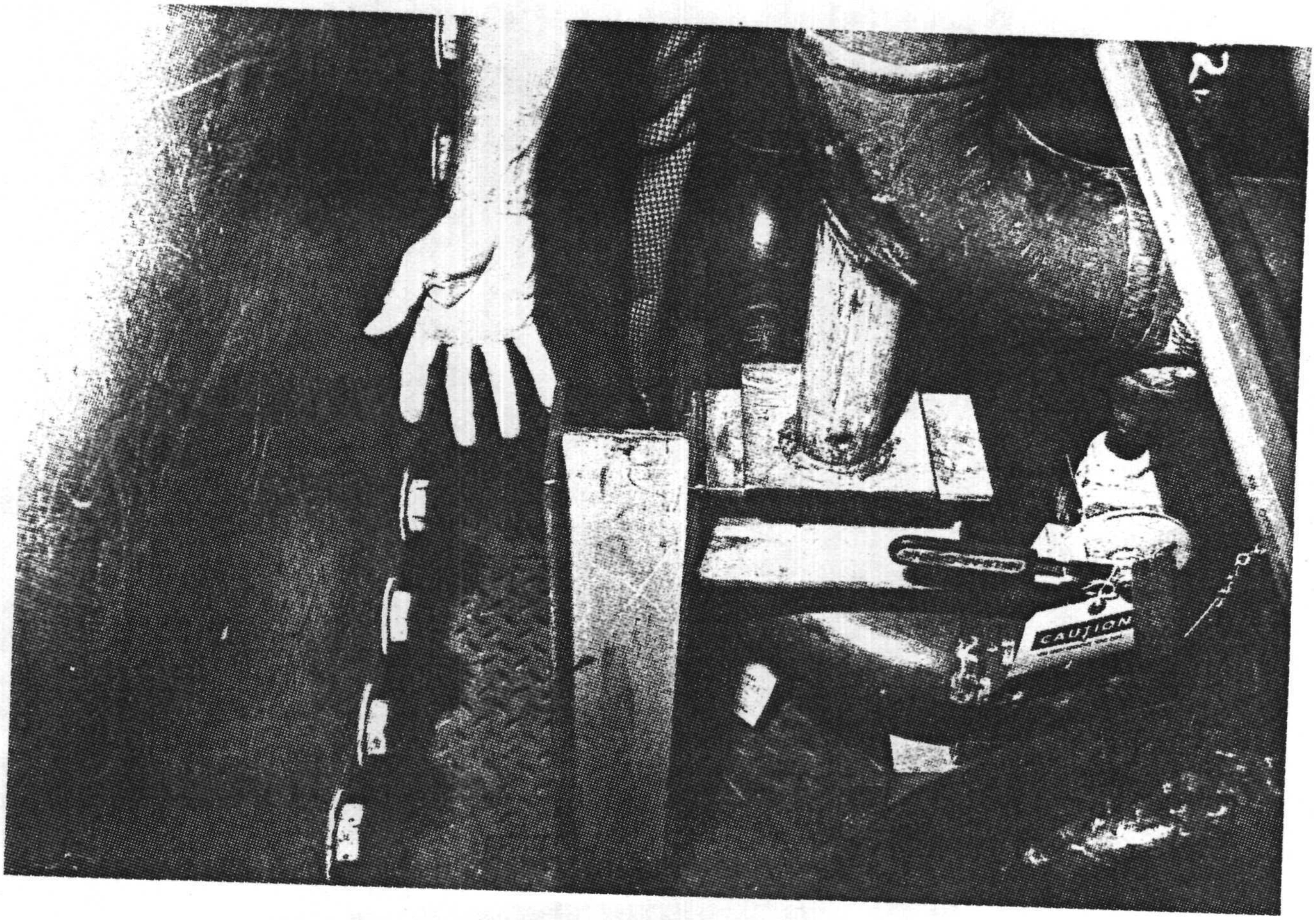

Figure 1.

View of the Northeast Cooler Room Showing the Main Passageway and Space For Removal of the Cooler Head

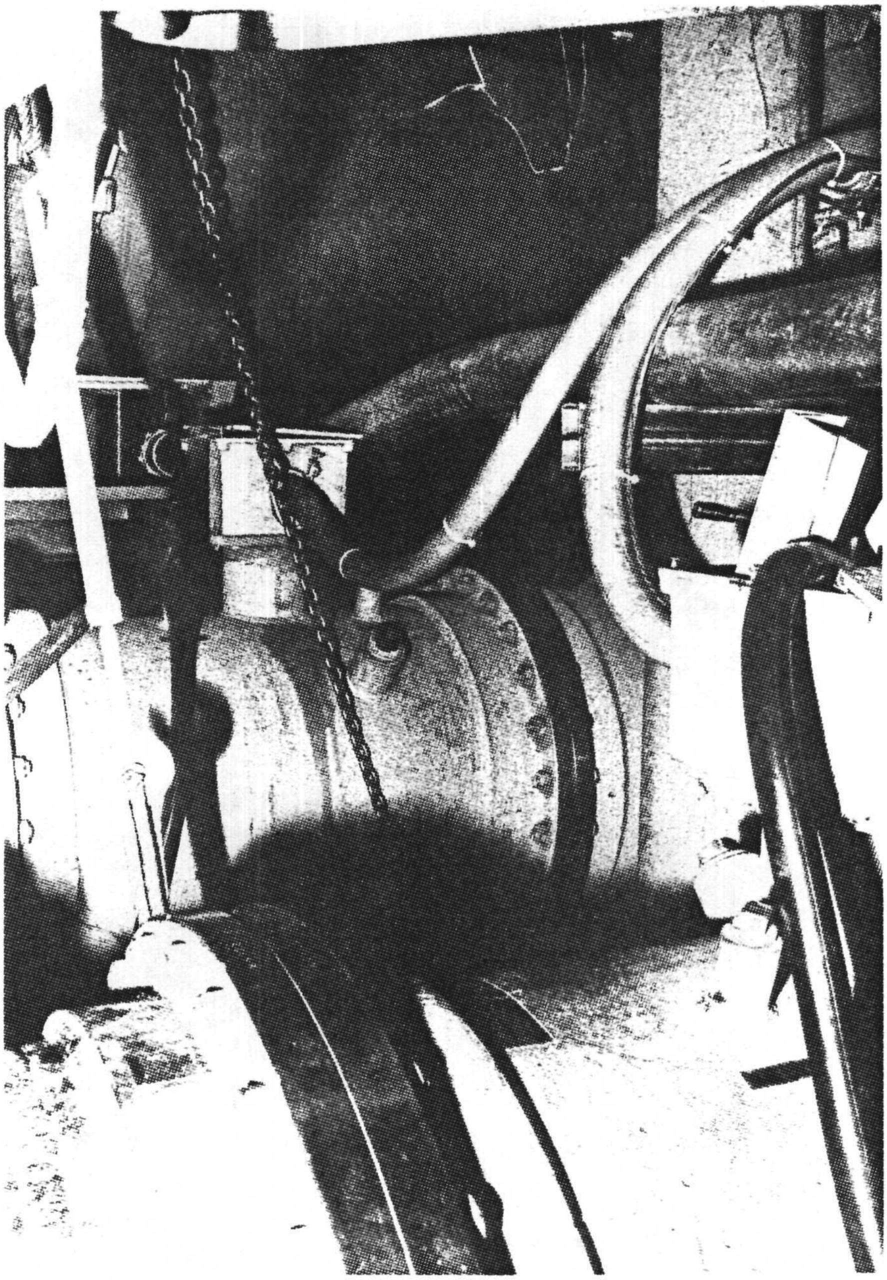

Figure 2. View of the Southeast Cooler Room, FFTF, Showing the Congestion Above and Around the Ventillating Fans

