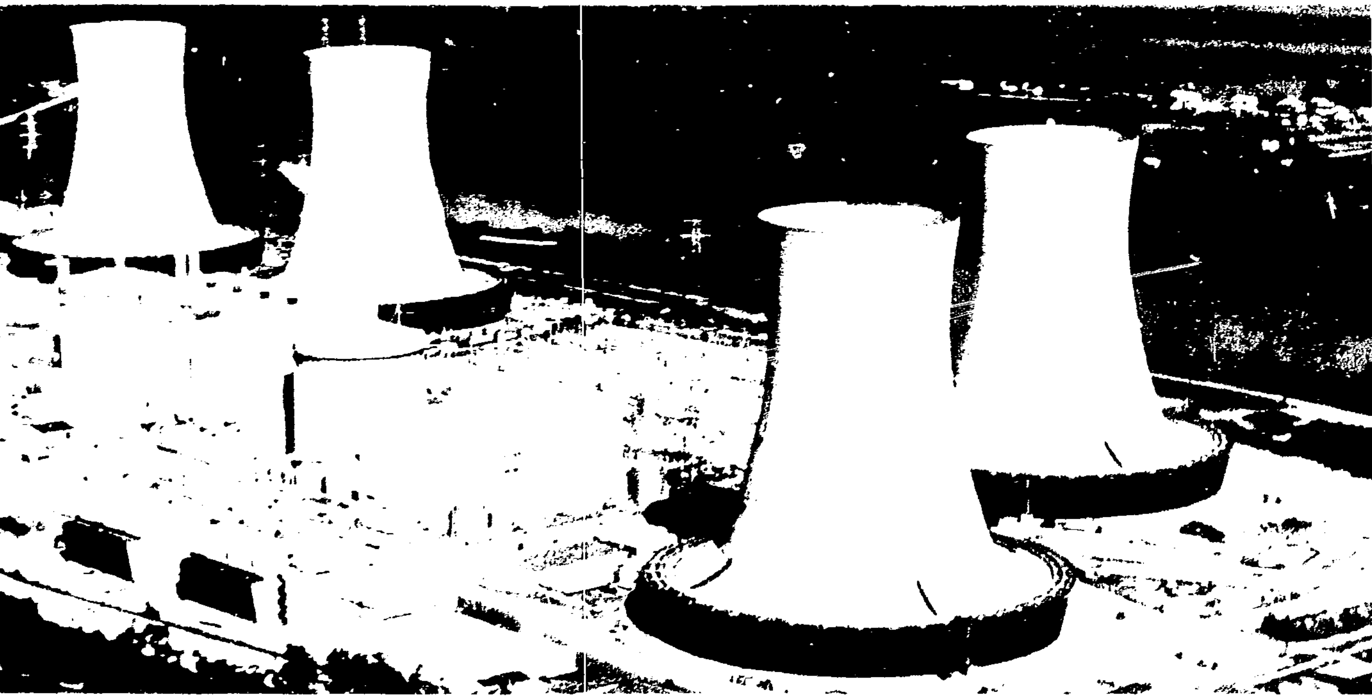
GEND-INF-

October 198[illegible]



END

EF CORE SUPPORT ASSEMBLY DEFUELING PLANS AND TOOLS

[illegible] Ryan
[illegible]

DE89 011030

LOWER CORE SUPPORT ASSEMBLY DEFUELING PLANS AND TOOLS

R. F. Ryan
R. Blumberg

Published October 1988

GPU Nuclear Corporation
Middletown, PA 17057

Prepared for
the U.S. Department of Energy
Under DOE Contract No. DE-AC07-76ID01570

LOWER CORE SUPPORT ASSEMBLY DEFUELING
PLANS AND TOOLS OUTLINE

LIST OF FIGURES

LIST OF TABLES

LOWER CORE SUPPORT ASSEMBLY DEFUELING
PLANS AND TOOLS

1.0 INTRODUCTION

1.1 Prior to February 1985 it was the accepted technical opinion that little or no fuel melting had occurred in the TMI-2 core during the accident of March 28, 1979. However, at this time a camera was inserted between the core support cylinder and the reactor vessel wall. This camera was inserted into the vessel down to the vicinity of the lower head (See Figure 2-1). Large rough pieces of corium were observed. The largest of which was approximately 8 inches across. Most of the lower head of the reactor vessel appeared full of rubble. This observation demonstrated that the material in the reactor vessel lower head did not pass through the steam generators with the reactor coolant water and deposit in the lower head due to passing through a region of low velocity. Instead, the rubble material in the lower head would have to have come directly from the core region above the lower head and the most likely transport method was that the core had melted and the core material flowed to its present resting place. Core melting and its impact on the reactor vessel lower internals and the reactor lower head must therefore be seriously considered. In order to defuel in lower head and remove large solidified pieces of corium a large hole would have to be made through the lower core support assembly (LCSA) to provide access to the lower head. This report describes the cutting planning, the cutting tools, the defueling tools and the methods of disposition of the cut pieces.

1.2 Lower Reactor Vessel Examination

1.2.1 Lower Core Support Assembly (LCSA)

Inspection of this region was made possible by using the ten holes created by the core stratification sampling program. Further, some inspection of the space between the flow distributor and the incore guide support plate was possible by using the holes in the flow distributor during the lower head inspections. In addition, a limited inspection was performed via the access created as the partial fuel assemblies were removed from the lower core region.

The various components of the LCSA appeared to be essentially clean and not significantly damaged. One support post appeared thermally damaged and, at one location, resolidified material appeared to be fused to the surface of the grid forging. At the same location, some spots of discoloration (possibly due to very high temperatures) were observed. The flow distributor head appears to have been damaged on the edges of the flow holes on the east. This is the only damage observed in the flow distributor.

In addition to the east, examinations also revealed a large quantity of resolidified material in the north under core grid location D-13 (see Figure 3-3), and in the west at a periphery of the region. The resolidified material distribution in the LCSA was both non-uniform and asymmetric. Several flow distributor head flow holes, as observed from below, are filled with resolidified material that also protrudes through the holes. At one of these holes, the material broke off when touched by the camera. This suggests that the material is friable and may be easily broken. All the resolidified material observed to date is limited to areas close to the periphery. The material seen in the west actually appears to have flowed down from the core former region.

Granular material has been observed on the various plates along with material piled in the lower head and extending into the flow distributor. In addition to the material that relocated during the accident, fine/granular material relocated to this region during various drilling operations. Furthermore, additional material (granular material, pieces of rods, "rocks", etc.) continue to relocate to this region as a result of defueling activities.

1.2.2 Lower Head Region

Access for inspection of the lower head was attained mainly through the fourteen vent valve exercise and surveillance capsule access holes in the core support shield flange. Additional, although limited, access was provided by the core stratification and sampling program at core grid locations N-12, D-4, and K-9.

During the inspections, 85% of the surface area of the material in the lower head was viewed. The inspections revealed a large quantity of material that has relocated from the core. At some points, the material reaches the flow distributor head and, hence, restricts inspections of the area beyond. Further, inspection of the structural components was limited to the visible portions extending above the surface of the material deposited in the lower head.

Most of the components inspected are clean and undamaged. The only damage observed was on the east side of the incore guide tube at R-7 and D-10, both of which lost material, and the guide tube at O-5, which suffered surface damage without any significant melt.

Distribution of the material in the lower head was neither uniform nor symmetric. Material size varied from large rocks (up to 8 in.) to granular particles. Early inspections showed the larger pieces and rocks towards the periphery, especially in the northeast and southwest. The granular material was located towards the center of the vessel. Inspections in the south revealed gravel-like material with no large rocks. Inspections in the north, however, showed a very different configuration. A large cliff, which appeared to be the north face of large resolidified mass, stood about 15 in. above the inner surface of the vessel at about core grid locations K-12, H-13, G-13, F-13, and extending west. These locations correspond to incore instrument guide tube Nos. 20, 21, 22, and 24. During this inspection in the north, no large quantities of rocks or granular material were visible.

Inspections showed a large quantity of very fine material that had relocated to the lower head since the first inspection. The fine material was generated during core drilling operations and was aided in its relocation by the vibration induced by the drilling. The same inspections revealed that the previous "cliff" observed in the north area has been completely buried under a newly relocated material. Also, the valley formed by the cliff and the lower head curvature has been almost filled by the same material. It is estimated that the newly relocated material north of the cliff at the time of the inspections was at least about 9 in. deep. Furthermore, additional material (granular material, pieces of rods, "rocks", etc.) continue to relocate to this region as a result of defueling activities.

Analysis of samples from this region revealed that the material was black, porous, once molten and had some brown areas, indicating oxidation. The matrix density varied between 6.5 and 8.25 g/cc. There appears to be less fuel per unit mass of material in this region when compared to samples taken from the upper debris bed before defueling started. The material in the lower head, at least at the surface, also appears not to contain the high (2.96%) fuel enrichment.

0 INTEGRATION INTO TMI-2 OPERATIONS

2.1 Safety and Licensing Issues

The use of a boring machine, a plasma arc torch, a vacuum system and other assorted tools have raised many potential nuclear and industrial safety concerns. The major concerns were:

1. RCS Criticality Control
2. Boron Dilution
3. Hydrogen Evolution
4. Pyrophoricity of Zirconium
5. Nuclear Instrumentation Interference
6. Release of Radioactivity
7. Reactor Vessel Lower Head Integrity
8. Basement Criticality
9. Electrical Shock

Each of these concerns was addressed during the development of the hardware or the planning phase of the use of the equipment. The first eight were nuclear safety and USNRC licensing issues which were finally resolved. The final concern was resolved by the care of operations as described in the operational procedures. Briefly, the resolution of each is described below.

2.1.1 The plasma arc torch is cooled with distilled or demineralized water because a coolant whose conductivity is above 10 micromhos would cause a short circuit of the arc start current which in turn would not permit the torch to be operated. Conversely, if the demineralized coolant were to leak into the fuel in the TMI-2 vessel a potential for a core criticality exists. To understand the extent of this possibility, an extensive criticality analysis was performed to determine the maximum quantity of unborated water that could be present in the interior of the fuel rubble without causing a critical event. It was determined that this was 3 gallons of unborated water. The delivered coolant system in the HE-200 cooling unit was then modified by removing the reservoir. This reduced the coolant volume to 3.5 gallons. Draindown tests of the hardware were then performed to ascertain that only 3.0 gallons of this volume would leak into the reactor vessel should a leak occur.

2.1.2 To preclude the possibility of a hydraulic fluid leak leading to a possible critical configuration of fuel and moderator, all hydraulic fluid used with the lower CSA and lower head defueling tools, with the exception of the core bore machine, was borated to at least 4350 ppm of natural boric acid. The hydraulic fluid in the core bore machine does not need to be borated as there is no potential for it to mix with the fuel.

2.1.3 Small quantities of hydrogen gas, less than 1/10 SCFM, are generated as a by-product of the plasma arc cutting operation underwater. This small quantity of hydrogen will rise to the water surface of the IIF, be released and then be diluted by the off-gas treatment system which continuously passes across the water surface at flow rates above 1000 SCFM. Therefore, a combustible concentration of hydrogen will not occur within the reactor building.

2.1.4 Zirconium in finely divided particulate form exhibits the potential to auto ignite. The high temperatures of the plasma torch would be expected to further enhance the burning potential for the zirconium rubble in the TMI-2 reactor. Tests were performed with zirconium tubing and particulates under water in the presence of the operating plasma torch to determine the pyrophoric possibilities. No evidence of a sustained ignition was observed. Therefore, it was considered reasonable not to postulate a combustion reaction of exposed fuel debris due to the plasma arc torch and eventually operation in the reactor proved this to be correct.

2.1.5 Previous experiences with plasma arc cutting onboard Navy submarines had resulted in significant electrical noise generation and inaccurate nuclear instrumentation displays. It was believed that a similar experience could occur at TMI-2.

The TMI-2 Technical Specifications require that the nuclear instrument start-up channels be operative at all times. Therefore, a significant electrical perturbation would have been inferred as a licensing violation. To determine if such electrical noise would be generated in the TMI-2 reactor building, tests were performed prior to continued torch operation. Fortunately, the tests proved that any electrical noise generated by the plasma torch was well filtered or shielded since no indication of torch operation was observed on the installed nuclear instrumentation.

2.1.6 The major components available for reaction with plasma gases would be iron, chromium and nickel all of which can theoretically form carbonyls; however, carbonyl formation for these elements under RCS solution chemistry conditions ranks less favorably, thermodynamically, than other reaction products. Furthermore, the chemical stability of such carbonyls in the TMI-2 environment would be unfavorable even if they were formed. Therefore, carbonyl formation may be neglected with respect to attaining or exceeding health and safety standards.

The amount of other materials adhered to the stainless steel components being cut are in general believed to be minimal, i.e., less than 1 Wt.% of the steel component. The amount of fuel (UO_2) associated with the steel components could potentially be transferred to the reactor coolant system (RCS) fluid was estimated to be approximately 21 kg (45 lbm) of UO_2. The high temperature properties of the transuranic elements assure that any reaction products from plasma arc cutting would exist in the RCS as particulates. The 21 kg of fuel associated with the cutting operation contributes less mass loading and activity to the RCS than the RCS gross alpha fluid loading observed from core drilling operations. Consequently, the degradation of fuel debris from plasma arc cutting did not involve additional RCS solution contamination beyond that evaluated.

2.1.7 The lower head of the reactor vessel is subject to damage and possible RCS leakage due to applying excessive loads to the incore nozzles during various defueling operations or from a load drop into the vessel. Similar damage could occur by the inadvertent drilling with the core bore machine. Each of these potentials was considered and resolved. Extensive thermal/hydraulic analyses were performed to depict the maximum temperature the nozzle structural welds could have experienced. These calculations showed that these nozzle welds could not have reached melting temperatures even though the top of the incore nozzles may have melted. Data as to the location of the thermocouple junction formed after the accident showed that each measured junction was above the reactor vessel lower head. This data was further confirmed by visual examination of incore assembly instrument strings during defueling. This data permitted the NRC to agree with GPUN that the RV lower head was relatively undamaged due to the accident and therefore, it was safe to permit the use of various aggressive defueling tools such as the cavitating water jet, the large clamp tools and hydraulic scrapers and chisels. To prevent drilling through the lower head, each core bore drill string was carefully measured and provided with a mechanical stop collar which prevented the cutting head of the drill string from reaching the RV lower head.

2.1.8 Although it was concluded that dropped objects will not cause reactor vessel leakage, the potential effect of reactor vessel leakage was considered. The case considered assumed the failure of one (1) nozzle resulting in a 125 gpm leak from the reactor vessel. Due to the recent defueling tasks, a large accumulation of small fuel bearing particles have been deposited into the reactor vessel lower head. Consequently, it is assumed that a portion of the fuel debris in the lower head could migrate into the basement cavity below the reactor vessel should a reactor vessel leak occur.

An analysis was performed to evaluate the criticality safety concerns associated with the relocated fuel within the reactor cavity. The results of this analysis was performed using optimum geometry and moderation. The analysis concludes that the maximum allowable fuel mass within the cavity assuming a 2950 ppm boron concentration is approximately 40,000 lbs. It is considered incredible that this much fuel could be relocated to the cavity via the failure of a degraded incore nozzle. Consequently, it is concluded that maintaining the boron concentration of any water within the reactor cavity above 2950 ppm will eliminate a criticality safety concern as a result of fuel relocating to the reactor cavity.

2.1.9 The plasma system cuts 2" thick stainless steel with 200 volts, approximately 850 amps, direct current, at a rate of 10 inches per minute, and at an estimated cutting period of 2 minutes/hour. The power is delivered to the torch by a cable encased in a hose that carries cooling water to the torch. The high current flows in the plasma stream to the structure being cut which is at ground potential. The circuit is completed by appropriately sized cables to the power supply. Thus, the entire CSA, the reactor vessel, and any structure such as the work platform are at ground potential, as related to the plasma power supply.

The grounding system is an important aspect of the operational safety of this equipment. The system will be grounded in accordance with the National Electrical Code and the manufacturer's recommendations. Based upon manufacturer advice, personnel shock hazards are nonexistent in the plasma cutting industry due to adherence to these grounding guidelines.

2.2 Training

2.2.1 Background

By the nature of the task of cutting up the LCSA, both the process and equipment falls into the category of research and development. The typical progression of activities involved procurement, design, testing, development, shipment, more testing and development, training, and finally operation. The latter stages of development and training used the TMI-2 vessel mockup called the DTA (Defueling Test Assembly). Because there was only one of most of the major components (e.g., XY bridge and manipulator), the training activity had to be scheduled in a narrow window between the end of development and the beginning of installation.

Planning, and conducting the ACES training program required a considerably larger effort than for previous defueling equipment. Compared to long handled tools, ACES is much more complex and less rugged (greater skill and care is required to avoid damage). It was therefore, realized that the attainment of the proper level of skills was important. The training program evolved over a period of months. The first training plan was issued by Power Cutting Incorporated (PCI) and concentrated exclusively on equipment operation, and understandably did not incorporate the TMI-2 environment. This missing ingredient was added as the operational requirements in the vessel were determined during DTA testing. Finally, the mechanical details were defined. Decisions were made on task assignments, the number of individuals to be trained, and the amount of time that could be devoted to training. The actual training was implemented by individuals from several departments, each instructor preparing his own lesson plans, and materials. These were quite varied in style and detail. The following paragraphs provide details on the specifics of training arranged by organizational grouping.

2.2.2 GPUN Operators

1. Task Assignment: Provide support during cutting operations, position lights and cameras, observe cutting, rotate SWP, fill and flush HE-200, check conductivity, operate valves, read gages, and install and remove the manipulator and PCEE.

2. Crew to be trained: TMI-Units 1 and 2 each provided six shifts of approximately 10 operators in each shift totaling 120 GPUN operators. These crews are rotated to work in the reactor building for one week out of six, thus it was known that there could be a six week gap between training and operation.

3. Description of Training:

   a. One to one and one-half hours of introduction and overview in a lecture/question and answer setting.

   b. One hour walk-around-inspection and description of the physical equipment.

   c. Two hours of demonstration and hands-on practice in installing and removing the manipulator and torch end effector and in filling flushing and taking conductivity measurements on the HE-200.

   d. Demonstrations of cutting including both observation of typical practices in the coordination center and on the SWP. The total training described took an eight hour day.

2.2.3 Contractor Crafts

1. Task Assignment: Support all maintenance operations. Fill and flush HE-200, maintain supply of demineralized water for the HE-200, rebuild all sections of the plasma end effector assembly including torches and connector, install and remove manipulator, XY Bridge, handling supports and perform the pre-operational checkout.

2. Crew to be Trained: Boiler-makers, electricians and Defueling Support engineers were trained on torch maintenance during an eight hour period of instruction. A total of 76 people in 12 classes were trained.

   In addition, electricians were given 2-1/2 hours each of an overview of the electrical systems where the class size was 3 or 4 trainees.

3. Description of Training: All training was done on a practical level using actual equipment to demonstrate and practice disassembly and reassembly of the torch assemblies, AVC mechanisms, torch whip and buoy can. Diagnosing of problems was emphasized.

2.2.4 Power Cutting, Inc. Personnel

1. Task Assignment: The original cadre of PCI field operators were considered to be trained by virtue of experience during design and testing. Three new technicians were added and these were trained as Manipulator Control Operators, Plasma Control Operators, and Mechanical, Electronic, and Plasma Specialists. Cross training was done so that most of the personnel can perform more than one specialty.

2. Crew to be Trained: Three new technicians.

3. Description of Training: During the training of the groups noted above, the three individuals observed and participated until their skills were adequate, and they could perform the tasks independently. Much of the training occurred during the training demonstrations provided to the GPUN operators, and the Catalytic Crafts.

2.2.5 Miscellaneous Personnel

During the training periods, the six Fuel Handling Senior Reactor Operators (FHSRO's) were provided with four hours of demonstration/question and answer/discussion of coordination center operations and when possible, cutting demonstrations. These discussions covered all phases of the cutting process from the programming of each cut to the actual button pushing.

During the training periods, individuals from other groups, e.g. Operations, Defueling Support, and NRC, sat in on various phases of training.