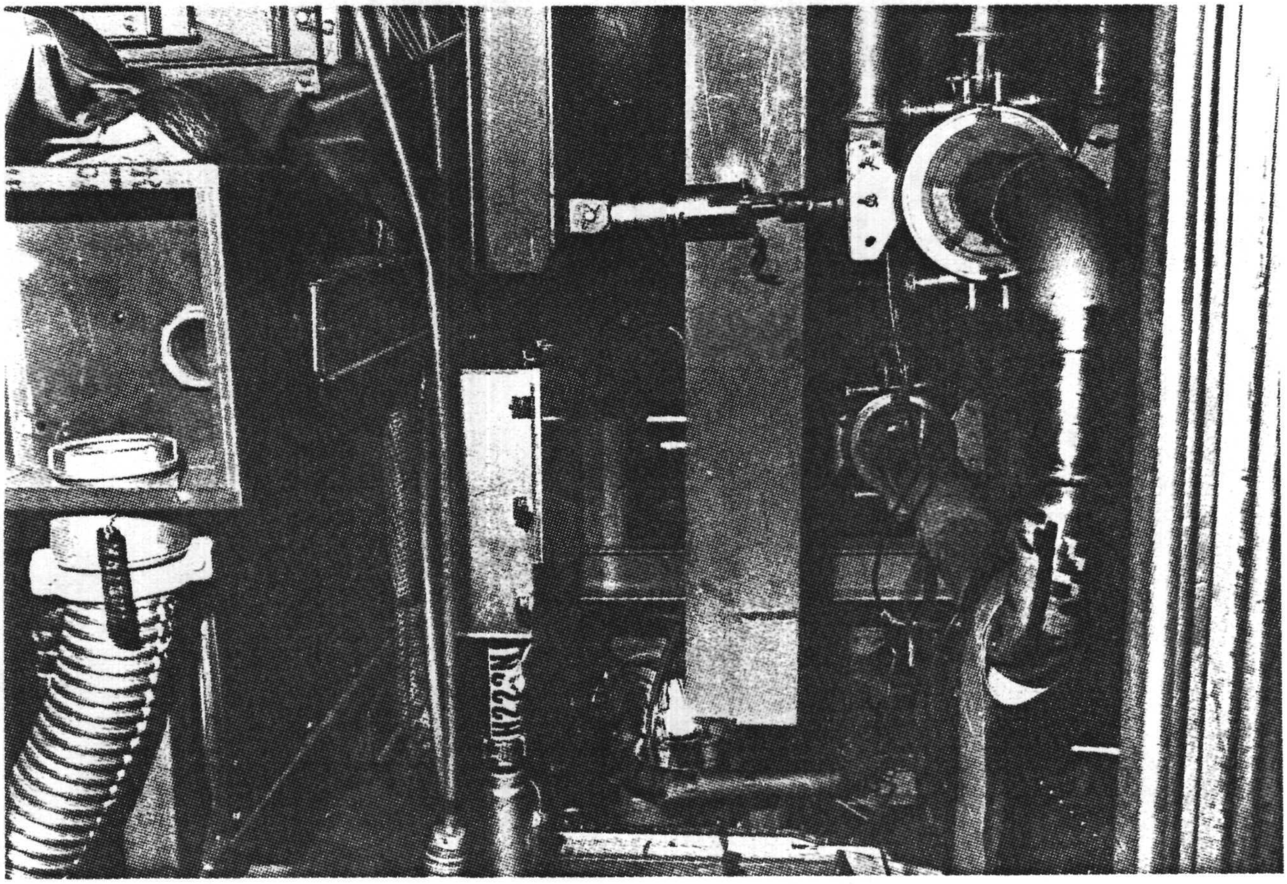

Figure 3. View of the West E/M Pump Cell Showing Some of the Interferences To Entry into the Cell. This View Is Looking Directly Into the Entry Port. Note That Insulation Is Not Installed.

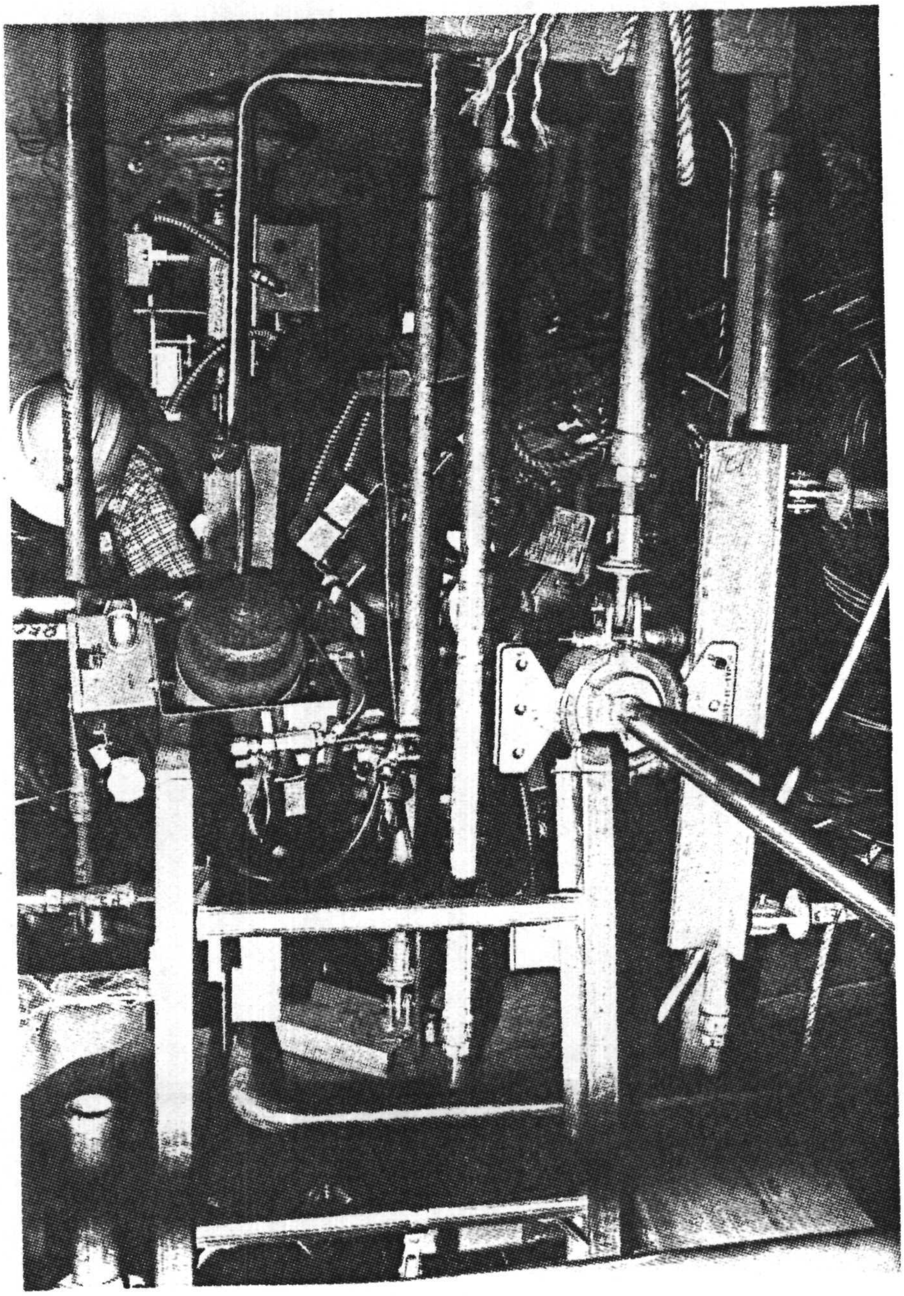

Figure 4. View of the Exterior of the Containment Building in HTS South Showing the Valve Installations. Note That the Valves Are Ten Ft Above the Floor, and that Insulation Is Not Installed.

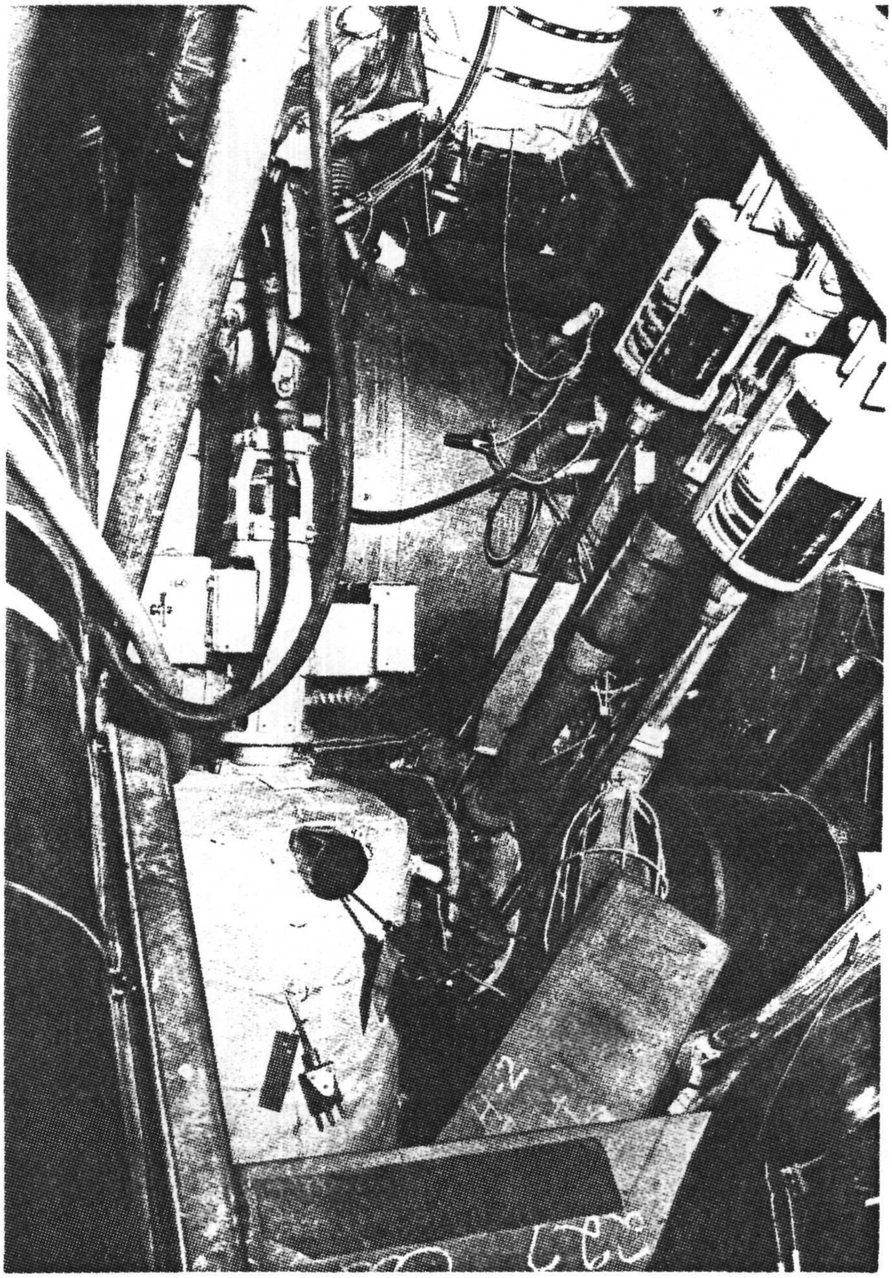

Figure 5. View Inside of HTS West, Showing the Main 16 " Check Valve, and a 2 " Drain Valve. Note the Snubbers, Hangers, and Structure Which Would Have to be Removed to Maintain the Valves.