3.0 PLANNING EVOLUTION

3.1 CSA Defueling Operational Criteria

The following criteria was followed in developing the initial defueling approach. These criteria were considered for individual tool design as well, though this list is not intended to provide detail design criteria for individual tools. These criteria would allow for shortest total overall defueling time for the lower CSA and lower head.

1. Minimize tool and equipment changeouts (or maximize use of a tool before it is withdrawn).

2. A large, open space allowing easy access should be provided to simplify tool use and control.

3. Minimize the need for structural and debris sizing in the reactor vessel.

4. Decontamination of cut-out structural material, if required, will be performed outside the reactor vessel (note that such decontamination is not within the scope of work of the CSA defueling tooling effort).

3.1.1 Initial Conditions Required to Commence CSA and Lower Head Defueling

The core region should be completely defueled before commencing CSA defueling. For the sake of defining a boundary, core region defueling includes removal of all loose end fittings from the rib section. This is necessary for the following reasons:

1. Core region fuel is the easiest to access and should be removed before attempting to remove the difficult to reach fuel in the CSA.

2. Unless the rib section is completely cleared, it will be difficult to identify what portion of the lower grid assembly is exposed. If the lower grid assembly is "attacked" prematurely, the likely result is a number of unnecessary cuts and an unnecessary number of tool change outs.

3. The end fittings can be deposited in fuel canisters and are likely to contain large amounts of fuel in the flow openings. While the core region tools are readily available, the end fittings should be removed and placed in the defueling canisters.

4. The entire rib section should be cleared to allow a complete estimation of the lower grid assembly condition and thereby allow for identifying the specific cuts needed (the absolute minimum number) to provide access through the structure. The approach will prevent having to reinstall cutting tools at a later time to make additional cuts in the lower grid assembly components.

5. Some end fittings may be fused to the rib section and not be removable with the core region defueling tools. CSA tooling will be devised to remove these fused end fittings. End fitting removal should be of the first priority, before any general destruction of the rib section.

The defueling work platform must be installed over the reactor vessel and the operational water level should be as required to provide shielding to operators on the platform and allow operation of the required defueling equipment. It is presently planned to operate with full water depth, but further tooling work may determine a requirement for a lowered water level to allow some tools (such as plasma arc cutting torch) to function most efficiently.

The storage location and storage containers for cut-out structural material must be prepared/fabricated and available for use.

3.1.2 Summary of Approach

The lower CSA should be defueled and access to the lower head obtained through a deliberate, controlled, layer-by-layer approach of structure cutting and removal and debris breaking and transport.

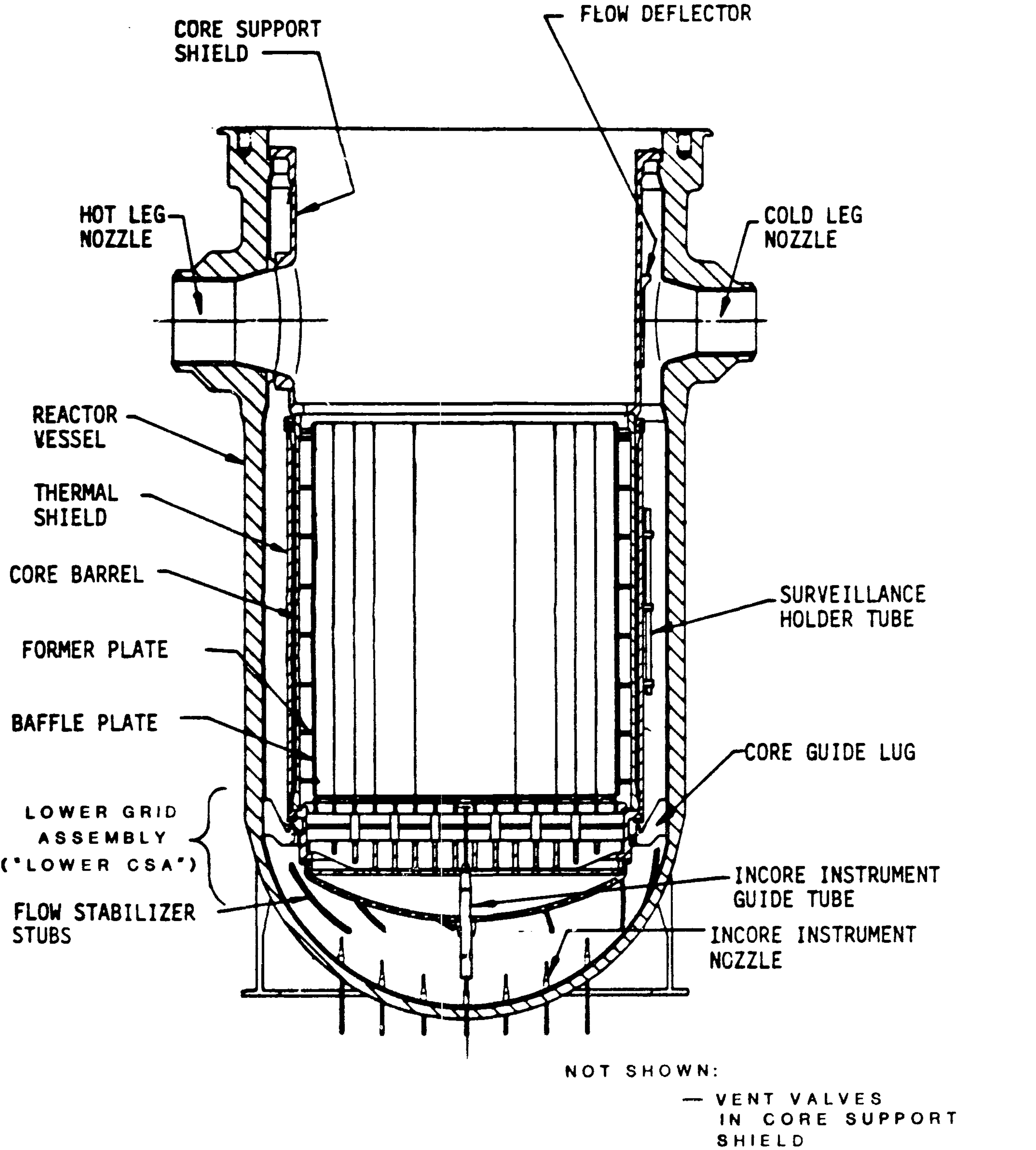
1. The lower head debris condition dictates that the entire monolithic core debris structure be exposed from above. One approach that was considered was to create a "mine shaft" through the structure to access the center of the debris bed. This would allow removal of the debris from below this shaft but because the remaining debris is likely solid rock, it will not be possible to push or pull the debris toward the shaft opening. Also, it is not practical to access far through the structure horizontally due to difficulty of control, interference from the vertical members and difficulty of lighting and viewing. A 74" diameter hole through the flow distributor is the minimum hole size suitable to remove the 84" diameter monolith in the lower head. The larger area removed from the plates above are required to permit cutting each plate below it, with only minimum interference. The end result is an "open-pit mining" approach to defueling the lower CSA and lower head.

2. The configuration of the structure makes lighting and viewing inside the structure very difficult. If the water is turbid, viewing will be next to impossible. Secondly, the residual fuel criteria dictate that the structure be fairly clean. To assure adequate cleanliness, good access is required to do the cleaning and then verify the cleanliness. Input from operations also is that open areas for working are essential. Therefore, working through the structure does not seem to be practical and thus the structure needs to be opened up (see Figures 2-1, 2-2 and 2-3).

From these two bases, it becomes apparent that the size opening is essentially the minimum opening that would result at the end of defueling. Therefore, even if the large rock postulated for the lower head does not prove to be the case, the need to have an open space for fuel debris removal still requires a large area. In the worst case, this need for access could conceivably result in the entire lower CSA being removed, but that approach is not recommended at this time.

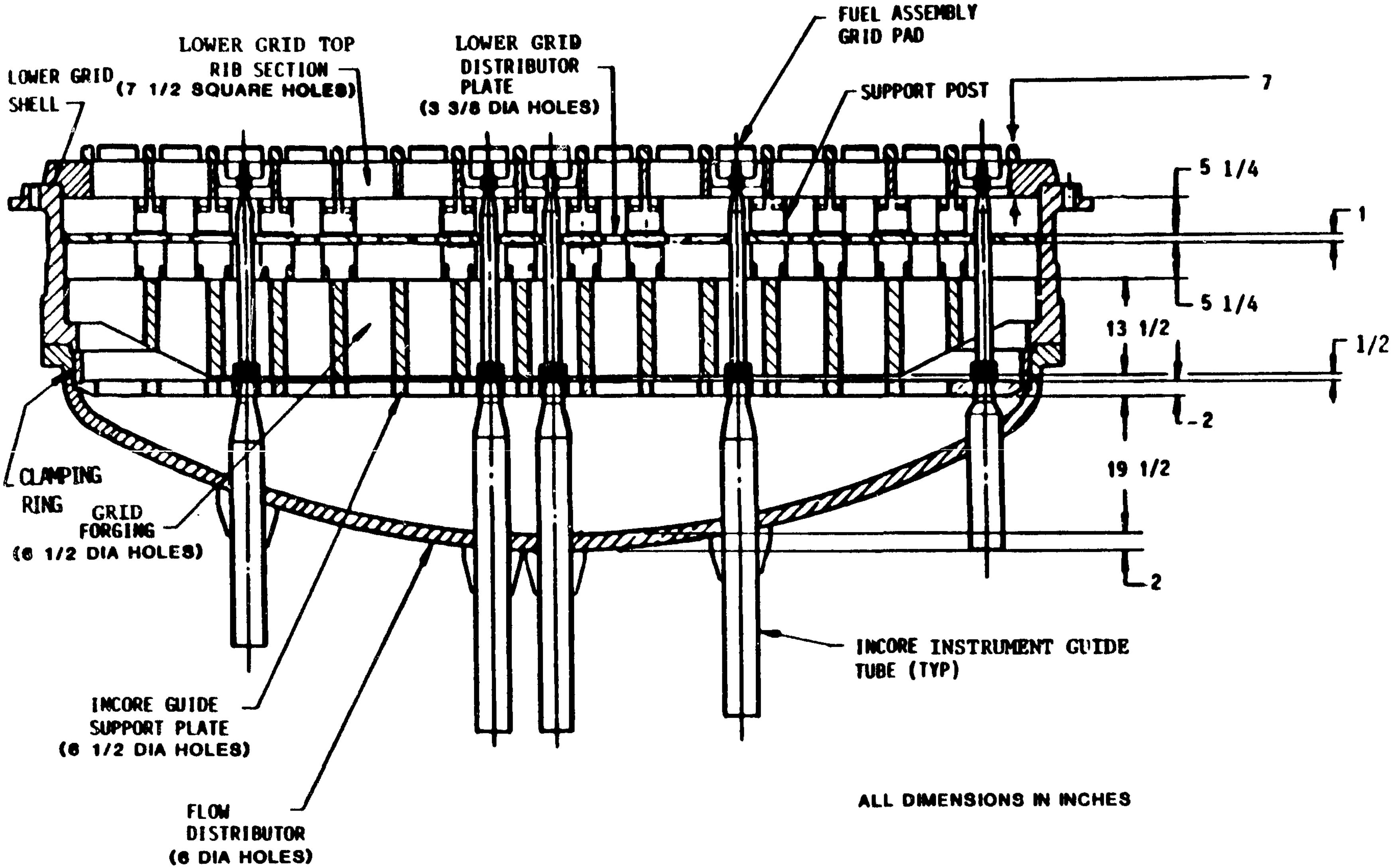
3.1.3 Step-by-Step Description

A general step-by-step approach to accomplish the dismantling summarized above is described below.



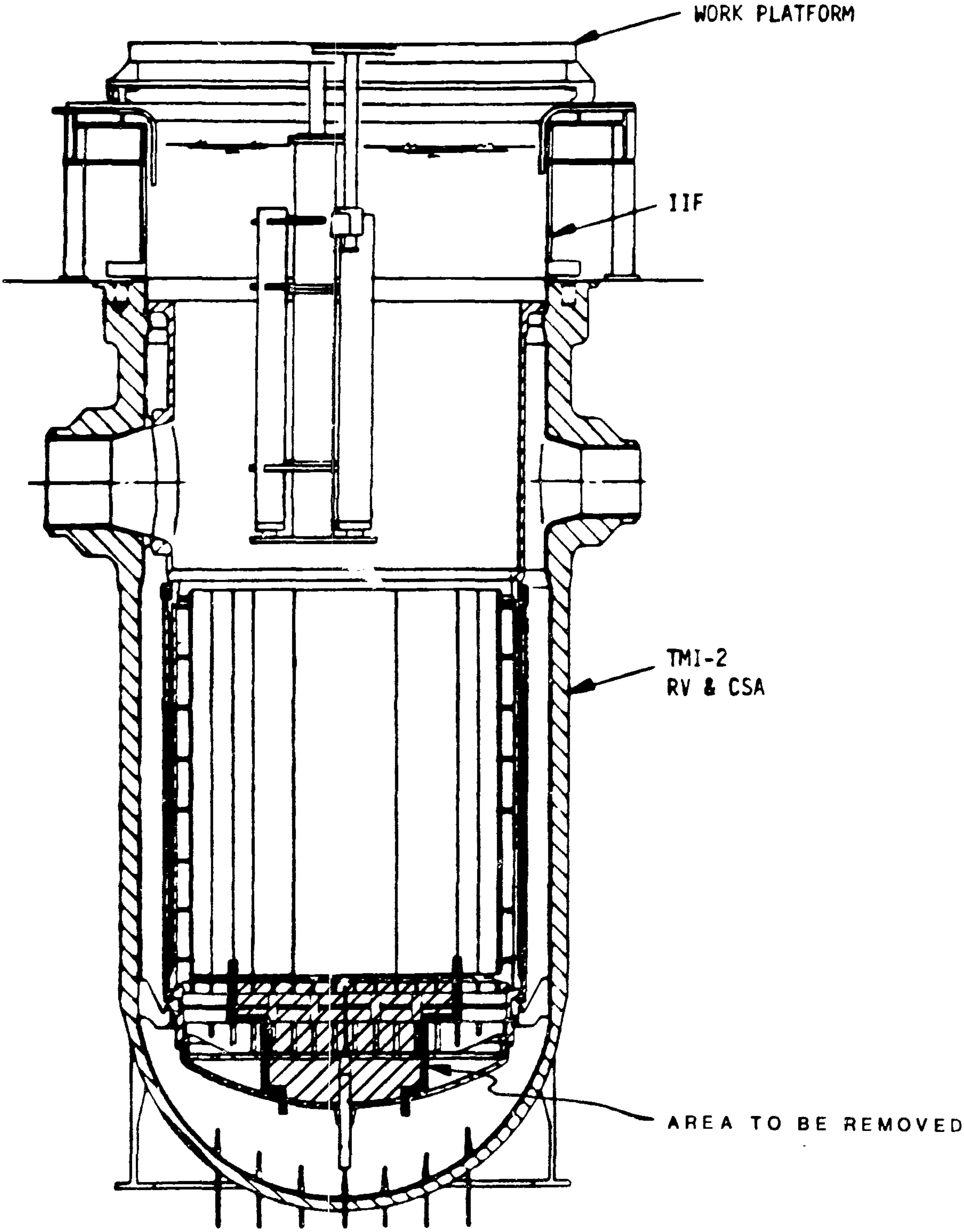
CORE SUPPORT ASSEMBLY IN REACTOR VESSEL

FIGURE 2-1



CROSS SECTION OF LOWER GRID ASSEMBLY
("LOWER CSA")

FIGURE 2-2



LOWER CSA DISMANTLEMENT

FIGURE 2-3

1. Remove fused end fittings from the rib section and deposit in defueling canisters. Pieces of rib section which may be removed with the end fittings and which remain attached can also be placed in the defueling canister.

2. Remove debris from within the grid rib and from between the rib section and distributor plate and put the debris in defueling canisters. This could involve considerable breaking of debris and cleaning of the rib section horizontal and vertical surfaces. The debris would be removed by the most efficient means that can access through the square grid openings.

3. Cut incore spiders for each of the incore guide tubes located within the grid area to be removed.

4. Sever the connections of the rib sections to the support posts if this will minimize the number of cuts. One method is to use metal disintegration machining (MDM) or milling to remove the cap screws.

5. In areas where the rib section is severely damaged, cut the rib ligaments to allow removal of small rib pieces with fused/embedded core debris deposits. This removal only applies where deposits exist in large enough quantities

that they cannot be readily removed by decontamination processes. Rib pieces with thin deposits should not be removed in this manner. The removed pieces shall be placed in defueling canisters. (A listing of horizontal structural members to be removed is shown in Table 2-1.)

Table 2-1 Horizontal Structural Member Removal

Component	Approx. Dia. of Removed Structure	Removed Structure "Enclosed" Volume	Weight of Removed Structure	No. of Pieces Cut	Total No. of Cuts**
Rib Section	100"	32 ft.^{3}	3,080 lb.	18	262*
Dist. Plate	100"	5 ft.^{3}	893 lb.	20	206
Forging	80"	40 ft.^{3}	11,610 lb.	25	110
Support Plate	80"	6 ft.^{3}	1,954 lb	16	207
Flow Dist.	74"	5 ft.^{3}	1,380 lb.	34	105
TOTAL		88 ft.^{3}	18,917 lb.	113	890

* Includes removing 20 grid rib/support post bolts and making 148 in-core spider cuts.

** No. of cuts is considered a "reasonable minimum".

0010B

6. Cut rib section ligaments and remove cut-out pieces from lower CSA. The cut out pieces will need visual examination as a minimum to determine cleanliness. At this time examination of the lower surface is essential. ..face sampling may be required for residual fuel accountability. Sampling location is either in the vessel or elsewhere (requires further evaluation).

7. After all rib section pieces are removed, surface clean the distributor plate and incore guide tube sections above the distributor plate and push or flush debris through flow holes. Large pieces should be removed by pick-and-place/manipulator.

8. Cut off the exposed incore guide tubes (which have had the spiders cut) at the distributor plate (optional). (A list of vertical circular pieces to be cut is shown on Table 2-2.)

9. Cut distributor plate ligaments and remove cut out pieces.

10. Clean and flush out the interior of the support posts (Cleaning may require cutting off top of post).

11. Clean and flush outer surfaces of support post, incore guide tubes, top of forging and forging flow holes (flow holes occupied by incores are likely to be plugged with debris).

TABLE 2-2 Vertical Structural Member Removal

Component	No. to be Removed	Approximate Weight of Material	Maximum No. of Pieces	Maximum No. of Cuts
Support Posts	20	134 lb.	20	20
In-core Guide Tubes	--	--	--	--
Complete	21	4010 lb.	105	84
Upper Half	16	474 lb.	48	48
TOTAL	--	4618 lb.	173	152

0010B

12. Cut off incore guide tubes and support posts at top of forging (both optional) and remove cut off piece. Some of the incore guide tubes may eventually need to be cut off at support plate nut, so that cut may be desirable at this time in lieu of the cut above the forging.

13. Cut forging ligaments and remove cut out pieces.

14. Clean incore guide tube support plate and the incore guide tubes above the plate and flush debris downward through the flow holes.

15. If not already accomplished, cut incore guide tube above support plate nut if required for access to cut the support plate and remove cut off piece.

16. Cut the incore guide support plate ligaments (various sizes) and remove cut out pieces similarly to Step 6.

17. Breakup and transport debris from within the flow distributor to defueling canisters. When lower head debris contacts the flow distributor, breakup and clear away debris, accessing through the flow holes.

18. Clean the surfaces of the incore guide tubes (within the flow distributor) and flow distributor (including flow holes). Attention may be needed to crevices between the incore guide tubes and flow distributor.

19. Cut off incore guide tube stubs at top of flow distributor and remove cut off pieces similarly to Step 6 (optional). Note the possible need to pull the guide tube below may require that this cut not be made.

20. Cut "free access" holes through flow distributor and remove cut out pieces. Do not detach incore guide tubes from flow distributor at this time except where guide tubes and nozzles are completely exposed.

21. Mine out (breakup and transport) lower head debris through the free access hole. Clear debris from all around the incore guide tubes and incore nozzles at the periphery of the free access hole.

22. Inspect the incore nozzle welds to determine their mechanical condition.

23. If the nozzle is in good condition, cut the flow distributor around incore guide tube stubs that are cleared of debris and pull the guide tube off the incore string (or pull with a maximum force of 5000 lbs. to part the incore string).