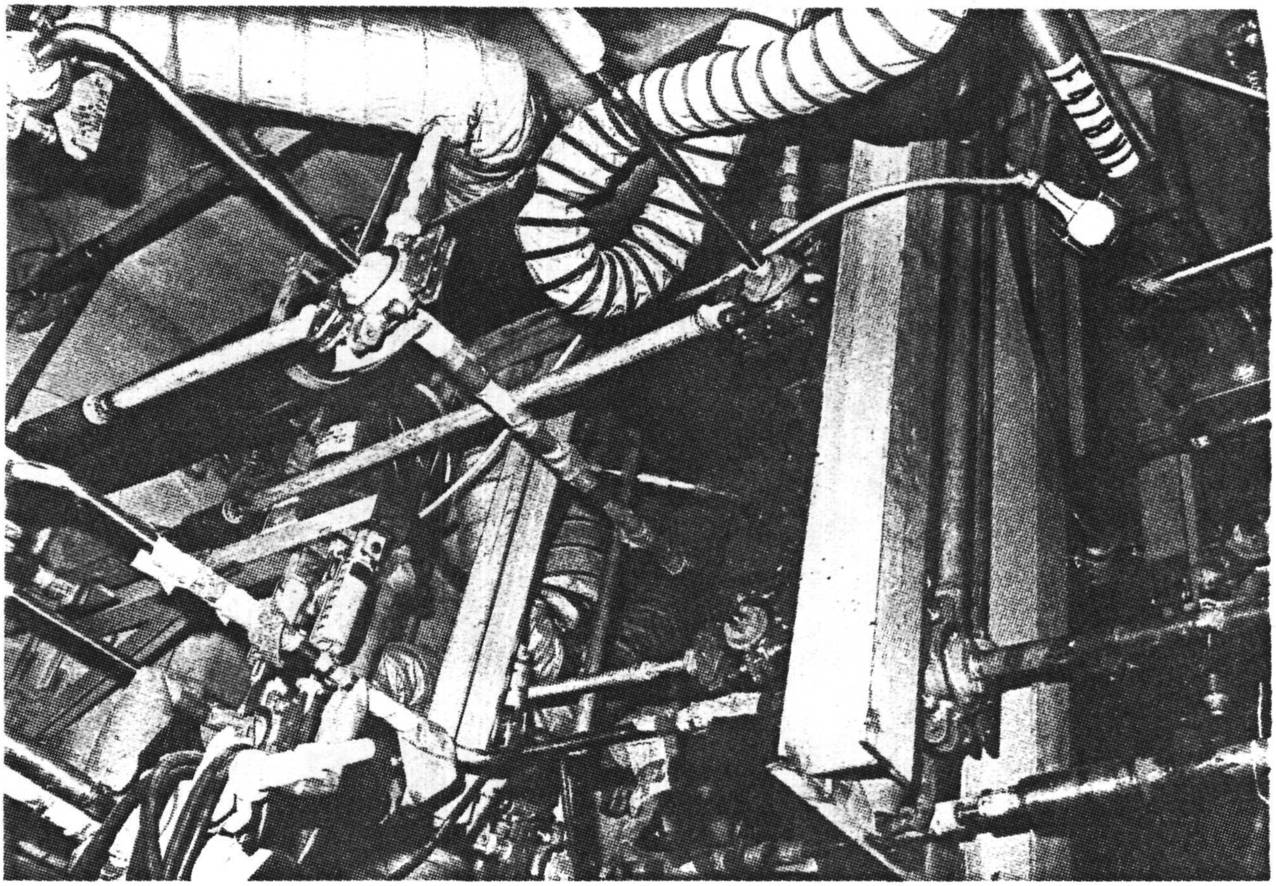

Figure 6. View Looking Up At The Ceiling of HTS South Pipeway. Note the Pipes are not yet insulated. Note the E/M Flowmeter against the Ceiling.

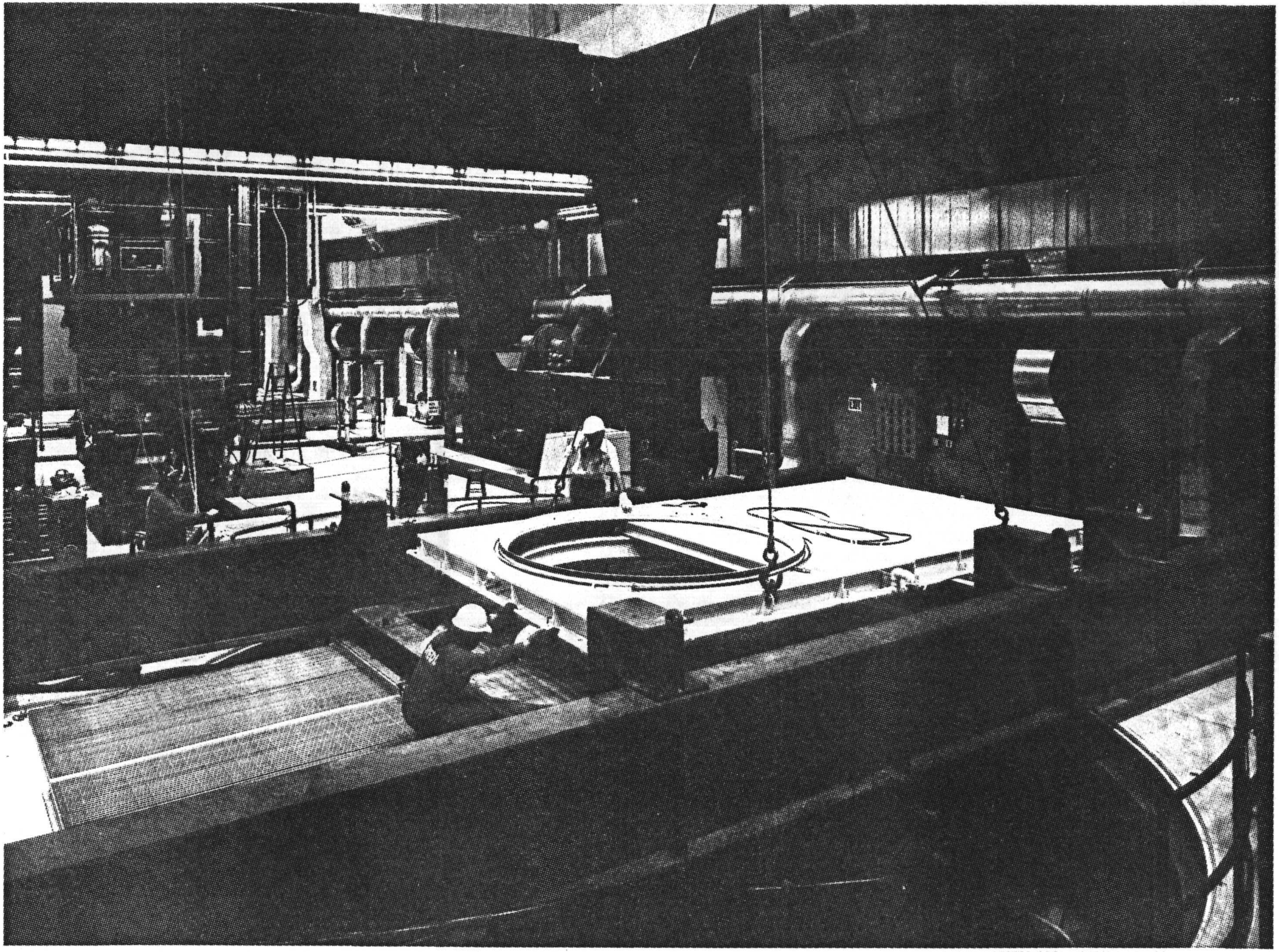

Figure 7. Large Component Handling System Floor Valve and Reactor Head Compartment Support Bridge.