24. Clean surfaces of incore guide tube stub and then remove from the reactor vessel.

25. If the incore nozzle condition is questionable, cut the exposed incore guide tube and incore string just above the top of the nozzle to separate the guide tube from the nozzle. Once accomplished, then cut the flow distributor around the incore guide tubes to release the guide tube and contained incore string.

26. Enlarge access hole through the flow distributor as necessary to access the remaining lower head debris.

27. Clean lower head surfaces of fuel debris and transport (vacuum) into defueling canisters.

28. After upper CSA is defueled, perform a final vacuuming of remaining lower CSA structure and lower head.

.2 Core Bore Approach

During the development and testing program for the Plasma Arc Torch, consideration for other methods of disassembling the LCSA arose. These considerations were chiefly directed toward the use of Core Bore Machine to drill through and thus sever portions of the LCSA. The core bore machine developed by EG&G to extract drilled samples of the damaged TMI-2 core had performed successfully in 1985. It performed again in 1986 to drill up a large portion of the large monolithic crust in the core rubble. It was not known if the machine would successfully drill through the large stainless steel parts of the lower core support assembly. In order to better determine if this drilling would be successful, a test program was established. The objective of the test program was to assess the suitability for use of the existing core bore machine and determine the drills which might perform best in cutting through various segments of the LCSA. The main objectives of the test program were:

- o Simulate the TMI-2 LCSA geometry to provide further assurance as to project feasibility and to identify unanticipated problems.
- o Simulate the drill string length and the guidance provided by the underwater stabilizing structure to the drill string.
- o Simulate the constant torque control scheme of the Core Bore Machine.

- Determine the appropriate range of the operating parameters for the various cuts and cutting tools.

- Simulate the damaged core materials, having ceramic properties, located in and/or possibly adhered to the LCSA.

Two different cutting tool designs were prepared for the drilling operation due to the core materials located in the LCSA. The primary cutting tool was a "Trepanning" style boring tool provided by Waukesha Cutting Tools. It consisted of a steel head or body which carried a series of replaceable "inserts" (blades) made of T-15 tool steel coated with titanium nitride; the coating protected the cutting edge of the inserts from the borated water. The operating parameters for this tool were in the following ranges, varying due to wear of the inserts and the cut geometry:

- RPM 50
- Torque 200 to 400 ft-lbs
- Weight on Bit 300 to 1500 lbs
- Rate of Penetration .001 to .006 inches/second.

The high volume ratio of chips produced versus the metal cut with this tool, at times approaching 30 to 1, required limitations on the cuts that could be made to assure adequate flushing of chips from the cut area and due to the eventual disposal costs for the chips. The secondary cutting tool was a "Junkmill" style tool provided by Christensen Mining Products. This tool consisted of a steel head or body faced with small gravel like pieces of tungsten carbide embedded in a matrix material. It was designed for use in mining or rock drilling applications to grind away broken tools lodged in a drilled hole. The operating parameters for this tool were in the following ranges, varying due to the cut geometry and the materials being cut:

- o RPM 30 to 70
- o Torque 200 to 1000 ft-lbs
- o Weight on bit 1000 to 8000 lbs
- o Rate of Penetration less than .0005 inches/second

The Junkmill style cutting tool was used in the operation to sever the incore guide tube spiders and to clear out core debris prior to using the Trepanning style tool.

The use of the core bore drilling machine, with its design characteristics, and standard cutting tool concepts for drilling through a stainless steel structure similar to the LCSA, though not necessarily an accepted method in the past, was necessary in order to perform this unique task at TMI-2. Plans have been prepared for the possible use of this cutting method as a contingency to plasma arc cutting for further removal of the TMI-2 LCSA components; including the distributor plate, support posts, incore guide tubes, forging, incore guide tube support plate, and flow distributor head. In any case, the techniques learned from this effort could be considered in future remote cutting of stainless steel structures.

3.3 Combined Core Bore and Plasma Torch LCSA Cutting

The objective of this combined program is to utilize the best features of the Core Bore Machine and the PCI plasma arc equipment to efficiently cut and remove the LCSA and to gain better and bigger access to defuel the LCSA and lower head. The previous baseline plan utilizing only the PCI plasma arc equipment to cut the LCSA was changed. This plan estimated that 890 (start-stop) cuts would be required to cut a 46" x 46" funnel shaped hole to the lower head; 30 fuel or storage cans would be required to store the pieces; and approximately 116 - four hour shifts would be needed to complete the job. Unfortunately, many of the cuts are circumferential (incore guide tubes and support posts), and the plasma arc torch has difficulty making these cuts; however, it makes linear cuts quite nicely. On the other hand, the Core Bore Machine (CBM) is well suited to accomplish the circumferential cutting task, but the CBM does not make linear cuts. Earlier tests have shown the CBM will drill through stainless steel up to two inches thick. The current test program will attempt to cut out the incore guides and support posts, and the second phase will attempt to drill the LCSA into pieces. The test program indicated that incore guide tubes and support posts could be cut out of the LCSA. It was necessary, however, to clean the spaces around and below these pieces in order to provide a space for the cut chips to fall away from the piece being drilled.

Recent inspections of the LCSA have revealed the presence of additional fuel rubble and a significant number of broken fuel rods in the LCSA. It became apparent that a much larger portion of the LCSA will have to be cut out and removed in order to access this debris. It also became apparent during the PCI wet checkout program that the PCI plasma arc equipment was sensitive to its operating environment and prone to breakdown. Unfortunately, GPUN may require the plasma arc torch equipment to make in excess of 2000 cuts if they proceeded with a revised plan to cut the LCSA out to the periphery and in small enough pieces to fit in fuel or storage canisters. The Plasma Arc Program probably was not prepared to accept such an increase.

The purpose of this new plan is to combine the best features of the PCI plasma arc equipment with the best features of the Core Bore Machine in order to cut and remove very large sections of the LCSA. This would limit the number of plasma arc cuts to a minimum and therefore, increase reliability. In turn, this would provide the maximum efficiency to the disassembly program, thus minimizing the in-containment time, reduce costs and be ALARA.

3.3.1 Key Assumptions

1. Large pieces of the LCSA can be removed from the RV and stored in the basement or other locations within the reactor building.

2. The test program for the Core Bore Machine currently is successful.

3. It is acceptable to drop incore guide tubes on the incore nozzles as a planned, non-accident operation.

4. The LCSA is cleaned adequately after bulk fuel removal so as to minimize contact between the core bore drill bits and ceramic material.

5. Fines have been removed from the vessel to the extent that water clarity problems will be minimized during plasma arc cutting, cavijet cleaning, or other aggressing operations.

6. There are no interaction zones in the LCSA whereas fuel cannot be separated from the structure. Video information to date supports this assumption.

3.3.2 Sequence of Operations

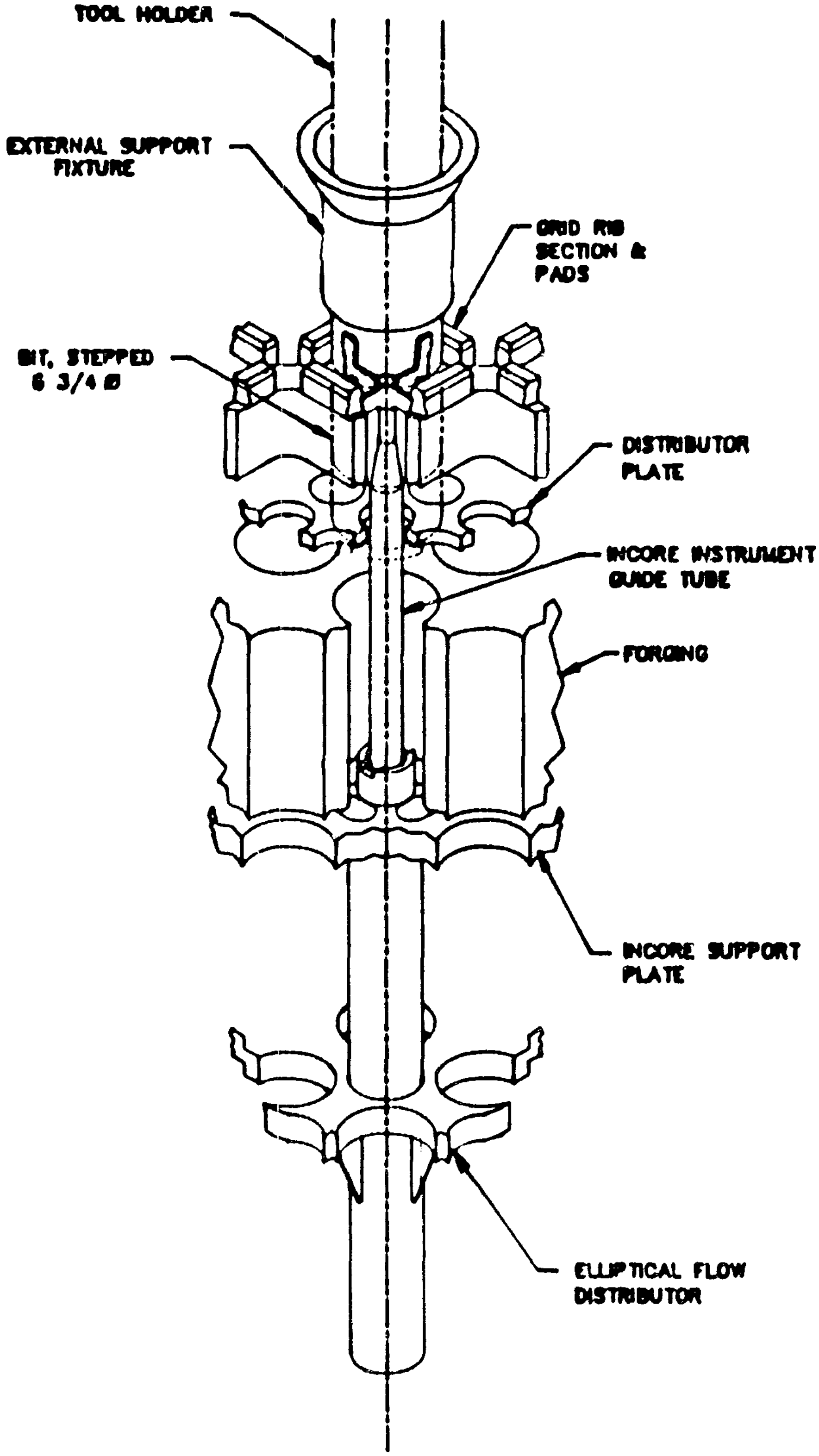
1. Clean lower grid rib section over incores. Remove loose rods if possible. Remove fuel debris from the area between the flow distributor head and the incore guide tube plate in preparation for core drilling.

2. Install the Core Bore Machine and any support hardware required for drilling the incore guide tubes.

3. Using a 6-3/4" OD x 3-1/4" ID (or 1-15/16" ID based on testing results) drill bit, bore all 52 of the incore instrument guide tubes through the lower grid rib section and distributor plate (see Figure 3-1). Change bit size to a 6-1/2" OD x 4-1/2" ID and bore through the forging, the incore guide support plate, the flow distributor head and the incore guide tube gussets. The core bore machine will have to be reversed on its transition plate in order to access all 52 locations (see Figure 3-2). Changing bits is required due to the method required for lateral support of the drill string. This operation will free all the incore guide tubes, and they will drop approximately 6" onto the incore nozzle (see Figure 3-3).

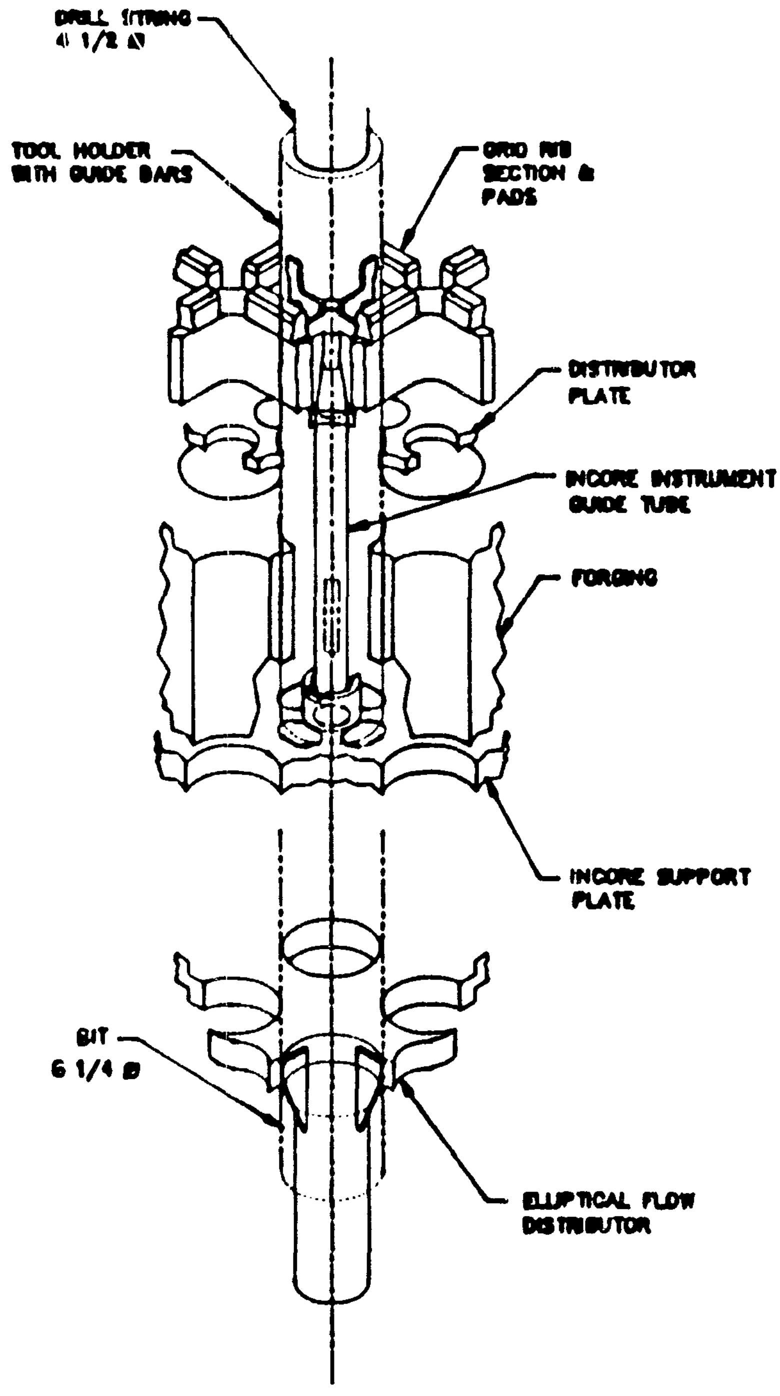
4. Remove the Core Bore Machine. An option is available to leave the CBM in place and continue by cutting the 48 support posts prior to removing the CBM and the incore guide tubes.

5. Using long handled tools, remove all incore guide tubes. The maximum length is 78" at H-8, and the maximum estimated weight is 230 lbs. Attempt to remove fuel internal to the



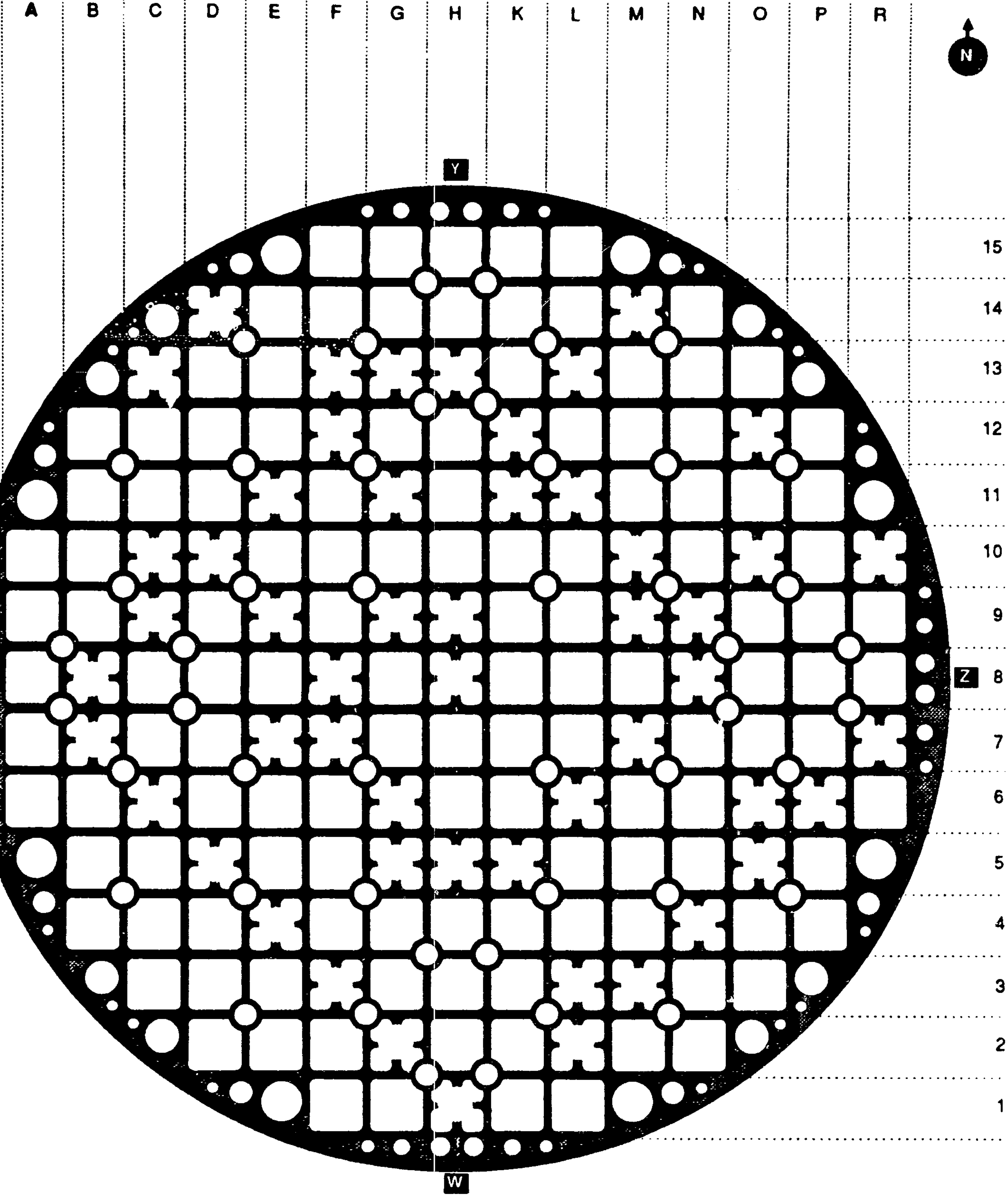
INSTRUMENT GUIDE TUBE CUT

FIGURE 3-1



INSTRUMENT GUIDE TUBE CUT THROUGH
ELLIPTICAL FLOW DISTRIBUTOR

FIGURE 3-2



Lower Grid Rib Section

After Drilling Out Incore Guide Tubes

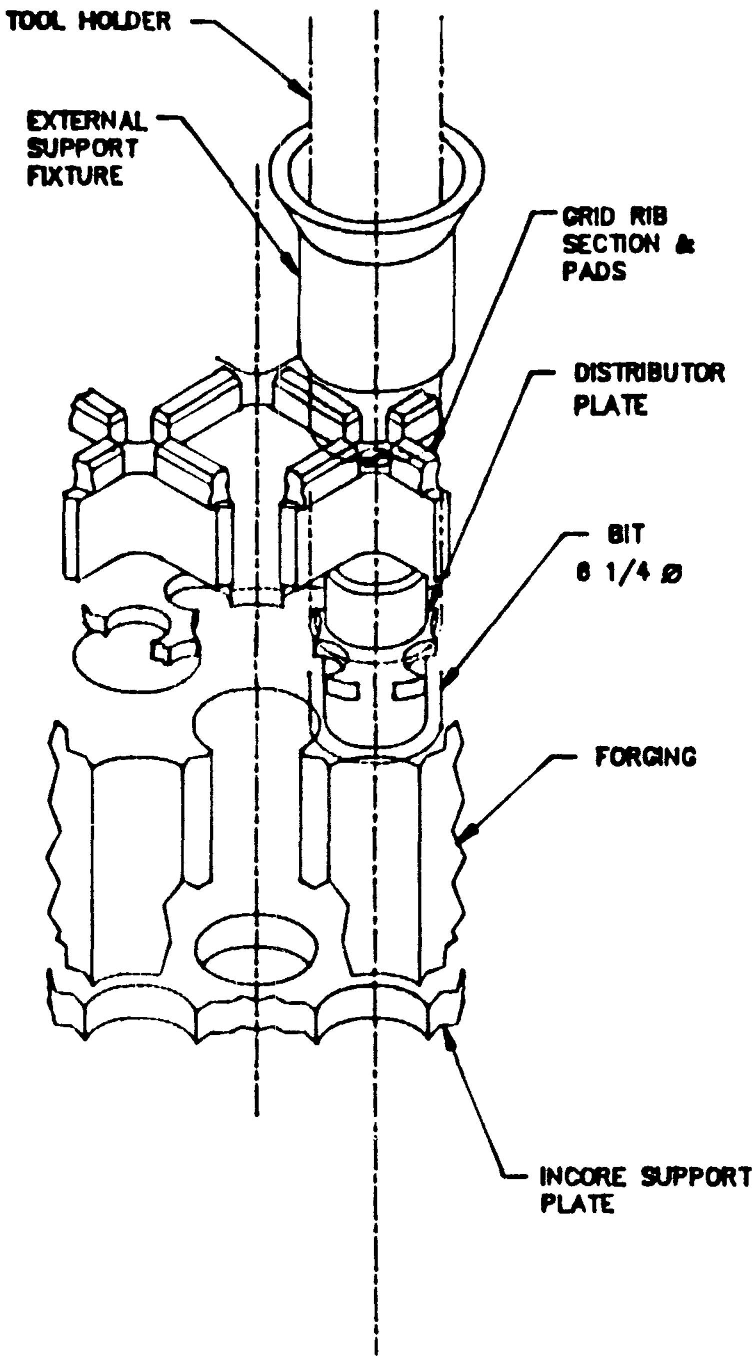
FIGURE 3-3

guide tube by inserting a rod through the opening in the tube. Remove any external debris by flushing. Verify that fuel debris has been removed from each tube and load in a storage canister. If fuel cannot be removed, place the incore guide tube in a fuel canister.

6. Reinstall the Core Bore Machine and any support hardware required for drilling the support posts.

7. Using a 6-3/4" OD x 5-1/4" ID drill bit, bore all 48 support posts through the lower grid rib section (7-1/4" thick), flow distributor (1" thick) and the forging (13-1/2" thick) (see Figure 3-4). Once the bit breaks through the forging, the support post will be free of the assembly. The majority of the support posts will drop 1/2 inch and land on the incore guide support plate. Only at the outer periphery will the support posts drop up to 7-1/2 inches. Upon completion of the support post boring operation, the LCSA will only be supported through its connection to the lower grid shell (see Figure 3-5).

8. Remove the Core Bore Machine.



SUPPORT POST CUT

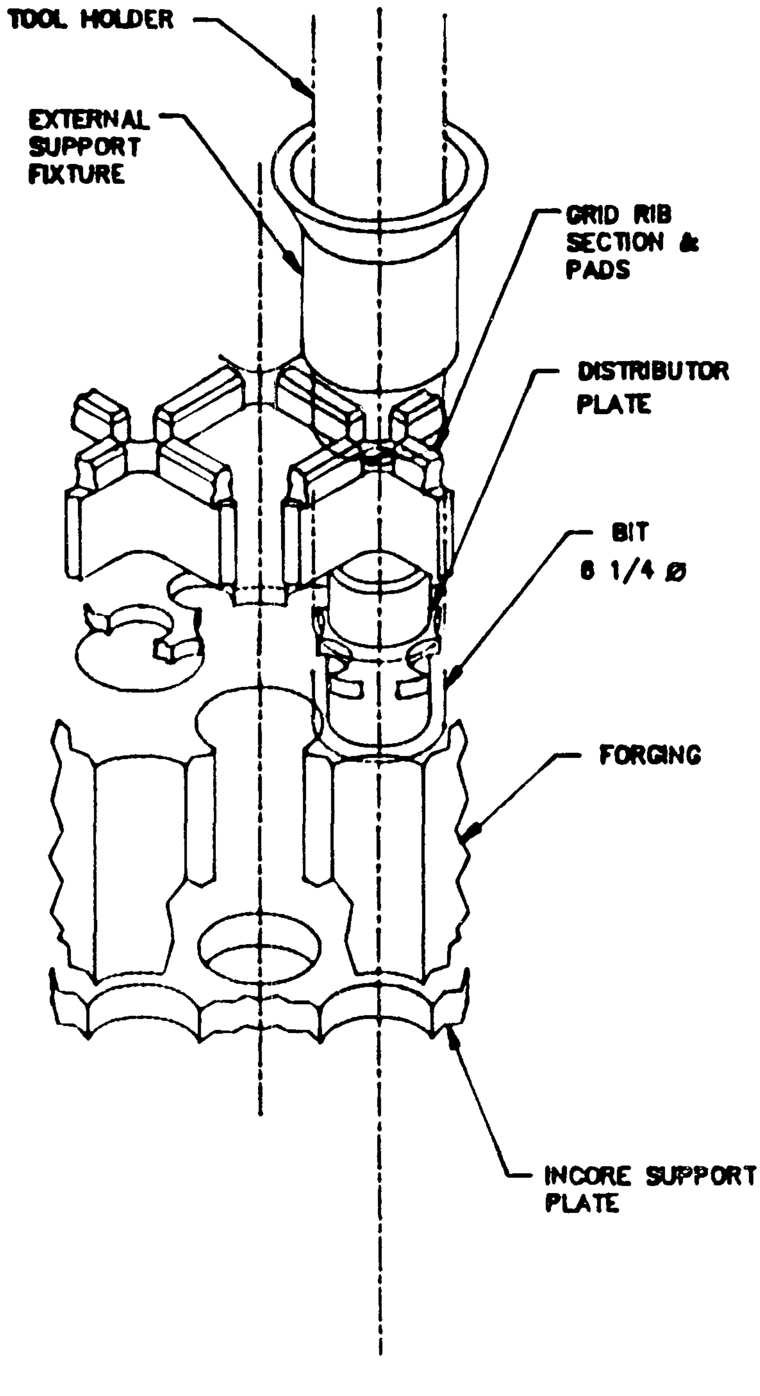
FIGURE 3-4

guide tube by inserting a rod through the opening in the tube. Remove any external debris by flushing. Verify that fuel debris has been removed from each tube and load in a storage canister. If fuel cannot be removed, place the incore guide tube in a fuel canister.

6. Reinstall the Core Bore Machine and any support hardware required for drilling the support posts.

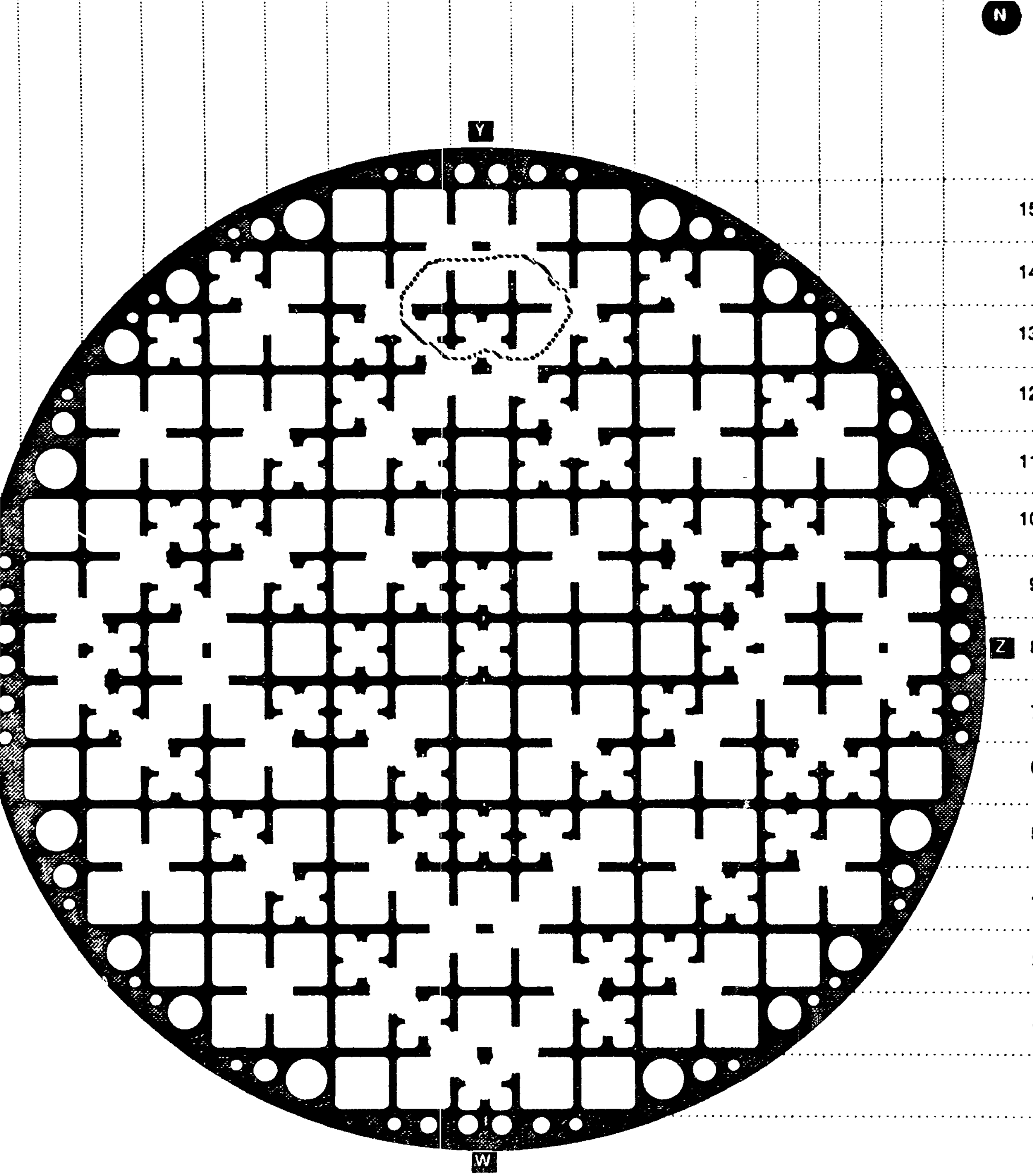
7. Using a 6-3/4" OD x 5-1/4" ID drill bit, bore all 48 support posts through the lower grid rib section (7-1/4" thick), flow distributor (1" thick) and the forging (13-1/2" thick) (see Figure 3-4). Once the bit breaks through the forging, the support post will be free of the assembly. The majority of the support posts will drop 1/2 inch and land on the incore guide support plate. Only at the outer periphery will the support posts drop up to 7-1/2 inches. Upon completion of the support post boring operation, the LCSA will only be supported through its connection to the lower grid shell (see Figure 3-5).

8. Remove the Core Bore Machine.



SUPPORT POST CUT

FIGURE 3-4



Lower Grid Rib Section

After Drilling Out Incore Guide Tubes And Support Posts

Note: Four H-Section dropouts (one at each axis)

9. Using long handled tools, remove all 48 support posts. The length is 32 inches, and the estimated weight without fuel in the post is 120 lbs. Video inspections have shown debris in the support posts and removal of the debris could be difficult. However, using an abrasive saw or flushing tools, cut the post or flush the post to remove the fuel. Verify removal of fuel and load in storage containers.

10. Install the PCI/ACES hardware in the RV utilizing the hanging supports in lieu of the stanchions. Using PCI/ACES plasma, cut the LCSA plates into various pieces and remove from the reactor.

0 CORE BORE EQUIPMENT

4.1 Introduction

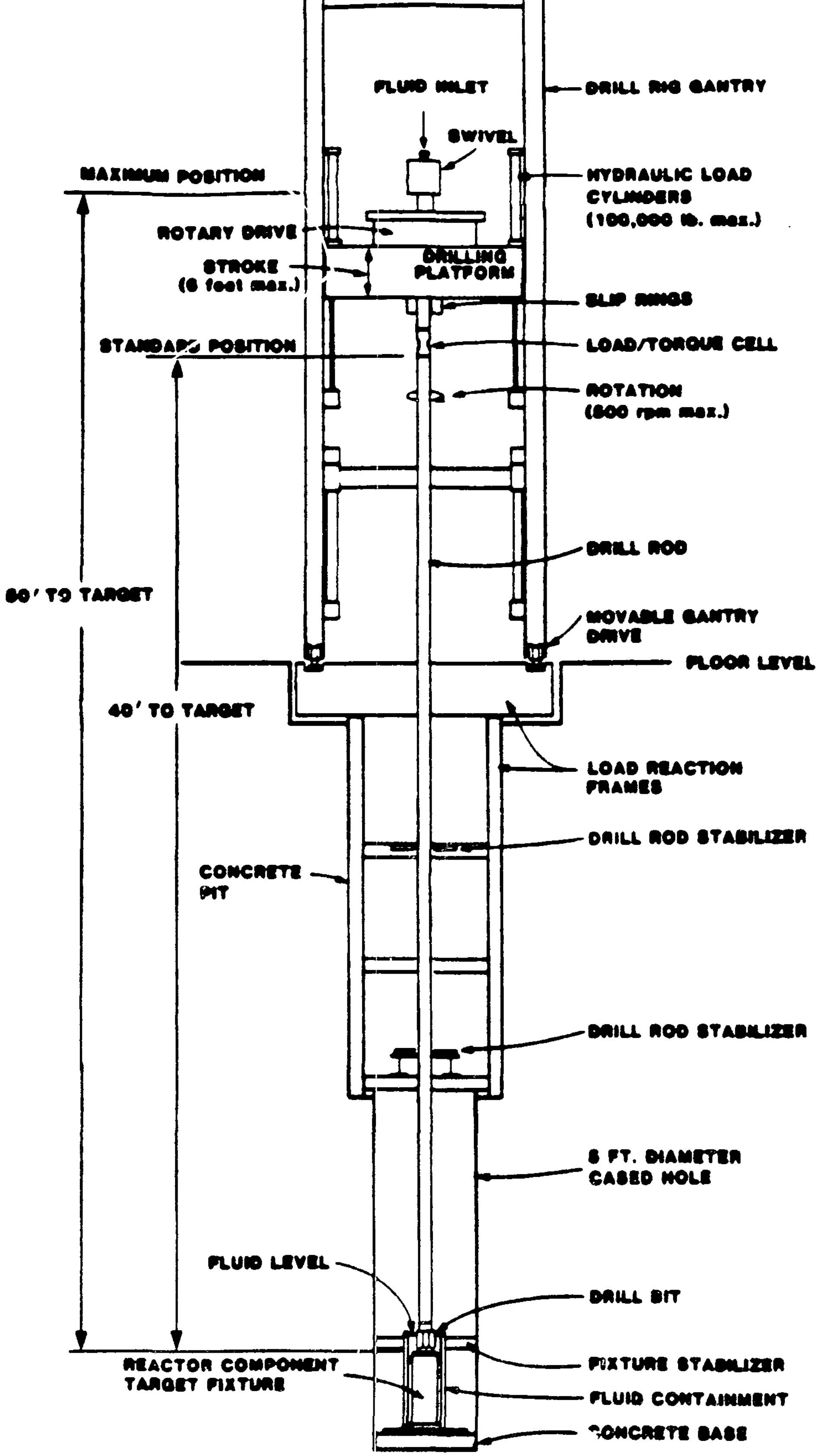
Early examination of the damaged core of the TMI-2 reactor revealed that the central portion of the core had collapsed approximately 5 ft. (1.5 m) below its original level, into a bed of loose rubble. Subsequent probing of the rubble bed revealed a solid sublayer some 2 to 3 ft. below the surface of the rubble. This discovery led to a decision that stratified vertical core samples would be required to provide data on what actually occurred during the accident and to aid in subsequent defueling of the reactor. This decision led to the development of the Core Bore Machine. Consequently, a series of tests were performed to evaluate various types of cutting tools. Composite samples were devised consisting of simulated partial fuel assemblies including lower end fittings, concrete blocks, gravel of various sizes, and hard-fired alumina plates.

Information obtained from these tests was combined and evaluated, and a version of the Norton-Christensen Chrisdril bit with the configuration of the cutting teeth modified was selected as the cutter most appropriate for the work at TMI-2. The bit has a rounded, cast-matrix crown set with industrial diamonds on the outer and inner surfaces and has cutter inserts made of "Stratapax" material set into the crown with silver solder. "Stratapax" is a tungsten carbide material with synthetic diamond bonded to it and is manufactured by the General Electric Corp.

4.2 Drill Unit

Once a usable bit had been obtained, efforts were then directed toward selecting a drill unit to drive it. Results of testing the bit had defined the required rotational speed, torque, and weight on bit capacities; the overall system requirements dictated other general requirements such as configuration, spindle size, and load (see Figure 4-1).

Based on a thorough tradeoff study, a unit manufactured by the Longyear Corp. was selected. The Longyear 38-EHS drill unit is a compact, self-contained machine. It consists basically of a hydrostatically driven spindle (which applies torque to the drill string) and hydraulic feed cylinders (which apply downward force on the bit during drilling operations). The cylinders also function to move the drill string into and out of the hole. Torque is transmitted to the drill string into and out of the hole. Torque is transmitted to the drill string through a hydraulically actuated chuck which is mounted on the spindle. The drill unit is equipped with a nonstandard spindle assembly called the Megalo head, which is manufactured by the Japanese subsidiary of the Longyear Corp. The Megalo head spindle and chuck are large enough to permit installation, removal, and casing. Different sizes of pipe are accommodated by changing the clamping jaws in the chuck to the required size.



TEST FACILITY SET-UP

FIGURE 4-1

The hydrostatic spindle drive system is powered by a 50-hp (37.3 kW) electric motor through a multi-speed gear system to provide a wide variation in available rotational speed and torque. A separate hydraulic pump, driven by the same electric motor, provides power to the feed cylinders, the spindle chuck, and two separately mounted clamps used in handling the drill and casing strings. Manual controls for all drilling operations are located within easy reach of an operator standing alongside the drill unit, as is instrumentation to provide visual indication of rotational speed and torque on the drill string and the weight being applied to the drill bit. The drill unit has a rotational speed range of 0 to 500 rpm and a torque range of 0 to 3000 ft-lb (0 to 4067 J). Downward and upward force capabilities are limited to 10,000 lb (4535 kg) each, due to design load considerations for the GPU Nuclear shielded work platform.

4.3 Drill Unit Supporting Equipment

The drill unit assembly is a complex combination of subassemblies and supporting structures. The drill and casing strings consist of a core barrel assembly, the drill string necessary to reach the desired sample depth, and casing to provide stability to the drill string during drilling operations. The casing also maintains a clear hole for video camera inspection of the lower reactor area once the core barrel and sample have been removed.

The core barrel, which is a standard commercial design, functions to contain and protect the core sample, support the drill bit, transmit drilling forces, and channel flush water through a bit. A double-tube core barrel is used, permitting the inner tube to remain stationary around the core sample while the outside tube rotates the bit. This requires a swivel mechanism built into the top of the core barrel. A vent with a check valve allows water to escape as it is displaced by the core sample.

The drill unit support system, consisting of an interface platform, drill indexing platform, indexing roller platform, tilt platform, and underwater stabilizing structure, is mounted on the GPU Nuclear shielded work platform. This shielded platform is a structure mounted on the reactor vessel flange for use in defueling operations. Secured to the defueling platform is an interface platform which was designed to ensure compatibility between the drilling equipment and the shielded work platform.

Drilling will be done with an essentially standard commercial drill string and casing, 3.5- and 4.5-in. (8.9- and 11.4-cm) outside diameter, respectively. However, some nonstandard lengths of drill string and casing are required, and the casing threads have been slightly modified to facilitate the breaking of joints in the proper locations.