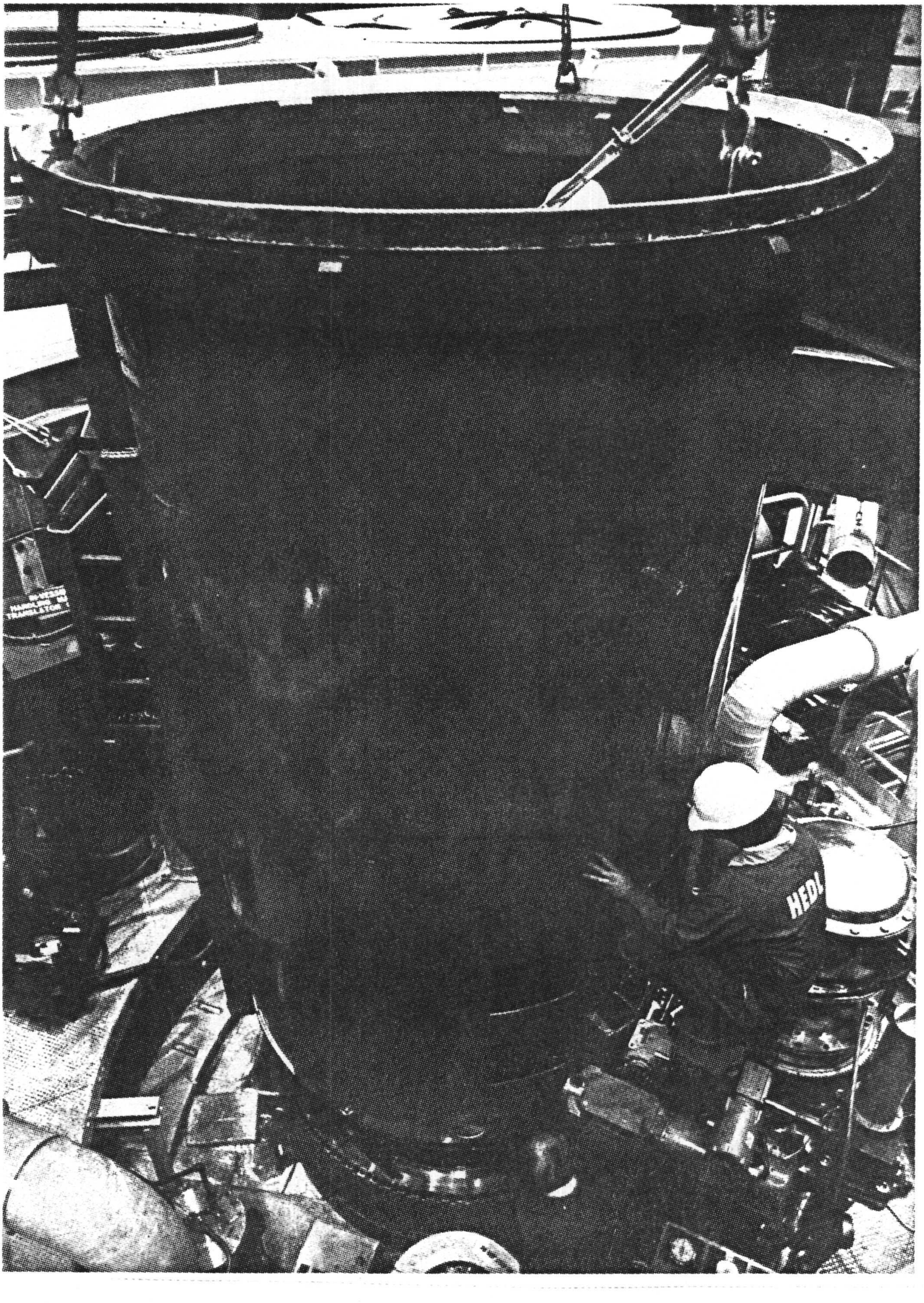

Figure 8. In-Vessel Handling Machine Shroud

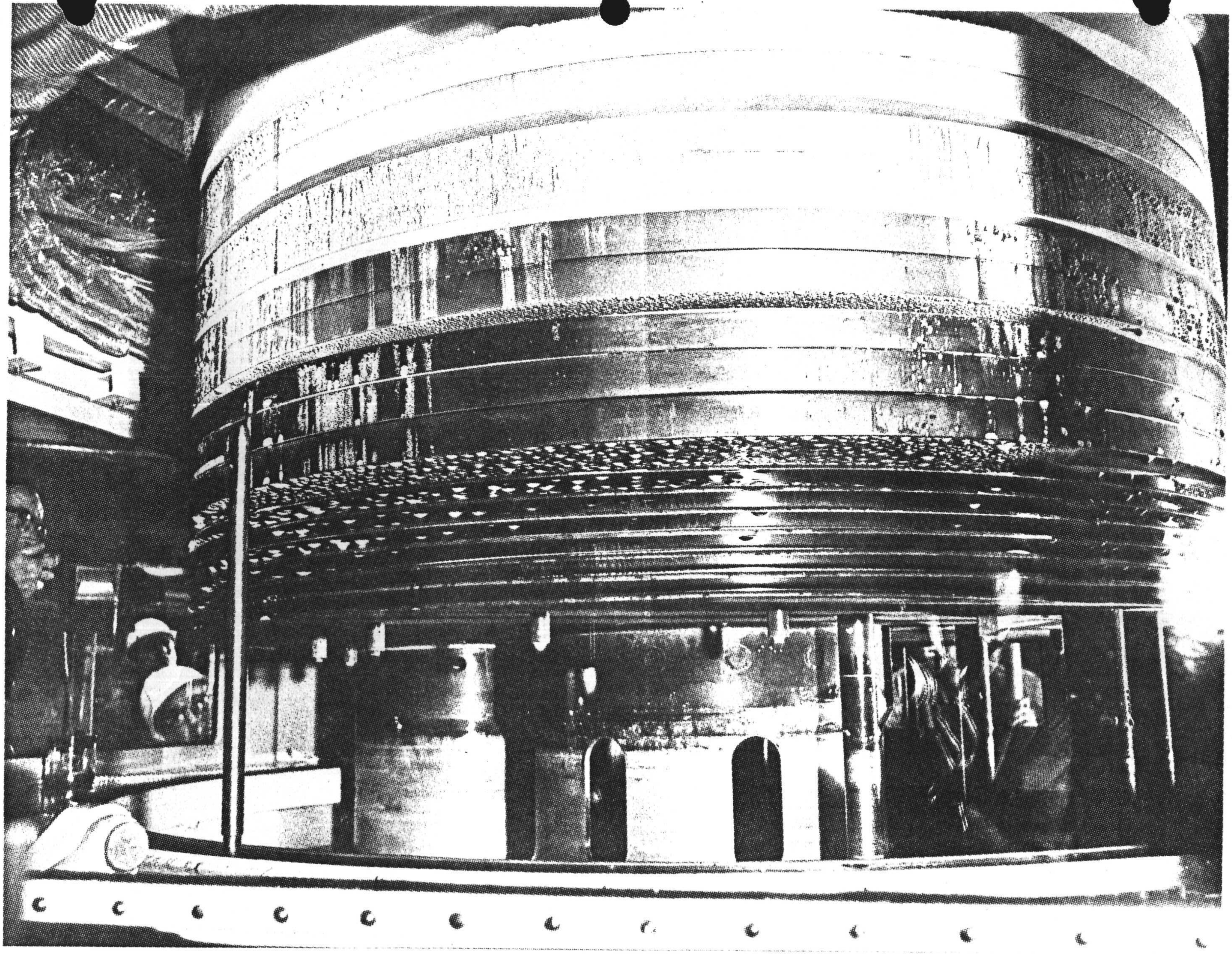

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Figure 9. View of the Bottom of the FHM Plug Showing Sodium Adhering to the Underside of the Plug.

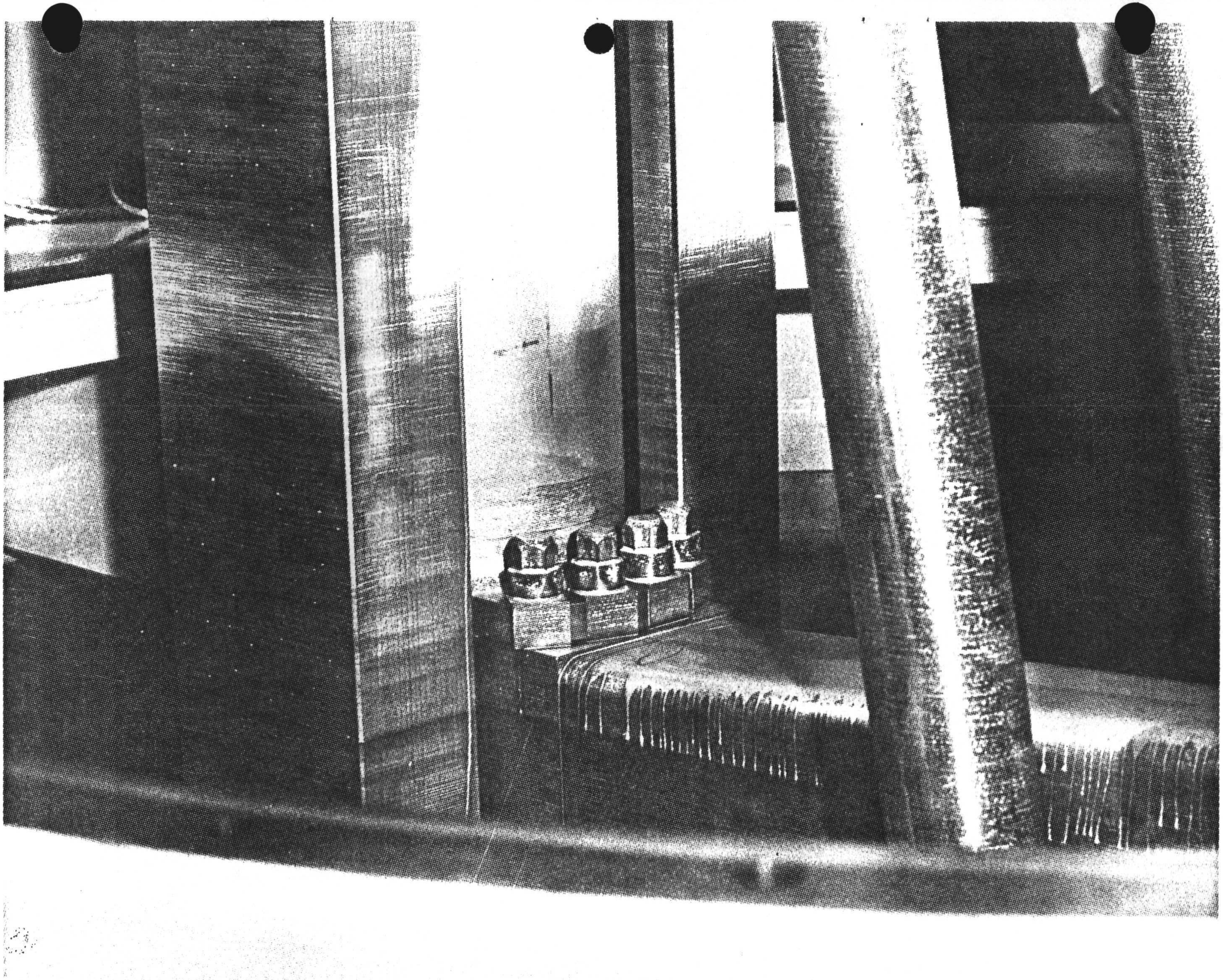

Figure 10. Grapple Support Arm of the In Vessel Handling Machine- Upper Surface.