During drilling operations, borated water at flow rates up to 6 gpm are required to provide cooling to the bit and flushing of drill fines. Clean borated water will be used to rinse the drill string and casing during their removal from the reactor for decontamination purposes. Coolant water will be provided by a standard, positive displacement pump. The suction for the pump will be taken directly from the reactor vessel for drilling purposes and from flush water supply tanks for rinsing of the drill string and casing.

An underwater stabilizing structure consists of a long, vertical tubular assembly and serves two purposes:

- Stabilization of the drill and casing strings during rotation, near the point of drilling.

- Support for a casing clamp located below the reactor water level. This clamp permits the casing string to be disconnected just below the bottom of the shielded transfer cask. The cask containing the core barrel and sample then can be moved into position over the canister and deposited into the canister.

Attached to the underwater stabilizing structure are inclinometers for use in vertically aligning the drill spindle and underwater structure. Also attached to the structure is a strain gage array with associated alarm circuitry to indicate excessive lateral deflection of the drill string during startup operations.

4.4 Core Bore Test Program for LCSA Removal

The objective of this program was to test several candidate boring tools to assess their suitability for use with the existing Core Boring Machine in dismantling the Lower Core Support Assembly (LCSA) in the TMI-2 reactor vessel. The tests consisted of the drilling of appropriately sized holes in test fixtures which duplicate the geometry of the LCSA as closely as practicable and the monitoring of the drilling parameters during the tests to evaluate the performance of each tool. The tests were conducted under conditions simulating those at TMI-2 as closely as practicable (see Figure 4-1).

The tests were conducted at the Terra Tek Drilling Research Laboratory in Salt Lake City, Utah. The facility contained a large drilling rig which is designed to test various types of petroleum and mining industry drilling equipment. The drill rig is a rail-mounted movable gantry which can be positioned over various stations for atmospheric and pressure drilling. The drilling platform is supported in the gantry and is adjustable vertically to accommodate various length tools. The platform contains a rotary table with a DC motor drive to allow continuously variable rotation from 0 to 500 rpm and torques up to 5,000 ft-lb. Hydraulic cylinders and a servo-controlled hydraulic power supply provide a drilling stroke of six feet at penetration rates up to 100 ft. per hour. Thrust can be applied up to 400,000 lbs as required to supply weight on the bit.

The drill rig gantry is located over a 23-ft deep drilling pit which has an additional 5-ft diameter cased hole extending 16-ft below the pit floor. With the drill target assembly installed in this hole and the drill platform raised in the gantry to the proper height above the drilling pit floor, the drill string length utilized for the bit tests will duplicate that required at TMI-2. The equipment set up for the test series is shown schematically in Figure 4-2.

All drill rig operations are controlled from a remote control room.

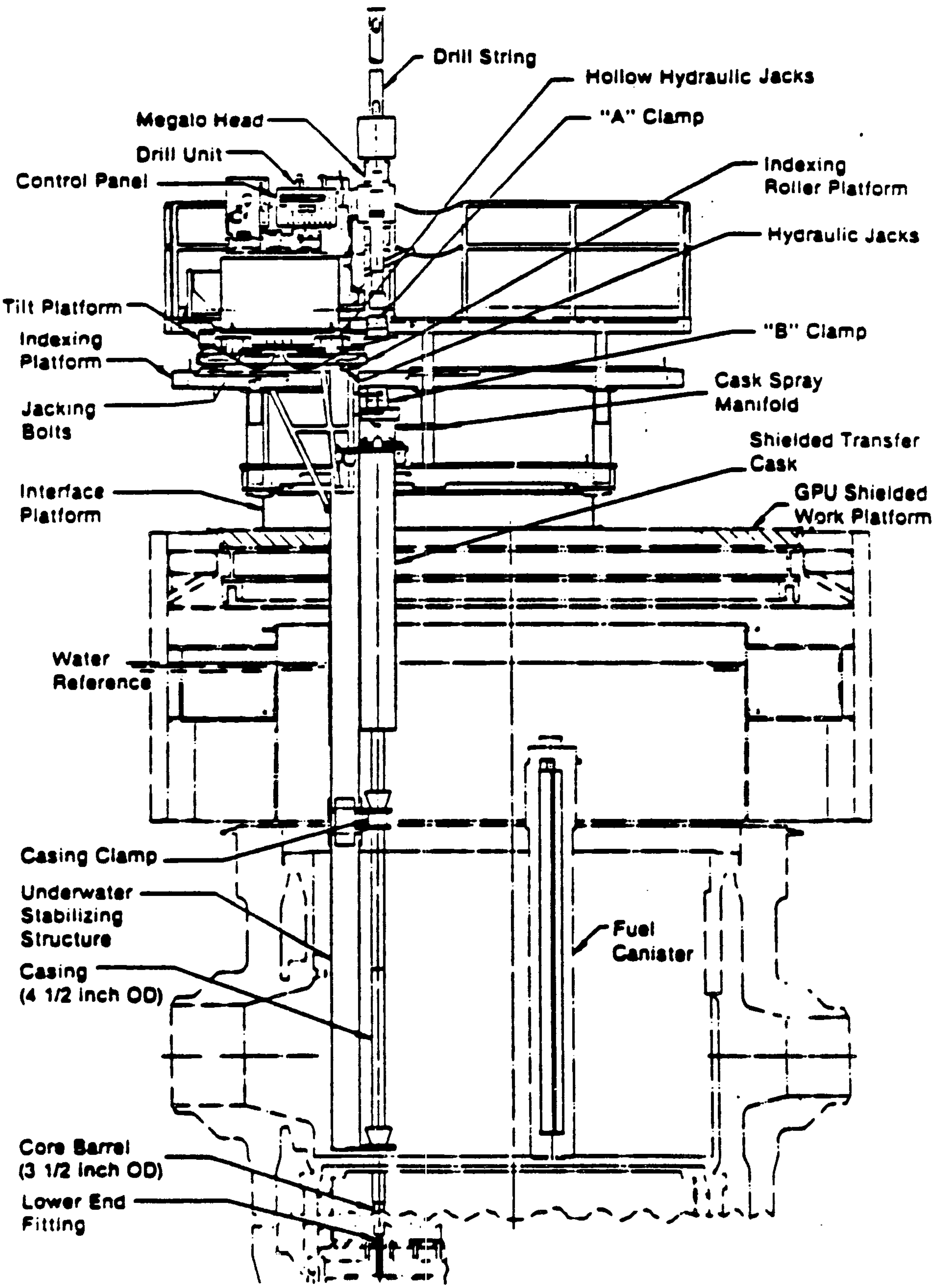
To simulate the Core Bore Machine, the drill rig control system was programmed to operate in the constant torque mode for this test series; that is, rotational speed and torque will be set in as controlled parameters, and the weight on bit will be varied as required to maintain the torque at the set value. Drill rig operating parameters were limited to the capabilities of the core bore machine. These values are: 500 rpm maximum, 3000 ft-lb torque maximum, and 10,000 lb weight on bit maximum.

The data requirements for each bit tested were as follows:

a. Optimum rotational speed.

b. Torque requirements, starting and sustained drilling.

c. Weight on bit requirements, starting and sustained.



ELEVATION VIEW OF THE DRILL UNIT
WITH ITS SUPPORTING STRUCTURES AND EQUIPMENT

FIGURE 4-2

d. Rate of penetration.

e. Bit life (inches of SST penetrated to bit failure). Initially, bit failure will be defined as that point at which penetration has dropped to 1/2 inches per hour. This will be evaluated further as the tests progress.

f. Sensitivity to vertical misalignment of drill string.

g. Stability sensitivity for drilling both plates.

h. Cooling water requirements.

The drill target fixtures were designed to simulate vertical sections through the LCSA. Each fixture consisted of a series of target plates which are clamped in position by four 2-1/2 inch diameter tie rods. The target plate material, thickness, vertical spacing, and existing hole patterns are all representative of the TMI-2 reactor.

Vertical spacing of the target plates is achieved by the use of spacer tubes over the tierods. The varying angle the flow distributor plate upper surface makes with the horizontal, because of its elliptical shape, is simulated through the use of angled spacer tubes. The flow distributor target plates were installed at either 0, or 14.5 degrees and at the correct vertical spacing below the simulated forging for each.

4.4.1 Core Bore Drill String and Tool Holders

The drill string required to transmit torque and load from the drill rig spindle to the tool holder/bit assemblies will be 4.5 inches in diameter with a 3/8 inch thick wall. It will be supplied in two approximately equal lengths which, when coupled together along with the tool holder/bit assemblies, will approximate the length between the bottom of the core bore machine spindle and the LCSA.

Six different tool holders will be required to adapt the bits to the drill string and to house various core catcher mechanisms and centering guides necessary in the test series. Each tool holder will be approximately 65 inches in length to maintain the same overall length for the different drill string/bit combinations. The tool holders will interface with the drill string and will have internal coolant channels which will, in concert with the bit, direct coolant to each cutter insert. The upper 16 inches of each tool holder will be 6-1/4 inches in outside diameter to interface with the tool changer mechanism which will be installed on the Core Bore Machine under water support structure.

4.4.2 Core Bore Bits to be Tested

Bit Types: Two types of bits will be tested in this program. Each type is described below.

Waukesha Trepanning Bits: These tools are special trepanning type bits manufactured by Waukesha Cutting Tools, Inc. Each bit incorporates replaceable cutter inserts. The primary type insert to be evaluated in this test series will be made of T-15 high speed steel with titanium nitride coating. The Waukesha bits, equipped with these inserts, were the most successful of the bits tested in the May, 1987 test series.

Two additional cutter insert configurations will be subjected to limited testing. One will be coated with Ovonic-47 Diamond Black, a boron-carbon compound manufactured by Ovonic Synthetic Materials Co. The second will be conventional inserts tipped with a material called Cermet, manufactured by NTK Cutting Tools, which was developed to handle high-level cutting forces, mechanical impact, and thermal shock. The ability of these inserts to penetrate ceramic-like material will be tested on target plates which will have been flame sprayed with a coating of Alumina approximately 3/8-inch thick.

Junkmill Bits: These bits, manufactured by Christensen Mining Products Company, consist of a cast crown covered with small, irregularly shaped pieces of tungsten carbide imbedded in silver solder. These bits performed satisfactorily in interrupted cut situations in the previous test series but failed in non-interrupted cuts due to chip removal problems.

0 PLASMA ARC TORCH CUTTING EQUIPMENT

5.1 Introduction

In order to defuel the lower head of the reactor vessel, it is necessary to cut away large portions of the structure, called the Lower Core Support Assembly (LCSA), that supported the core. Five horizontal plates of varying thickness tied together with vertical members compose the structure to be cut. Access openings will be cut in this system first by a core drill apparatus and then by a plasma arc system called ACES (Automated Cutting Equipment System).

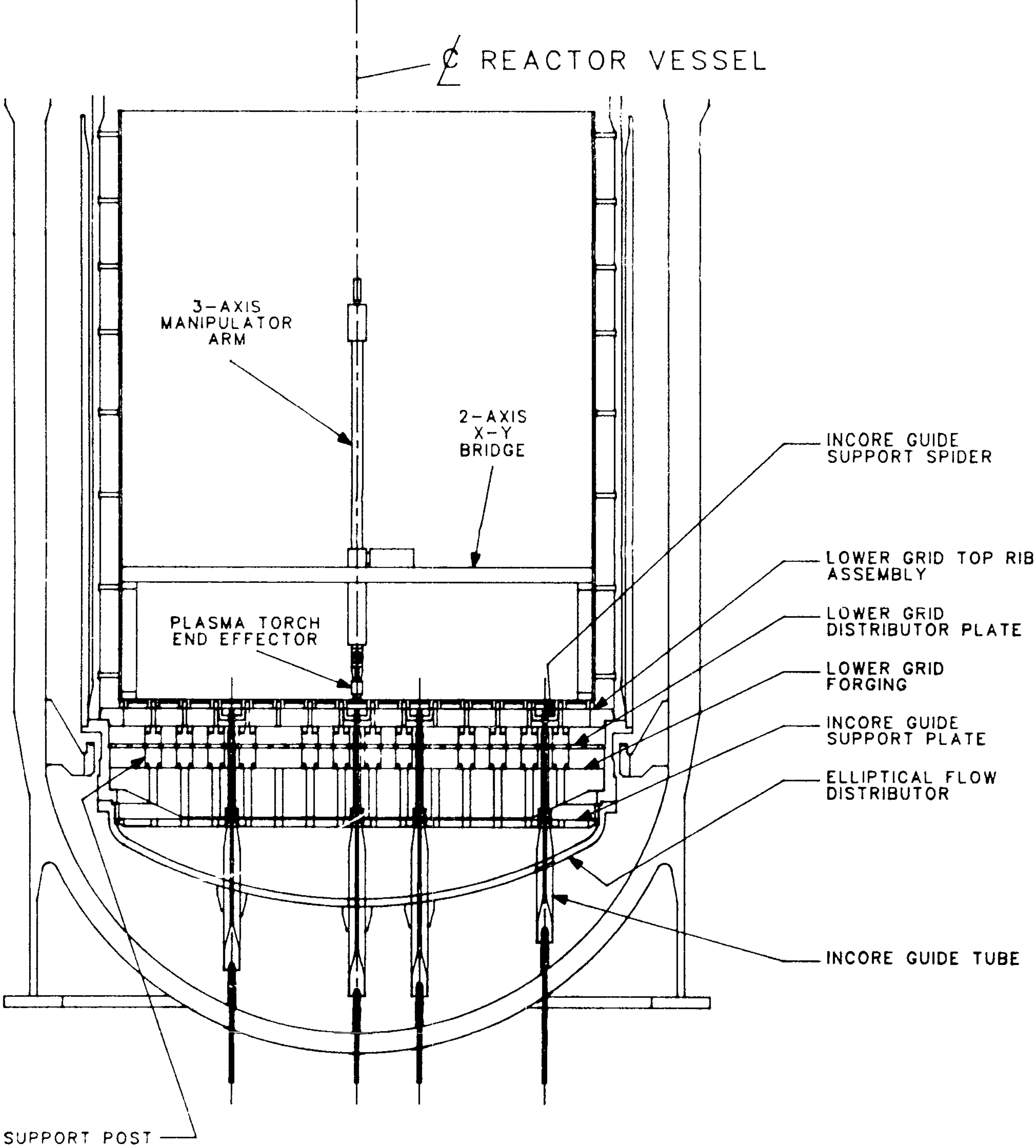
The plasma arc process is used industrially to cut metal shapes and has been adapted to several nuclear applications as well. Cuts were made underwater, remotely, and in radioactive areas, with varying degrees of success. TMI-2 presented special problems, including the 35 ft. depth underwater, the high boron content (5300 ppm) of the water, low visibility, a large complex geometry with up to 2-1/2" thick sections to be cut, and restricted access. In addition to these particular problems, the radiation/contamination environment imposes difficulties on the operation and maintenance of the equipment. These problems and conditions influenced the design of the equipment, resulting in a system that is significantly more complex than any defueling tool used at TMI-2 thus far.

5.2 Development

ACES was procured by GPUN from Power Cutting Inc. (PCI) of Lake Bluff, IL under a contract that covered design, fabrication, development and testing. Prior to shipment, PCI conducted two series of acceptance tests which demonstrated that the torches furnished could cut the required thickness of material in 5300 ppm borated water in 35 ft. depth, and that the equipment, operated as a system from a remote control room, could cut the specific geometry of the LCSA. After the equipment was delivered, extensive testing was conducted in a full scale mockup of the reactor vessel with mockups of the LCSA. This effort resulted in a number of design and hardware improvements, the development of cutting techniques and procedures as well as providing the background for training personnel in the installation, operation and maintenance of the equipment. The most important modification was the addition of a multi-position spray system that cleans and prevents damage to critical drive components from the debris that is generated during cutting. The equipment, prior to the improvements, has been described previously. Basic descriptive data is given in Table 5-1 and the equipment is shown in Figure 5-1.

5.3 Equipment System Description

The principle tooling consists of a support bridge, carriage, trolley and a manipulator, which rest on the LCSA, under thirty-five feet of reactor coolant head. The carriage and trolley provide movement of a torch head or tool in the horizontal X-Y plane. The manipulator provides motion in the vertical Z axis direction. At the lower end of the manipulator arm is the pneumatically operated gripper. The arm also provides the two



ELEVATION VIEW OF LCSA

AND

PLASMA ARC CUTTING EQUIPMENT

FIGURE 5-1

TABLE 5-1 TABULAR DATA ON ACES

Capability	
Depth underwater meters (ft)	10.7 (35)
Boron Concentration (pH)	5300 ppm (7. - 7.5)
Thickness of Stainless Steel, demonstrated cm (in)	6.35 (2.5)
Power Supply	3, PAK-45[1]
Capacity	1350 a. @ 200 v. (open circuit)
Torch Coolant Unit	HE-200[2]
Flow (gpm)	5.5
Fluid Used	Demineralized Water
Type System	Closed, recirculating loop
Conductivity Range (micro mhos)	0 - 13
Positioning	
No of axes of motion	5
Prime Mover	24v DC Servo Motor
Position Indication	Shaft Encoder
Plan View Range (cm, (in))	316 (124)
Elevation Range (cm (in))	142 (56)
Rotation (degrees)	± 180

1 PAK-45 is the thermal dynamics (0, trade name for its standard power supply.

2 HE-200 is the Thermal Dynamics (trade name for its standard torch cooler.

additional axes of motion. The A axis (360° rotation about the Z axis) and the B axis (90° bend from the Z axis). Adapted to robotic gripper are specially designed plasma torches and effector for cutting sections of the LCSA. Three PAK-45 power units are combined to provide 1500 amperes to the torches. A separate HE-200 cooling unit is included.

Umbilical type control cables connected to the tooling system go to the work platform where control junction/union consoles, plasma power sources, and other equipment are staged. From the work platform, cables lead to a command center, outside of containment, where the operation of the manipulator and end effectors are computer controlled.

The system will be controlled by a state-of-the-art programmable control system consisting of special control consoles, including a Sperry PC/IT microcomputer system, a specially modified General Numerics/Fanuc Numerical Controller, and an End Effector Control Console, which will provide control and full monitoring of all end effector functions.

The ACES tooling is programmed to cut each of the LCSA plates to a predetermined geometry. After cutting a plate, the ACES tooling will move aside and allow other systems to remove the cut sections from the reactor.

5.3.1 Support Stanchion

Support stanchions are used to support the ACES on the top rib section plate or from hanging supports off the baffle plates. These stanchion supports are located under the four corners of the X-Y axes assembly. At each corner the stanchion consists of three separate pipe legs set between two plates. The top plate of the stanchion is shaped to match the corner plate of the X-Y axes assembly frame. The legs extend through both the top and bottom plates. The bottom of two of the three legs have locking devices which are inserted into and lock to the existing four sided grid pads.

5.3.2 X-Y Axes Assembly

X-Y axes assembly consists of three subassemblies. The first is the X-Y frame, which supports the X axis carriage. The second is the X axis carriage which moves in the X direction and supports the Y axis trolley. The third subassembly is the trolley which moves in the Y axis, and it supports the Z axis manipulator arm.

The X-Y frame is a four sided assembly. The four sides are constructed of 4 inch stainless steel "H" beams. The four sides are truncated at the corners, with 3/4 inch thick stainless steel plates, bolted to the underside of the "H" beams. These corner plates are the plates that sit on the top stanchion plates. Two parallel sides of the frame have bearing tracks and gear tracks attached to the top flange of the "H" beam. These tracks are for the X axis carriage.

The X axis carriage subassembly consists of two connected, parallel "H" beams, spanning the two sides of the frame which have the gear tracks and linear bearing tracks. This parallel set of beams moves along the frame to provide X axis motion. Set between the parallel "H" beams is a servo motor which drives a pinion gear which transmits power and motion to the carriage on gear tracks of the frame (the servo motor is sealed in a housing). Each end of the parallel "H" beams have linear bearings on the bottom flange surface which move on the bearing tracks of the frame. The two parallel "H" beams each have a bearing track on their upper surface. These tracks are for the Y axis trolley. One of the parallel beams has a gear track on its upper surface. This is also for the Y axis trolley.

The Y axis trolley subassembly consists of a 3/4 inch thick stainless steel plate which spans and sits on the two parallel beams of the X axis carriage, on the bearing tracks. Mounted to the plate, but situated between the parallel "H" beams is a sealed servo motor driving a pinion gear providing motion to the Y axis trolley (plate), above the gear track on the parallel "H" beams.

There are two stainless steel saddle plates used to support the manipulator on the trolley. One plate contains three slots. The other contains two slots. These slots are for supporting the manipulator. The middle slot on the three slotted saddle allows the manipulator to pass between and down through the two parallel beams. The two other slots in the plate allow the manipulator to be supported on either side of the parallel beams.

5.3.3 Manipulator

The manipulator is the key element of ACES. It provides the Z axis motion to all end effectors. Also, at the lower end, it provides two other axes of motion. Axis A is a 360° rotational motion about the manipulator. Axis B is a 90° bending motion in the last 12 inches of Z axis motion. At the bottom of the manipulator is a pneumatically operated gripper, designed to interface with the end effectors.

The Z axis motion is provided by a telescoping tube within a tube. A servo motor and lead screw drives the inner tube up and down. A canned servo motor sits on top of the vertical outer tube. The inner tube, or extending tube, contains the A and B axes of motion. The A axis motion is driven by an internal servo motor and a keyed shaft. The 90° bending B axis motion is driven by a servo motor and two bevel gears. Both servo motors are sealed.

At the end (bottom) of the manipulator is the gripper. The gripper is a three (3) finger unit. It is a two position gripper (open/close) operated pneumatically, on nitrogen at 125 psi.

5.3.4 X-Y Bridge Accessory Systems

a. X-Y Motor, Nitrogen Purge

A nitrogen purge system is utilized to eliminate the possibility of borated water leaking into the X-Y motor housing.

b. X-Y Gear Rack Spray System

In order to eliminate the X and Y axes drive gears from becoming immobile due to metal fragment settlement on the X and Y rack, a borated water spray system to clear the racks of debris is utilized.

c. Y Axis Lock

A locking mechanism has been incorporated to fasten the Y axis trolley to the X axis carriage. The locking mechanism is engaged before the X-Y axis assembly is delivered into or removed from the reactor. To lock or unlock the mechanism, when it is set in the reactor, a long handled tool is utilized. The same tool used to lock or unlock the support stanchions from the X-Y axis assembly is used for this lock.

5.4 Plasma Cutting Equipment Description

Plasma is formed when a gas (N_2 in this case) has been heated to an extremely high temperature (30,000° - 50,000°F) and ionized so that the gas becomes electrically conductive. The plasma cutting process uses this plasma to transfer an electric arc to the workpiece. The metal to be cut is melted by the heat of the arc and then blown away by a secondary gas. N_2 is used for the secondary gas.

5.4.1 PAK-45 (Power Supply)

Three PAK-45 units hooked in parallel are utilized. One unit is the master unit. The PAK-45 has the following features:

- 50-450 amps DCSP at 300 volts with open lead
- Automatic Standoff Control for arc starting and control

Used in conjunction with the PAK-45's is a water cooling unit. This unit dissipates the heat generated in the torch and power cable. It incorporates a closed circuit recirculating cooling system. Features of the HE-200 coolant recirculator are:

Reservoir Capacity:	Approx. 5.5 gals. plus hose volume
Recirculation Rate:	5.2 GPM at 120 psi (closed loop) through 1/2 inch line, 100 feet
Input Power:	480 volt, 30 amp, 3 phase
Max Cooling Capacity:	80,000 BTU/Hr.

5.4.2 Plasma Junction Box

The plasma junction box is located in containment. It provides the monitoring sensors and instruments required for the operation of plasma cutting.

The junction box has fault circuitry incorporated such that two adverse conditions can be monitored:

1. Low pressure and high flow - indicates a broken hose
2. High pressure and low flow - indicates a clogged hose

The plasma junction box also monitors the HE-200. Coolant flow, temperature, pressure and conductivity readings are transmitted to the End Effector Control Console.

Primary and secondary plasma gases and plasma coolant are controlled and monitored at the plasma junction box. The gases enter the junction box at 120 psi in two separate lines. Each line is controlled and monitored by solenoids, regulators, gages, and transducers. The three valve and regulator sets control the purge, arc start and full plasma cut operations.

Gases entering the junction box flow through a flowmeter. Exiting the flowmeter, gases pass through one of the three sets of solenoid valve and regulator, depending on whether a purge, arc start or full plasma cut operation is being performed. Gas pressure at the junction box is determined as the gas exits the regulator.

5.4.3 Plasma Distribution Box

The plasma distribution box is a standard metal wall-mounted electrical cabinet. It receives the main power supply and distributes the power to the three PAK-45's. It contains electrical and electronic switching to control the current flow for standoff control and current supply. The physical size of the unit is 18 inches deep by 36 inches high by 36 inches wide. It is located in containment with the PAK-45's.

5.4.4 Plasma Control Console

The plasma control console controls the main power on/off to the distribution box, junction box and remote pendant control. The plasma control console also provides the following control over the distribution and plasma junction boxes.

Distribution Box	Junction Box
Standoff Control Supply Current	Primary & Secondary gas flow - 3 stage (Purge/Arc Start/Plasma Cut) Primary & Secondary gas pressure. Coolant flow/Pressure temp/Conductivity

Data received at the distribution and junction boxes is transmitted via cable to the plasma control console in the command center. (The plasma control console has fault logic wired into it for various conditions and combinations of temperature, pressure, conductivity and flow rates of HE-200 coolant and primary and secondary gas flow. Plasma voltage and supply current are also monitored. The fault logic will either shut down the plasma cutting operation or warn the operator of potential problems when specific conditions are approached, met or exceeded.

The plasma control console is a floor mounted, standard console with digital monitoring display and control panel arrangement. It is located in the command center.

5.4.5 Portable Plasma Remote Control Box

The plasma remote control box is a fully-equipped auxiliary control and monitoring station with the following features:

Controls:	Start torch
	Stop torch
	Find standoff height
	Hold standoff height
	Jog UP
	Jog DOWN
	Center torch
	E-STOP
Indicators:	Torch centered
	Arc current
	Remote enabled
	Fault (E-STOP)

An electronically controlled fault logic system is incorporated into the plasma control console. This system will identify conditions that may present hazards to torch operation and conditions which would inhibit torch longevity.

5.5 ACES Control System Description

Control of the ACES equipment is provided by a set of micro processor-based units that allow for programmed as well as direct control of all aspects of the system.

Control and monitoring of the ACES is concentrated in the Command Center. There are also various controls available to personnel in the containment vessel. In the following paragraphs, both in- and out-of-containment controls are discussed in detail.

The Command Center, located in a designated area of the Turbine Building, is the focal point for day-to-day operation of the ACES system. From here, all activities necessary to operation are facilitated. The manipulator is positioned and programmed to follow cut trajectories, and the plasma torch and other end effector systems are controlled and monitored.

Three control console stations provide all control and monitoring required by the system. The three consoles are the "Host" Mapping System (a Sperry PC/IT microcomputer system), the General Numerics/Fanuc Numerical Manipulator Controller, and the specially-assembled Plasma Control Console. Together, these units provide an operator with the ability to program the manipulator with interactive graphic inputs. The inputs correlate exactly with a cut trajectory as it must be performed on a given plate. With the aid of various software packages, the entire cut can be specified on the Sperry PC/IT Host System. This information is downloaded to the General Numeric/Fanuc Numerical Controller which, in turn, uses the information to command all movements and functions of the ACES X Axis Carriage, Y Axis Trolley, and Manipulator.

.0 CUT PIECE HANDLING AND STORAGE

Cutting large pieces from the LCSA as opposed to making many small pieces necessitated that a storage location be found in the reactor building for the LCSA pieces. A review of the available storage locations resolved itself initially into storing all the large LCSA pieces into the RB basement. Further, the more highly radioactive pieces, i.e., the lower grid rib sections and later the baffle plates will have to be stored in the basement under the 305' elevation concrete floor in order to provide the necessary shielding. Due to contaminated material disposal problems, additional lead shielding in the reactor building is greatly discouraged. Every effort will be made to utilize the shielding already available in the building.

This further required that a receptacle be provided in the reactor building basement for the large pieces to be stored there. A cart was designed to accommodate this requirement. It was designed to receive the large cut pieces while positioned under the 305' elevation hatch, and then it could be rolled under the 305' floor. This requirement became necessary due to the expected neutron activation of the grid rib section which was estimated to have been at least 280 REM/hr on the surface. Storing this plate in the basement under the open hatch would result in radiation levels on the 305' elevation floor of 500 to 1000 milrem/hr. Therefore, it became necessary to be able to position the plate under the 305' concrete floor and use the floor as a built-in shield.

About one month prior to the completion of the initial core bore portion of LCSA removal, a decision was made to use the core flood tanks as a storage receptacle for the cut pieces of the LCSA in lieu of the cart in the basement. CRT "A" was prepared to receive the cut pieces by cutting an eight foot diameter hole in the top of the tank, filling the tank with borated water and providing a platform in the tank to land the pieces of the LCSA on. The tank is a more desirable storage location than the basement because it is a simpler rigging job, building dose rates can be reduced, basement access is not affected, and retrieval of the parts from the tank (for accountability measurements or return to the RV) is simpler. In order to use the A core flood tank the following had to be completed:

a. Remove the hatch plugs and two removable 13.5 ft long 18WF64 beams from the hatch openings.

b. Cut off the top of the tank at about a 9 ft diameter.

c. Install a support structure inside the tank for receiving the LCSA pieces.

d. Fill the tank with borated water. A fill system must be installed.

e. Erect a "work platform" and handrails around the hatch to allow worker access to the rigging.

f. Install lighting (and underwater cameras as required) in the tank.

g. Install radiation monitors as required (Rad Con responsibility).

h. Relocate building cameras as necessary for monitoring the load path.

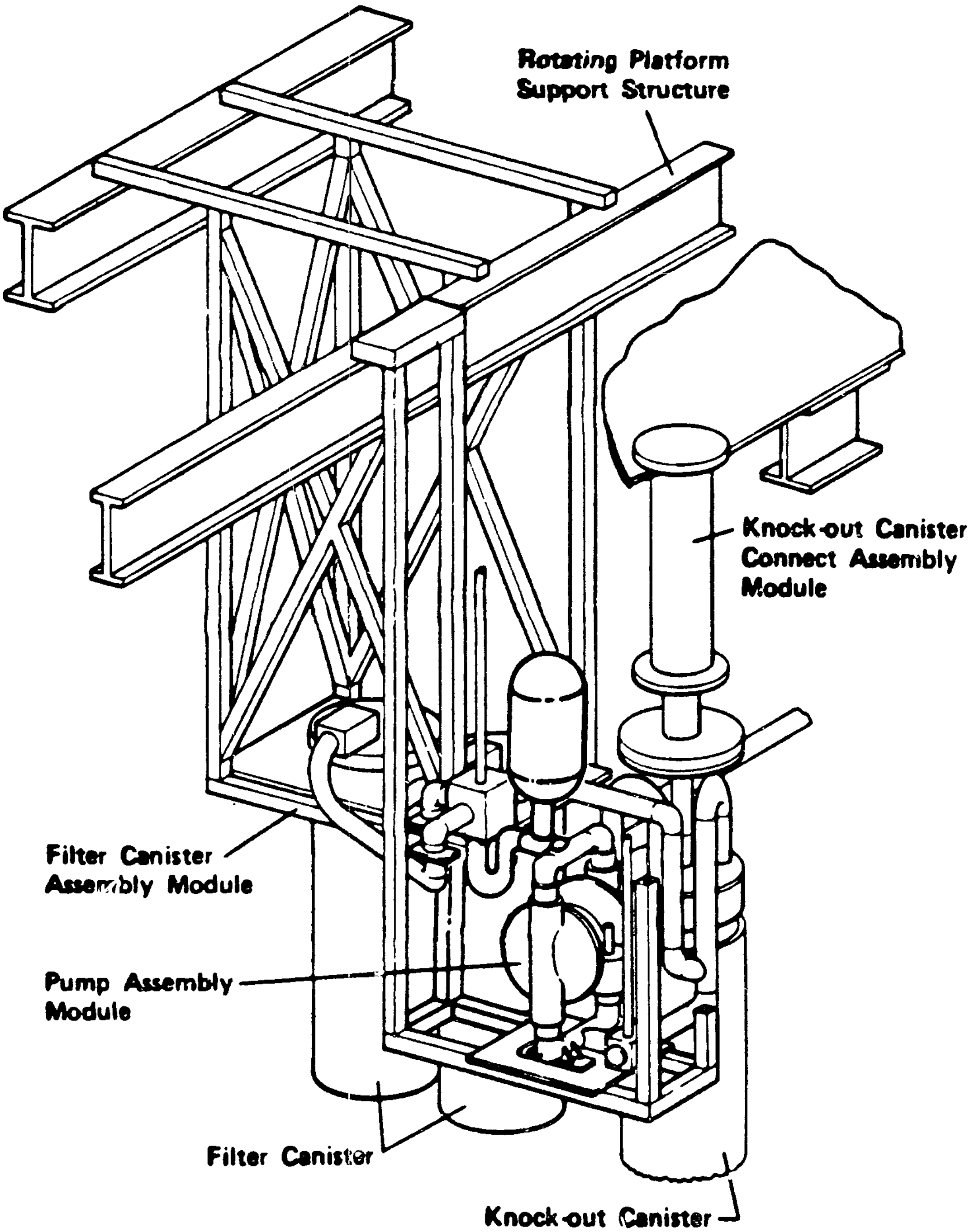
DEFUELING EQUIPMENT

7.1 Fines/Debris Vacuum System

The Fines/Debris Vacuum System is designed to perform its function submerged in the reactor vessel water supported from a rotatable shielded work platform, as illustrated in Figure 7-1. The system consists of the following subsystems:

- o Nozzle assembly module
- o Pump assembly module
- o Knock-out canister connect assembly module
- o Filter canister assembly module
- o Support tooling
- o Instrumentation and controls

The system is designed to remove debris from the reactor core by vacuuming. Debris is vacuumed through the nozzle and transported through 2-inch stainless steel pipe and 2-inch flexible hose to a knock-out canister. Because of the hydraulic flow profile established in the canister, debris particle size up to an intact fuel pellet are deposited. The effluence from the knock-out canister is then drawn through the pump and discharged into a filter canister. Here debris down to a 0.5 micron in size is entrapped. The discharge is then returned to the reactor vessel.



FINES / DEBRIS VACUUM SYSTEM - I

FIGURE 7-1

The system is designed for manual operations. The nozzle end of the system is manipulated in and around the core debris by an operator on the Shielded Work Platform. This is done primarily through a long handled tool slot for core area fuel debris removal. All valving and filter canister connect/disconnect operations are done manually using long and short handled tools. The only remote operation is the vacuum system connect/disconnect operation to the knock-out canister. This is accomplished using double action hydraulic cylinders.

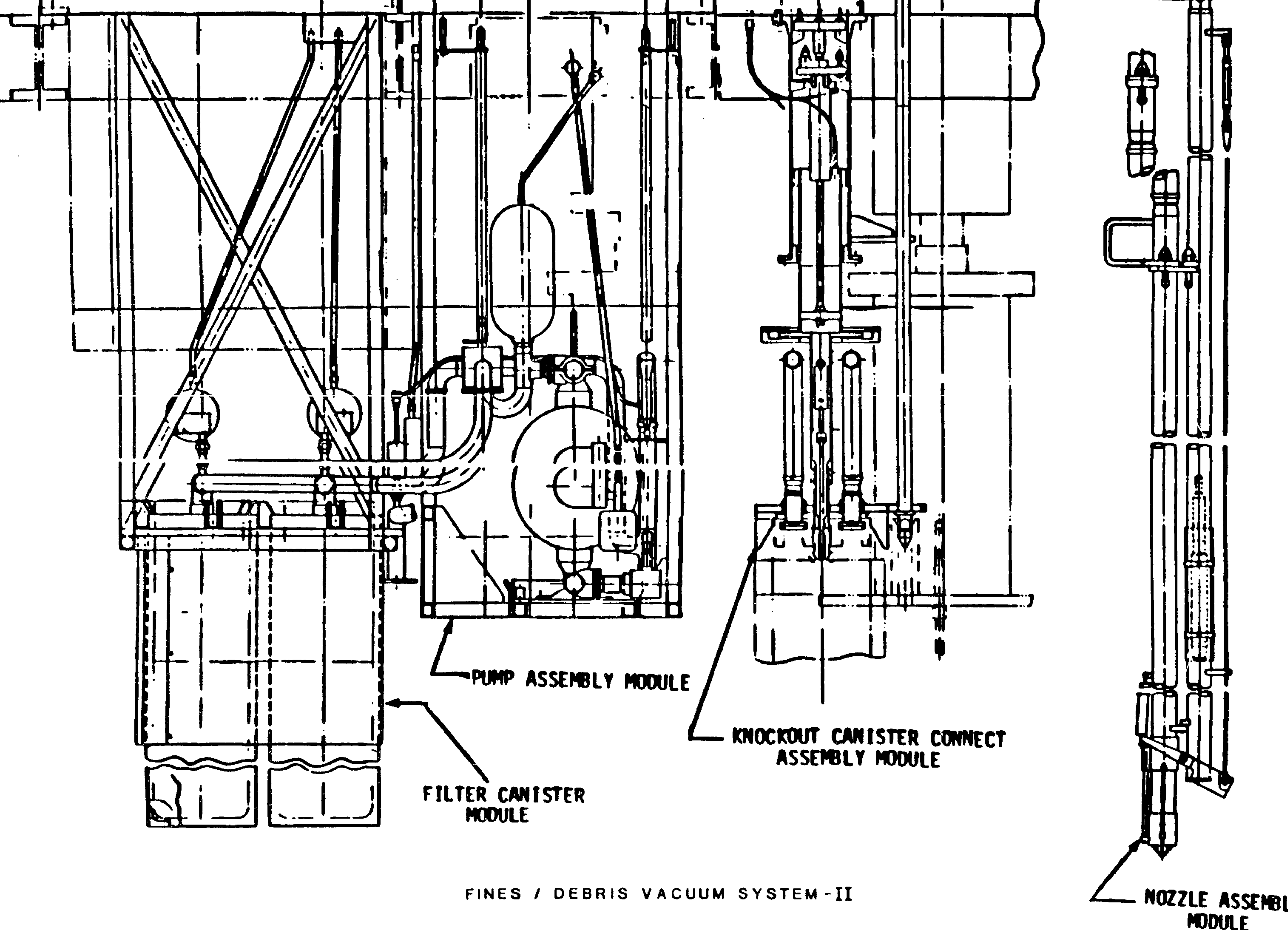
For ease of maintenance the system can be assembled and disassembled from the shielded work platform. Any subassembly can be removed with no impact on the remaining system. All subsystem interfaces are standardized, therefore, standardizing all assembly/disassembly operations.

The Fines/Debris Vacuum System design is supported by engineering design, calculations and proof-of-principle testing. The knock-out canister internals design and testing limit the size of particles exiting the canister to 100% of all particles smaller than 500 microns in size and 85% of all particles smaller than 130 microns in size. The calculated effluent concentration based on test results was less than 800 ppm for the maximum attainable vacuuming rate. The vacuum system test results established a required flow rate of 60 gpm to vacuum debris up to a fuel pellet in size. This is 79% of the maximum design flow rate (76 gpm) thus providing the design margin that insures system flexibility.

Figure 7-2 illustrates the general layout of the vacuum system design within the reactor vessel. The vacuum system design uses an air operated diaphragm type pump to transport the fines/debris from the reactor pool to the knock-out canister, where particles from 500 micron to the size of a fuel pellet (3/8 dia. x 5/8 long) are entrapped. Fines/debris that are not entrapped by the knock-out canisters are delivered to the filter canister(s) where particles down to a 0.5 micron are entrapped in the filtration media. Water exiting the filter canister(s) is returned to the reactor pool.

The nozzle assembly module design is comprised of equipment to perform the following functions:

- o Present the nozzle assembly to the fines/debris located in the reactor vessel.
- o Provide the camera for remotely monitoring the vacuuming of the fines/debris.
- o Provide the means for delivering the fines/debris to the filtration systems.
- o Provide the means for manually unclogging the nozzle.