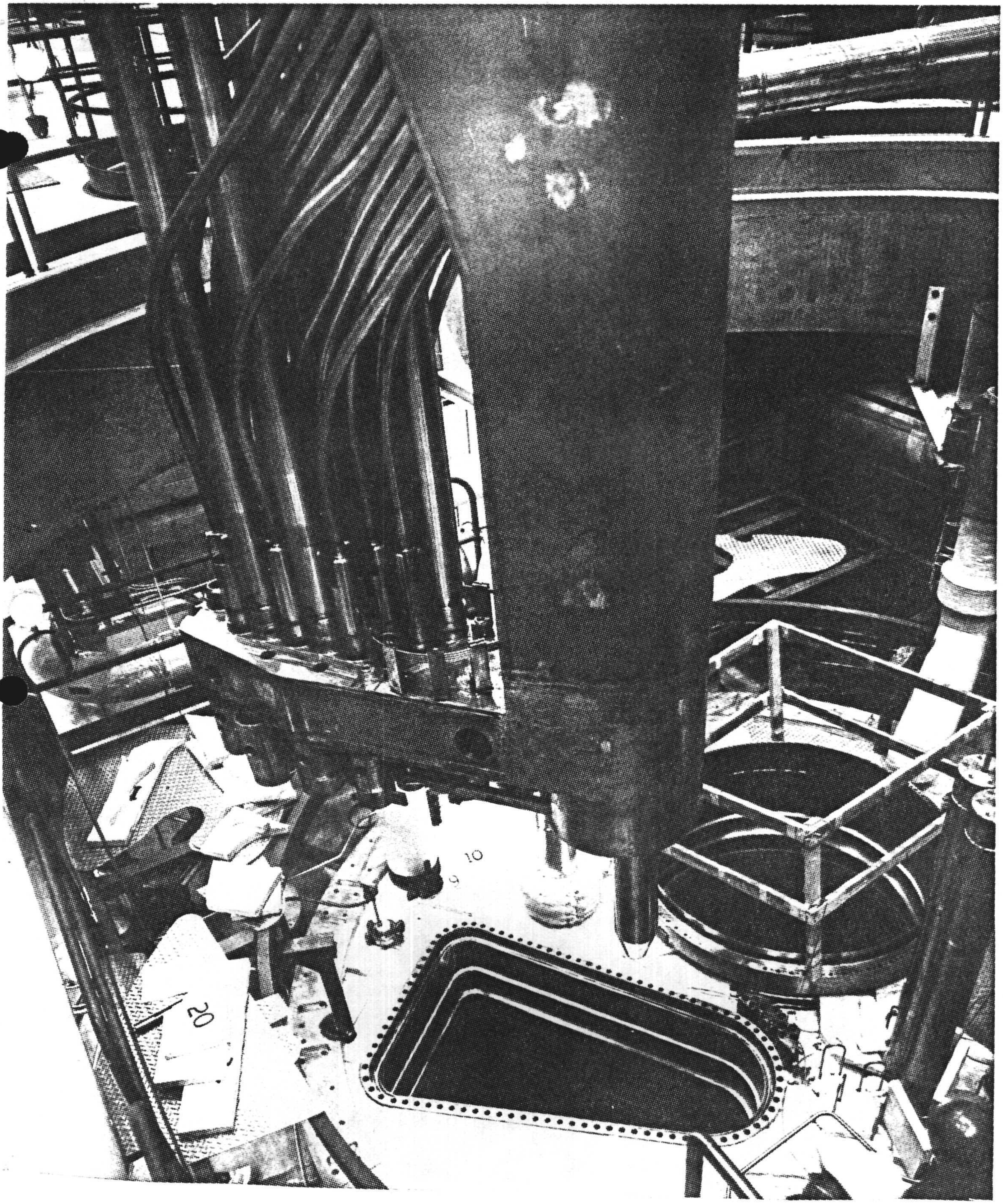

Figure No. 11 View of the Bottom of the Instrument Tree Showing the Weldment That is Difficult To Drain Due to the Configuration.

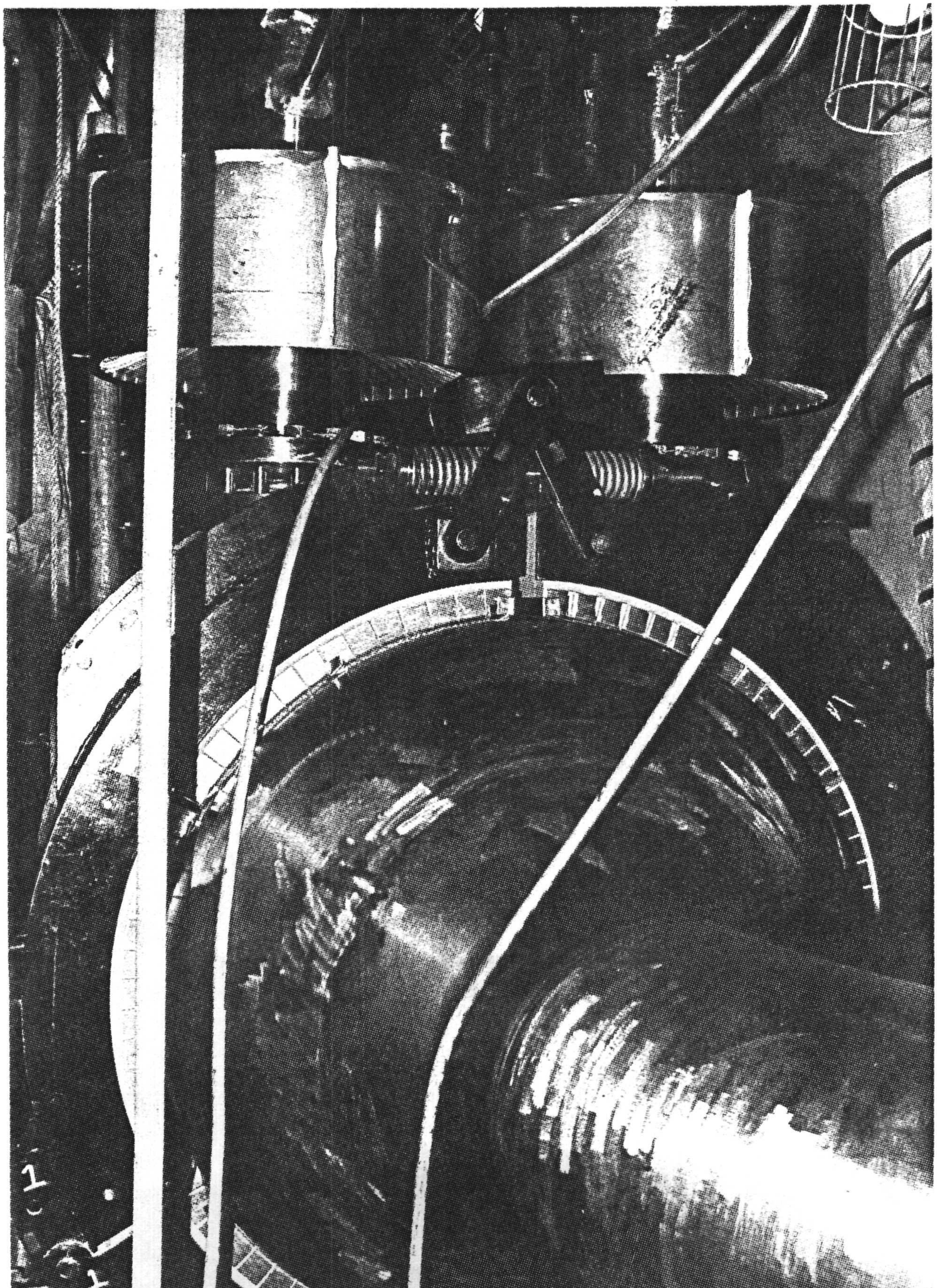

Figure 12. View of the Main 16" Check Valve Before insulation.
Note the large pocket at the bottom of the valve for collection of sodium.

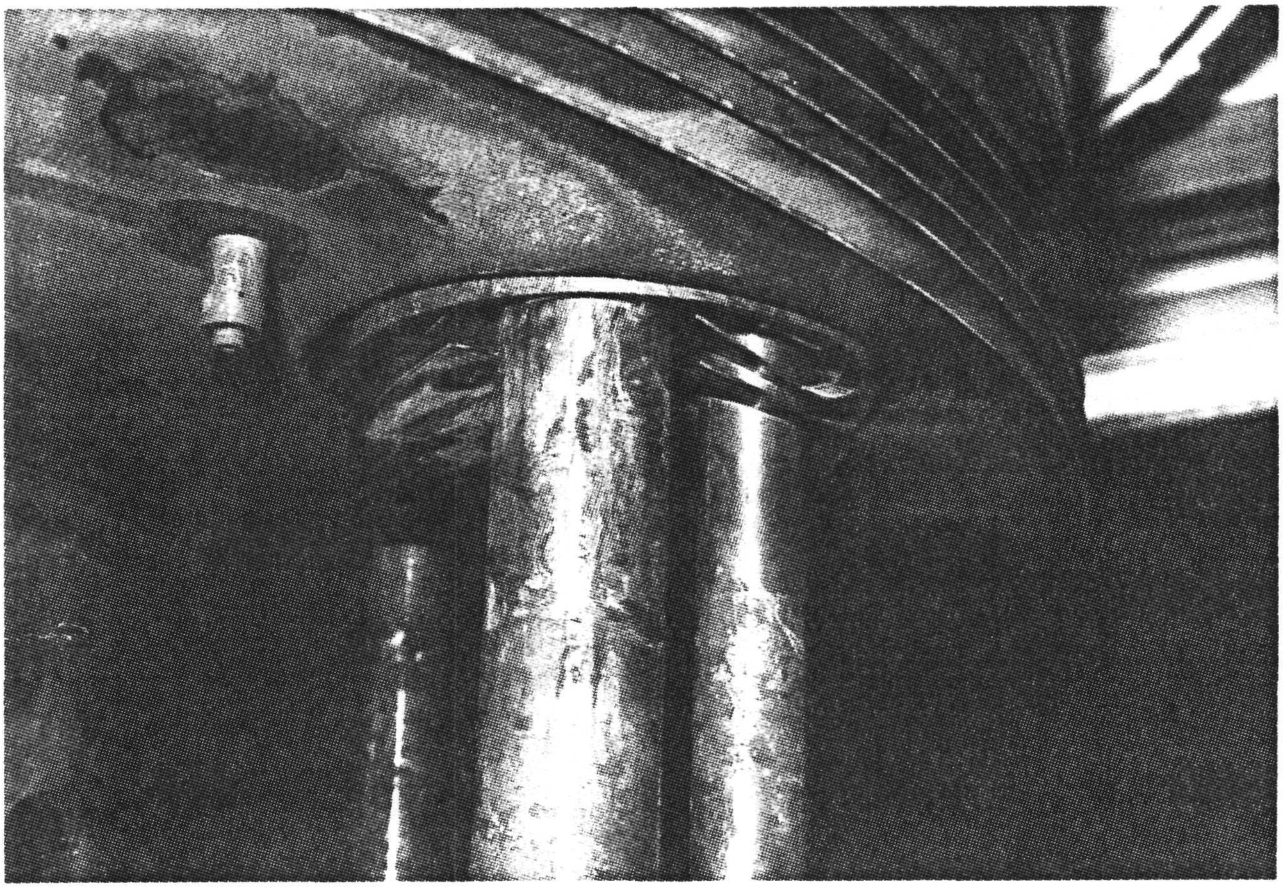

Figure 13. View of the In Vessel Handling Machine Orientation Identification System Thermal Baffles. Deformation caused by poor gas circulation during cleaning.

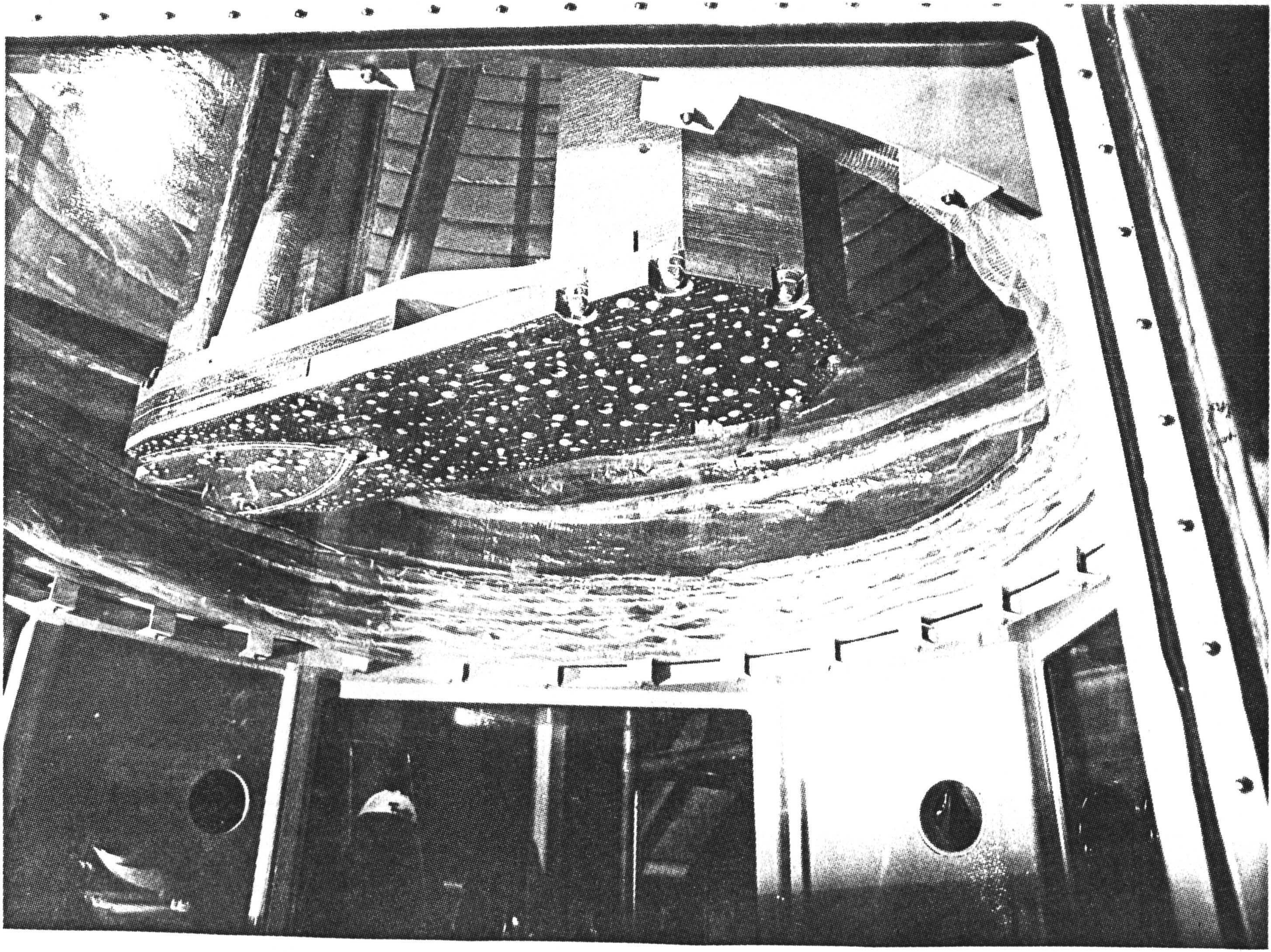

Figure 14.

Foot Of the In-Vessel Handling Machine. Sodium adhering to the underside of the foot.