FINES / DEBRIS VACUUM SYSTEM-II

The Nozzle Handling Tool is a stainless steel tubing fabrication to which is attached the nozzle assembly. The Nozzle Handling Tool is suspended from a crane and is manually manipulated within the fines/debris bed. The Nozzle Handling Tool is provided with a pull cable that is manually actuated to unclog the nozzle assembly should clogging occur. Flexible hose and solid piping deliver the vacuumed debris to the knock-out canister.

The nozzle assembly limits the size of the particles entering the system to a maximum of 3/8 inch diameter by 1 inch long. The nozzle assembly incorporates a manually actuated pull cable for unclogging purposes.

The pump assembly module consists of equipment to perform the following functions:

- Induce flow (suction) for transporting the fines/debris to the filtration system

- Divert the flow to the selected filter canister

- Divert the flow to backflush the nozzle/hose assembly if clogging occurs

- Provide a minimum pulsating flow to the filter canisters

- Provide a support for the pump module

- Provide the means for actuation of the four-way and diverter ball valve from the Shielded Work Platform

- Provide manually operated disconnects for the hose/piping connections

The pump is a stainless steel, air operated, variable flow, M-15 type pump manufactured by Wilden Pump and Engineering Company. The pump provides the driving force (suction) for transporting the fines/debris through the vacuum system. The Wilden pump was selected for the vacuum system because of the following features:

- No close-fit sliding or rotating parts
- High pressure capability up to 125 psi
- Infinitely variable capacity and discharge pressure range
- No shaft seals or packing glands to maintain
- Power consumption directly related to pump performance
- Runs dry indefinitely without damage
- No pressure relief or bypass piping required
- Pump discharge may be closed as required and virtually no power consumed.
- No gradual deterioration of performance due to wear
- Instantly variable performance
- No close fit, no precision adjustments
- Simplicity of installation
- Stainless steel construction with Viton Bladders

The filter canister assembly module consists of equipment to perform the following functions:

- o Support the filter canisters
- o Position and orient the filter canisters with respect to the shielded work platform and other interface components within the reactor vessel.
- o Provide a coupling between the outlet hoses of the pump assembly module and the filter canisters.
- o Measure the differential pressure drop (%P) across the filter canister.
- o Measure the flow rate of the vacuum system pump.
- o Provide a means for constantly monitoring the weight of the filter canisters.
- o Provide a means to secure the inlet hose and outlet connection to the filter canister support frame during filter canister change-out.
- o Provide a means to disperse the flow exiting the filter canister(s).
- o Provide shielding to reduce the radiation shine emanating from the filter canisters.

- Provides a means for storing the nozzle assembly and suction hose.

7.2 Debris Air Lift System

7.2.1 Introduction

The Air Lift System (ALS) will provide the means to capture, transport and contain the fuel debris located beneath the LCSA. The debris containers will then be transferred into fuel shipping canisters located in the Canister Positioning System within the reactor.

A simple air lift system consists of a tube/pipe submerged in a tank of water with air injected near the foot of the pipe. The bubbles rise through the pipe and when they are small and dispersed evenly throughout the water in the pipe a two phase mixture that has a specific gravity less than solid water is achieved. Consequently, the liquid/air mixture within the pipe will tend to rise to the surface of the tank and draw solid water through the opening at the foot of the pipe.

The particles to be lifted were assumed to be non-porous 1/2 in. dia. spheres with a drag coefficient of 0.4 and a density of 0.376 lbs./in.^{3}. Using a pipe with a 4 in. ID, the water velocity must exceed 7 ft/sec. Calculations indicated that a min. of 10 ft/sec water velocity can be achieved with an air supply of 98 SCFM at a pressure of 14.3 psi.

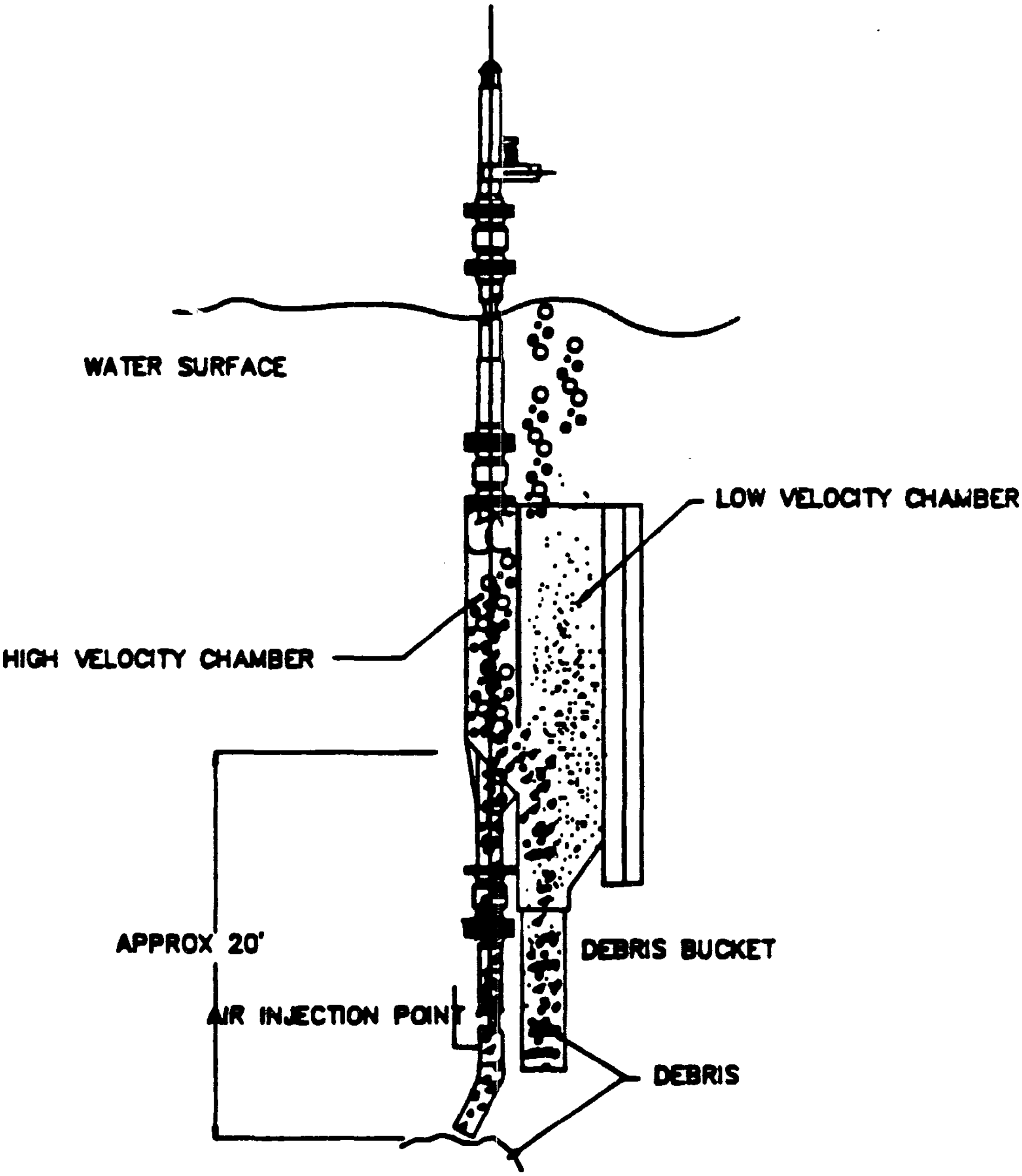
The operation of the Air Lift System Involves submerging a 4 in. ID Lift Pipe completely under water. Air is then supplied to the lower portion of the lift pipe at approximately 100 SCFM and 15 psi. The air lift effect will cause water and debris to be drawn through the foot of the lift pipe. The debris/water/air mixture travels up approximately 20 ft. through the pipe at velocities in excess of 10 ft/sec. The mixture is then released into a separation chamber where the air separates from the mixture and exits at the top of the chamber through vent holes. The debris/water mixture velocity is slowed by a baffle in the separator causing the debris to settle to the bottom. Particles as small as 500 micron will settle out of the water when the velocity within the separator slows to below 0.56 ft/sec. A replaceable canister is located in the bottom of the separator to catch the debris as it settles out. The water will continue around the baffle and exit the separation chamber at the top.

In order to gain access to the lower head of the reactor vessel, several holes will be cut in the LCSA. The access envelope to the lower head of the reactor is controlled by these access holes.

7.2.2 System Description

The overall ALS assembly is 48'-2.13" long (Figure 7-3). It is designed to be broken down into three major sections for installation into the reactor. The first section is the nozzle assembly that is 10'-4.6" long and contains the lower portion and foot piece of the ALS lift pipe. The second section in the debris separator assembly which is 15'-8.8" long and contains the upper portion of the lift pipe and the separation chamber. The last assembly is the hose connection assembly.

The separator assembly is used to separate the air/debris/water mixture from the lift pipe. The separation chamber is an odd shaped sst box that facilitates the operation of adjacent tools and interfaces with the access slot on the reactor top. The design allows easy disassembly of the chamber to allow for decon. The upper portion of the lift pipe is attached to the bottom side of the chamber, and an interface for the stem assembly is located on the top side. Within the chamber is a baffle plate that is used to slow the velocity of the mixture and allow the debris to fall to the bottom of the chamber. There are a series of holes located at the top of the baffle to allow the air to exit when the mixture enters the chamber. A square seal at the bottom of the chamber channels the debris into the fuel canister suspended in the bottom of the chamber.



AIR LIFT

FIGURE 7-3

The chamber is open at the top on the opposite side of the baffle from the lift pipe to allow the effluent water to exit after the debris has settled out.

Seven mostly air filled ballast tubes are attached to the side of the separation chamber. As the ALS is lowered near the LCSA these tubes provide a ballast counterforce to offset the unsymmetrical weight of the separator and allow the ALS to hang nearly vertical. A small amount of water is placed in each tube and by adjusting its depth the buoyant forces imposed by the tube can be adjusted.

The upper and lower connection points are joined to the rest of the ALS by two rotating couplings. A gear has been welded on to the interfacing ends of the two couplings. Two pinion gears and a shaft that is mounted to the chamber connect the two coupling gears. This arrangement allows the debris separator to rotate independently of the upper stem assembly and the lower nozzle and lift pipe portion. Through this connection the stem assembly and the nozzle assembly will rotate relative to each other.

The primary function of the separator stem assembly is to provide a means to handle and operate the ALS. The stem made of 4.5 OD drill rod extends from the top of the debris separator to above the rotating work platform. A lifting ring is attached to the top of the stem for manipulation by the crane. A rotating coupling has been placed near the top of the stem to provide independent rotation of the debris bucket hanger arrangement. The stem has been marked with elevation marks that allow the operator to determine the elevation of the nozzle within the reactor. The stem also provides a means to determine the articulating plane of the Nozzle.

Housed within the stem is the lower section of the clean out tool. This section is made of 1.125" drill rod and is pinned within the top portion of the stem. Extension pieces are added to the clean out tool by removing the lifting bail on the stem and joining additional pieces of drill rod. The stem portion of the ALS is clamped stationary relative to the work platform while the crane is used to lower the clean out string down through the separation chamber and lift pipe. A "trap door" is located in the separator to block flow into the stem from the lift pipe. This door is opened by the clean out string to gain access to the lift pipe.

The bucket hanger, located at the top of the stem, is used to hold the bucket hanger tool which suspends the debris bucket in the bottom of the separator assembly. A load cell has been placed on the Hanger to weigh the debris as it settles into the debris bucket.

When the debris bucket is full, the hanger tool assembly is used to remove the debris bucket from the debris separator and transfer it to the debris canister located in the canister positioning system. The hanger tool is constructed with two concentric tubings. Two scissor-like arms are located at the bottom of the inner tubing. The outer tubing holds these arms in position for attachment to the debris bucket. When the outer tubing is pulled up, the arms are allowed to collapse and free the debris bucket.

The hose connection assembly serves as a lift pipe spool piece connecting the nozzle assembly and the debris separator assembly. In addition the spool piece is a connection point for the air, hydraulic, and instrumentation lines that control the nozzle assembly. The control lines run from the connection piece to the top of the work platform. These lines are maintained in a draped fashion within the reactor to allow manipulation of the ALS. At the work platform level the lines are tied off to the hand railings to become stationary. The bunch of lines are connected to the junction box located on the work platform. The J-box is also connected to the local service panel and to the air lift control console.

.3 Cavijet Manipulation Tool

The design of the cavijet manipulation tool consists of two separate tools, (1) a 90° nozzle assembly and (2) a dual nozzle assembly consisting of an offset straight nozzle and a 15° nozzle. Both assemblies incorporate many similar parts and features. The main body is a rigid tube assembly with two joints. The number and location of these joints is based on available material lengths, and to facilitate transporting the equipment through the TMI-2 airlock and assembly in the TMI-2 containment (see Figure 7-4.)

The tools are designed to be used in conjunction with the X-Y positioning table and associated clamp assembly. These factors were used in determining lengths for individual components as well as overall lengths. A rotating bearing sleeve is located in the area of the X-Y positioner clamp that allows the tool to be clamped into a fixed position and rotated 360°. The length of this sleeve allows the nozzle to be positioned through a range, accessing the lower elliptical flow distributor to the bottom of the vessel, then clamped in place and rotated.

A bullet nosed assembly protects the nozzle while guiding the tool in and out of access holes and acts as a support member against the walls of the hole.

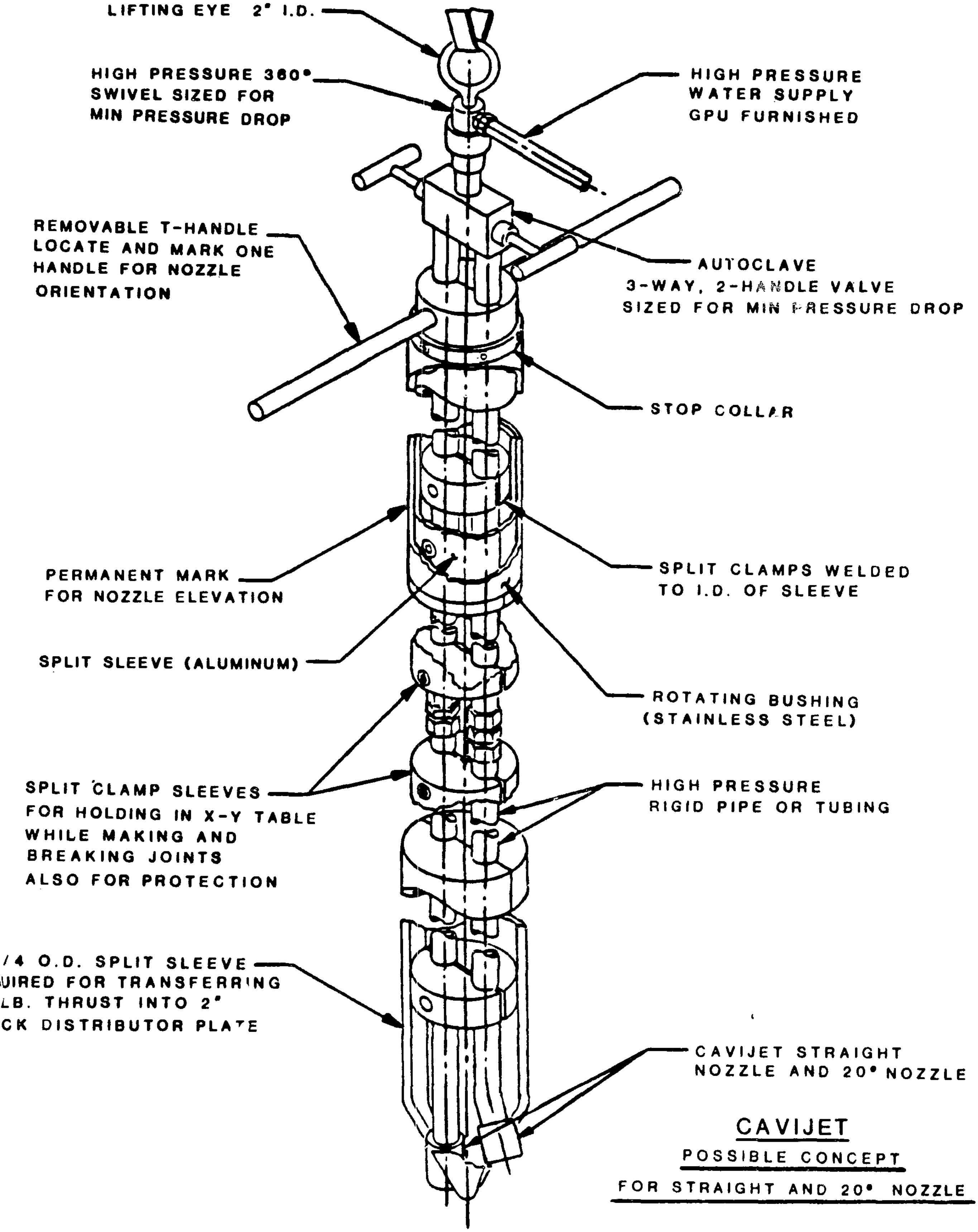

LIFTING EYE 2" I.D.
HIGH PRESSURE 360° SWIVEL SIZED FOR MIN PRESSURE DROP
HIGH PRESSURE WATER SUPPLY GPU FURNISHED
REMOVABLE T-HANDLE LOCATE AND MARK ONE HANDLE FOR NOZZLE ORIENTATION
AUTOCLAVE 3-WAY, 2-HANDLE VALVE SIZED FOR MIN PRESSURE DROP
STOP COLLAR
PERMANENT MARK FOR NOZZLE ELEVATION
SPLIT CLAMPS WELDED TO I.D. OF SLEEVE
SPLIT SLEEVE (ALUMINUM)
ROTATING BUSHING (STAINLESS STEEL)
SPLIT CLAMP SLEEVES FOR HOLDING IN X-Y TABLE WHILE MAKING AND BREAKING JOINTS ALSO FOR PROTECTION
HIGH PRESSURE RIGID PIPE OR TUBING
/4 O.D. SPLIT SLEEVE
UIRED FOR TRANSFERRING
LB. THRUST INTO 2"
CK DISTRIBUTOR PLATE
CAVIJET STRAIGHT NOZZLE AND 20° NOZZLE
CAVIJET
POSSIBLE CONCEPT
FOR STRAIGHT AND 20° NOZZLE

FIGURE 7-4

The tool connects to the high pressure hose from the power unit using a quick connect coupling attached to a swivel near the top of the assembly allowing the tool to rotate while the hose from the power unit remains stationary. A bearing assembly with lifting device, located at the top of the rigid body, allows the body to rotate while being supported by the crane.

The cavijet system supplied to GPUN by Tracor Hydronautics was sized for 175 feet of high pressure hose length. This tooling design uses the same sizes assuming its length to be a part of the 175 feet. Because it uses the same sizes as the original equipment, the design does not include flow or pressure drop calculations.

Both the straight configuration and the 15° utilize the same type cavijet, 10,000 psi nozzle. The 90° configuration uses a similar cavijet, 10,000 psi nozzle modified for the 90° application. All nozzles are made by Tracor Hydronautics.

The manipulator tool is designed to be supported from a crane, or clamped in position, with the ability to be rotated manually 360°. A bar is inserted into its sleeve, pinned in place, and used to rotate the nozzle. All manipulation is done manually by the operator using the crane, clamp, and rotating handles. The only other control is the 3-way valve on the dual nozzle manipulator tool which is used to select the desired nozzle. The system cannot operate both nozzles simultaneously.

The tool is not designed to be assembled and disassembled repeatedly in containment. It should be assembled prior to entry and then broken down into 2 pieces for entry and assembly in containment. When not in use the alternate tool is stored in the vessel in its assembled condition.

The bullet shaped nose is split in half for ease of nozzle installation and as a means of securing the nozzle assembly. The body sleeve is then slid over the high pressure lines and bolted to the assembled nose piece. Baffle plates in the body keep the high pressure lines in position to reduce the possibility of damage during assembly and operation. The couplings joining the high pressure line along its length are made up after the tubes have been installed in the body. The body sleeve is slid back to allow the connection to be made then slid into place and bolted to the mating body sleeve. Holes located at the top of a body sleeve are for shackles used in lifting assembly. The two lower portions are assembled prior to entry. Assembly in containment is performed by lowering the bottom section through the clamp on the X-Y positioner and clamping as low as possible on the built up area located just below the unmade joint. The upper section is positioned over the unmade joint, aligned, and the high pressure line made up. The body sleeve held by the crane is then lowered over the joint and bolted in place.

The tool is then attached to the power unit flexible high pressure line by quick connect at the top of the tool. This step may have to be performed prior to installation of the upper section of the body if there is no access to the coupling due to its height.

0 MANFRED SYSTEM DESCRIPTION

The MANFRED (MANipulators For REactor Defueling) System is a remotely-operated manipulator system designed specifically to assist in the reactor defueling operations in the TMI-2 nuclear reactor. In particular, the MANFRED System provides the capability to operate remotely a variety of custom-designed work tools which are used to gain access to areas within and below the lower core support assembly.

The major components of the MANFRED System are:

- A pair of manipulators -- the work manipulator and the grabber manipulator -- mounted on the manipulator mounting post;
- A primary control console outside the containment building (called the "Control Room Console"), and two master controllers (a "Work Master Controller" and a "Grabber Master Controller");
- A secondary control console on the work platform inside the containment building (called the work platform console), and two master controllers (a "Work Master Controller" and a "Grabber Master Controller");
- The valve rack located on the work platform;
- The Hydraulic Power Unit (HPU) on the work platform;

) The pan-and-tilt arrangement consisting of a stereo camera pair, a color video camera, two lights and a pan-and-tilt unit deployed on a light-duty pole;

) A set of tools, each of which can be held in the jaws of the work manipulator.

].1 Manipulator Support Structure

The manipulator support structure consists of the manipulator mounting post, junction cans and various fasteners.

The manipulator mounting post is fastened to the bottom of GPUN's Manual Tool Positioner (MTP) to deploy the two manipulators in the reactor vessel. The mounting post is a pipe section, a top plate, a base plates subassembly, and an upper plates subassembly welded together. The top plate is used to fasten the mounting post to the MTP. The base and upper plates subassemblies are the mounting points for the vertical column subassembly of the work manipulator. The grabber manipulator is suspended from the base plate of the manipulator mounting post. The manipulator mounting post is made entirely of 316 stainless steel. Two junction cans, two servo valve packs, and two sets of check valves are mounted on the post in addition to the two manipulators. The two junction cans -- one for the feedback wiring of each manipulator -- are considered part of the manipulator support structure, but the wires connecting the manipulator joint feedback sensors to the cans and the wiring terminals the cans contain are considered electrical components of the manipulators.

2 Gas Compensation Subsystem

The gas compensation subsystem consists of several gas circuit items and hoses. The gas supply delivers Nitrogen gas at a pressure of 15 to 20 psi to a fitting manifold on the back of the valve rack. The gas is used to compensate the feedback sensor housings, the feedback cables, the junction cans, and the servo pack housings and cables.

3 Hydraulic Subsystem

The hydraulic subsystem consists of the Hydraulic Power Unit (HPU), the valve rack (including the rate packs, tool manifold and pressure reducing valves), two servo packs, two sets of check valves, and the tubing, hoses and fittings associated with these components.

The HPU, located in the containment building near the work platform, provides hydraulic fluid at an operating pressure of 2200 to 2500 psi.

The valve rack, located on the work platform, consists of a frame on which two rate packs, several pressure reducing valves, the tool manifold, and the associated tubing and fittings are mounted. The main rate pack and the auxiliary rate pack are identical; each contains eight solenoid valves with flow controls. The pressure reducing valves on the valve rack limit the hydraulic pressure to 2500, 1500, and 800 psi for the servo packs, the main rate pack, and the auxiliary rate pack respectively. The tool manifold is pilot-operated from the auxiliary rate pack.

The two servo valve packs mounted on the manipulator mounting post are called the work servo pack and the grabber servo pack as they provide hydraulic power separately to the actuators in the two manipulators. The work servo pack contains six servo valves, the grabber servo pack contains three servo valves, and each servo pack also contains a poppet valve which is used to lock the manipulator in position.

4 Electric Power Subsystem

The electric power subsystem consists of two power distribution units, the valve electrical distribution box, and electric power cables.

The power distribution units, which are mounted on the sides of the work platform console, are Siemens motor control units with additional electric power items installed. The PDU's receive 480 VAC, 3-phase, 60 Hz power which is distributed to the two electric motors (3-phase) in the HPU and the step-down transformer (single-phase) in PDU #1. The transformer provides 120 VAC power for the PDU contactors, multiple voltages for the video lights (40, 65 and 90 VAC), and 24 VAC for the servo valves and rate valves.

The valve electrical distribution box is mounted on the back of valve rack. It is the junction box for the cables from the work platform console, the wires to the rate packs on the valve rack, the wires to the servo packs and junction cans on the manipulator mounting post, and the cables to the pan-and-tilt arrangement.

5 Control and Telemetry Subsystem

The control and telemetry subsystem consists of the control consoles, most importantly the telemetry electronics units in each console, and the signal cables in the MANFRED System. A significant feature of this subsystem is the graphics computer software.

8.5.1 Control Consoles

The consoles are wired so that only one can be in control of the system during operation, but both must agree on which console is in control. If the "MASTER" control keys on the two consoles are not in agreement, or if both are turned to the "DISABLE" position, the system is disabled.

8.5.2 Telemetry Electronics Unit

The telemetry electronics units are supplied by RMS Industrial Controls of Coquitlam, B.C. The telemetry electronics include a microprocessor in each console connected by a half-duplex, pulse-code modulated data link. The input/output circuitry is RS232 compatible for flexibility in interfacing to peripheral equipment.

The telemetry electronics units consist primarily of Siemens SMP electronic components, i.e., electronics boards, power supplies and card cages. RMS components, including special-purpose electronic boards, termination boards and racks, and flexible connectors are integrated with the SMP components.

Both telemetry units -- one in the telemetry tray of the control room console, the other in the telemetry tray of the work platform console -- contain the same CPU board which has an Intel 80188 microprocessor.

The SMP boards are the standard Eurocard type (160 mm x 100 mm). They are mounted in a SMP card cage which holds a number of SMP and RMS boards. The boards are interconnected by a SMP bus unit attached to the card cage. The SMP board system has an addressing capability of 1 Megabyte and executes application software on Kadak's AMX Operating System.

A specially-designed RMS board integrated with the telemetry electronics allows a video overlay of graphics to be superimposed over one of the camera video signals. Text may also be added on the video overlay. The IBM graphics computer and keyboard in the control room console allows an operator to select programmed RMS and ISE software features to set up and monitor the operation of the system. All analog signals have software scale and bias values which can be set or altered using the keyboard.

Serial data is transmitted between the consoles in a half-duplex mode, i.e., not simultaneously in both directions. The data transmission rate is 125,000 bits per second, and the update rate is 25 times per second.

8.5.3 Manipulator Control Method

Using the "Normal" manipulator control method, a master controller at the console in control is used to operate the corresponding manipulator directly. The position signals which are used to provide spatially-correspondent (SC) control are "setpoint" signals, "feedback" signals, and "servo output" signals.

"Setpoint" signals from the joint position sensors on the master controller are transmitted through an electrical cable to the telemetry tray of the console in control. These signals are compared in software to the "feedback" signals from the joint position sensors on the corresponding manipulator, and a "servo output" signal is generated for each servo valve from the "error" between the "setpoint" signal and the "feedback" signal from corresponding joints. The "servo output" signals from the control console to the servo valves adjust them causing the corresponding manipulator joints to move.

In addition to the "Normal" control method described above, the work manipulator can also be operated in a "Teach" sequence, during which the setpoint positions are sampled frequently and stored in memory in the graphics computer, and in a "Playback" sequence, during which the stored setpoint positions are used to repeat the "Teach" sequence automatically with the work manipulator.

.6 Video Subsystem

The video subsystem consists of one color and three black-and-white video cameras (Camera #1 is color, Cameras #2 and #3 are black-and-white for the stereo system), a stereo cameras assembly, a pan-and-tilt unit, and three lights.

The Rees R600 color camera is mounted with a light on each side in a bracket fastened to the stereo cameras assembly, which is in turn mounted on the pan-and-tilt unit. The R600 camera is controlled from the Rees color camera control unit incorporated in the work platform console. The stereo cameras assembly mounted on the pan-and-tilt unit is part of the Stereographics 3VISION Stereoscopic Video Camera System incorporated in the MANFRED System. The twin cameras used are Rees R93 black-and-white cameras. 115 VAC power is supplied from the work platform console for the cameras. The cameras are controlled through Stereographics and Rees control units incorporated in the work platform console.

.7 Manipulator Subsystem

The manipulator subsystem consists of the master controllers for the work and grabber manipulators as well as two "slave" manipulators.

Both the work manipulator and the grabber manipulator are the spatially-correspondent (SC) type. The work manipulator is operated using a 6 SC master controller (one at each console location) and the grabber manipulator is operated using a 3 SC master controller (one at each console location).

The power to and "setpoint" position signals from the master joint pots of each master controller are transmitted through individual wires to/from each pot. The wires running to each pot are sheathed, and collectively form a cable which terminates at the telemetry tray of the console associated with the master controller.

The master controller for the work manipulator has six SC functions -- Swing, Shoulder, Elbow, Wrist Roll, Wrist Pitch and Wrist Yaw -- one rate function -- Jaws Latch/Unlatch -- and a manipulator Lock/Unlock function. The master controller for the grabber manipulator has three SC functions -- Swing, Shoulder, and Wrist -- one rate function -- Jaws Open/Close -- and a manipulator Lock/Unlock function. Two pairs of master controllers, each pair consisting of a work master controller (6 SC) and a grabber master controller (3 SC), are included in the system. One pair of master controllers is located beside the control room console and the other pair is located near the work platform console.

LONG HANDLED TOOLS

Various hand operated speciality tools are required to assist in the defueling operation of the LCSA. Chief of these is the pan-and-tilt camera on the long pole. In order to better ascertain the condition of the area to be worked on (cut, moved, lifted, etc.), a camera is needed to view the work area clearly. Substantial debris in the form of partial length fuel rods, resolidified core debris and small pieces cut from the LCSA frequently obstruct access. Pick and place operations using long handled grippers had been preferred previously and is expected to prove to be similarly successful in TMI-2.

In addition, a variety of impact hammers and chisels can be made available, positioned by long handled tools. It is worthy of note, however, that tooling is not available to access horizontally between the various plates of the LCSA. Access to LCSA rubble must, in general, come from the above. Consequently, the extended effort to remove as much of the LCSA as practical.

The following is a brief description of the light weight tools used in conjunction with LCSA disassembly and defueling:

The light weight tools will be mounted on aluminum conduit coupled together in sections. These tools can be manually operated with or without using the crane and have been found to be very useful in unstructured underwater operations.

Vise Grips - Several configurations and types of remotely operated vise grips will be used for various operations. All use a double-acting cylinder. Vertically and horizontally oriented vise grips with standard, needle nose, and tube gripper ends are provided for defueling operations (Figure 9-1).

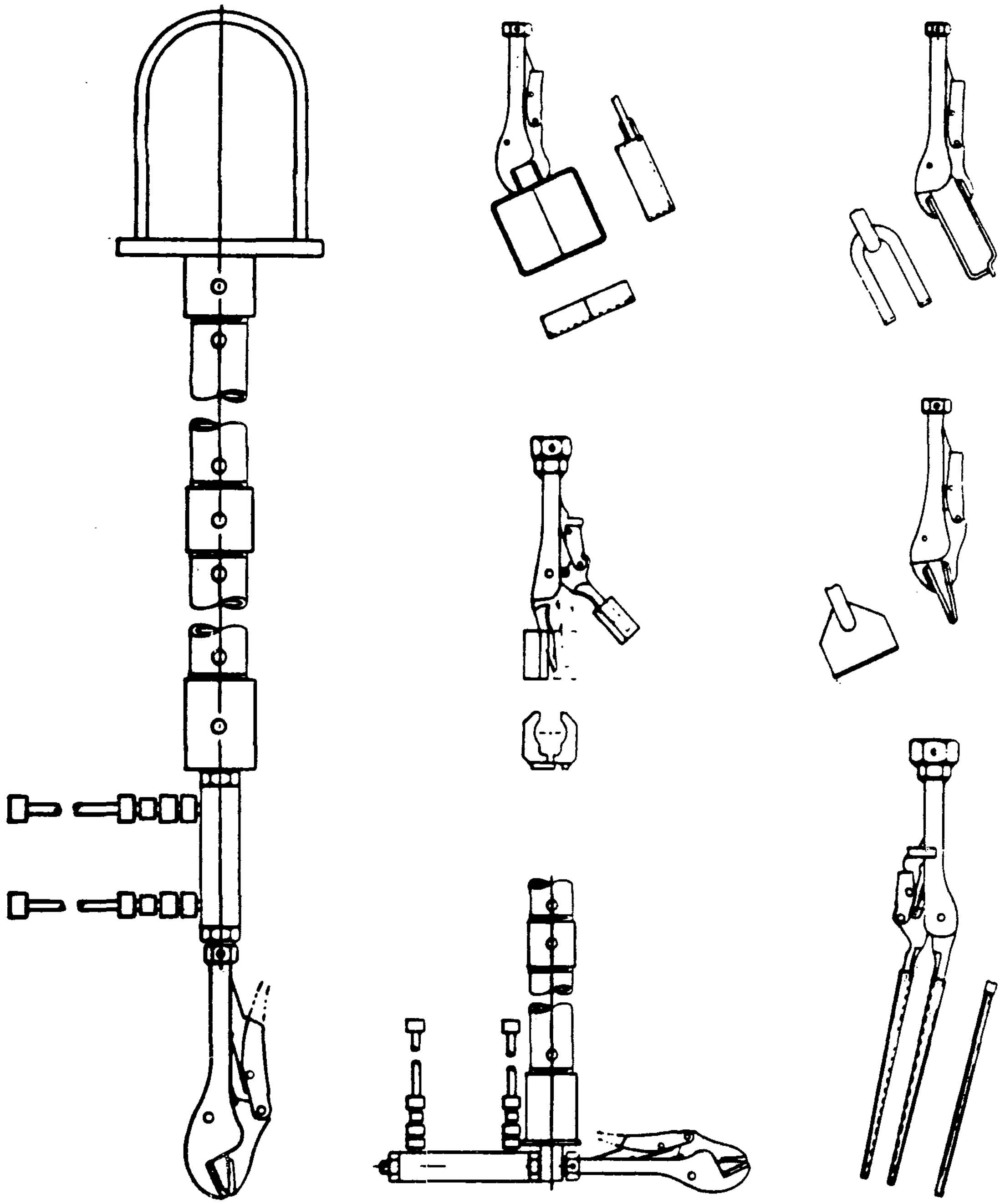
Bolt Cutters - The bolt cutters will be used for various light duty cutting operations. Interchangeable cutting heads are available. These tools will be capable of cutting horizontally and vertically. The cutting force is expected to be in the 1500-lb to 1800-lb range (Figure 9-2).

Hook Tools - Various size hook tools will be used to lift and remove debris, hoses, and cables. Capacity is 50 lb (Figure 9-3).

Socket Wrench - The socket wrench is a long-handled tool used to connect and disconnect end effectors and end effector handling tool pole sections (Figure 9-4).

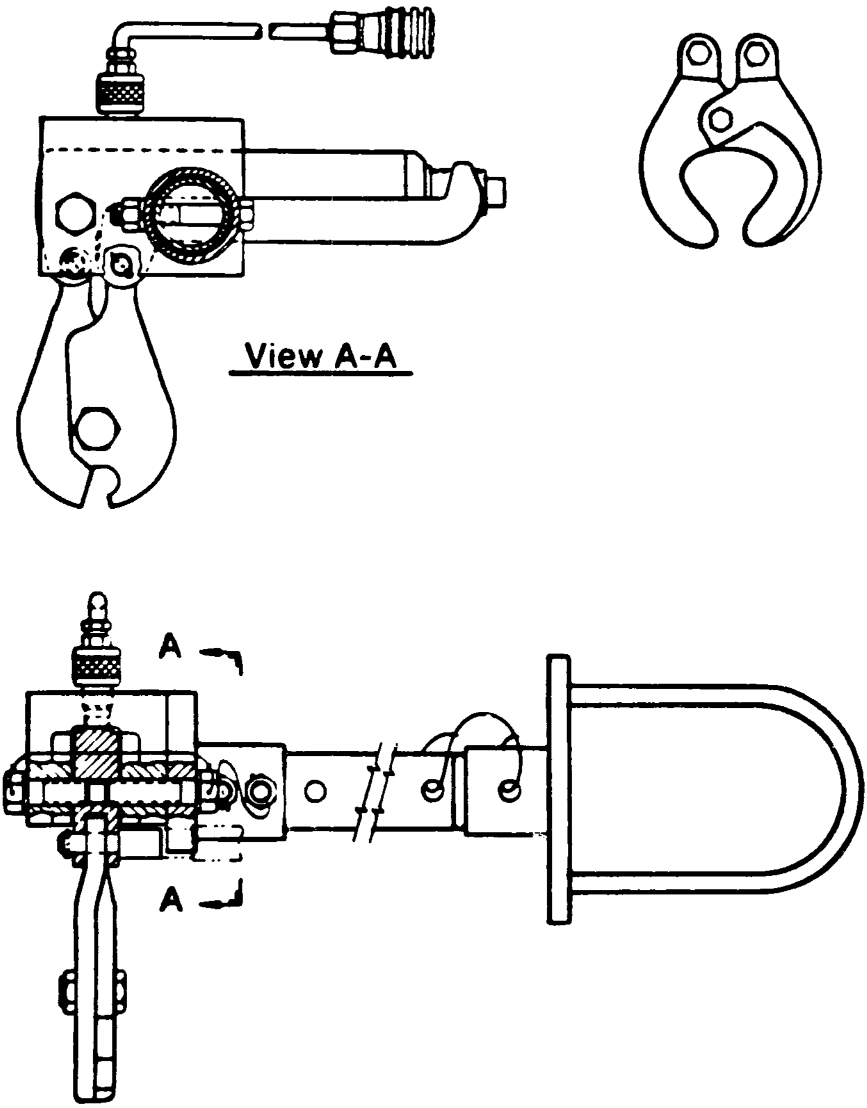
Measuring Probe - The measuring probe will be used to determine the overall length of partial fuel assemblies prior to cutting operations. The probe consists of a 15-ft scale that is stamped to an aluminum pole section.

Light Duty Tong Tool - The light duty tong tool will be used to reposition and deposit debris up to 100 lbs into debris buckets (Figure 9-5).



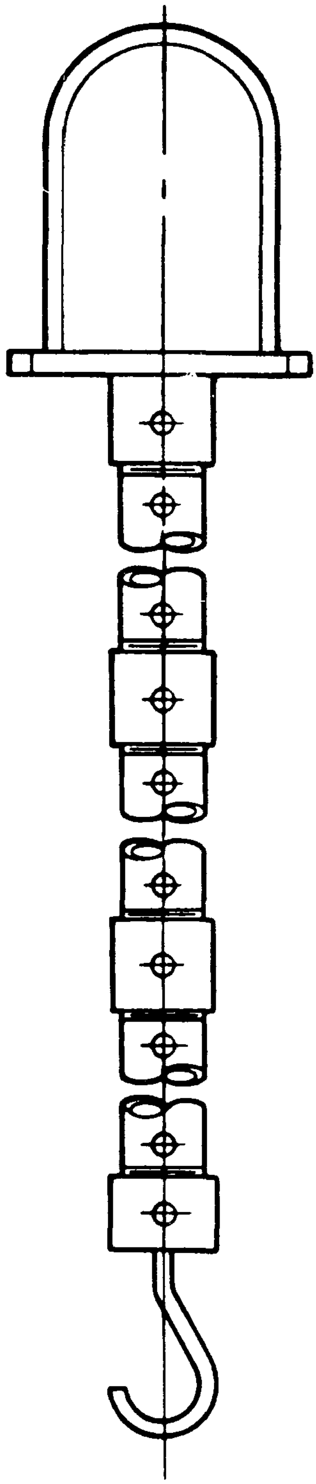
VISE GRIPS

FIGURE 9-1



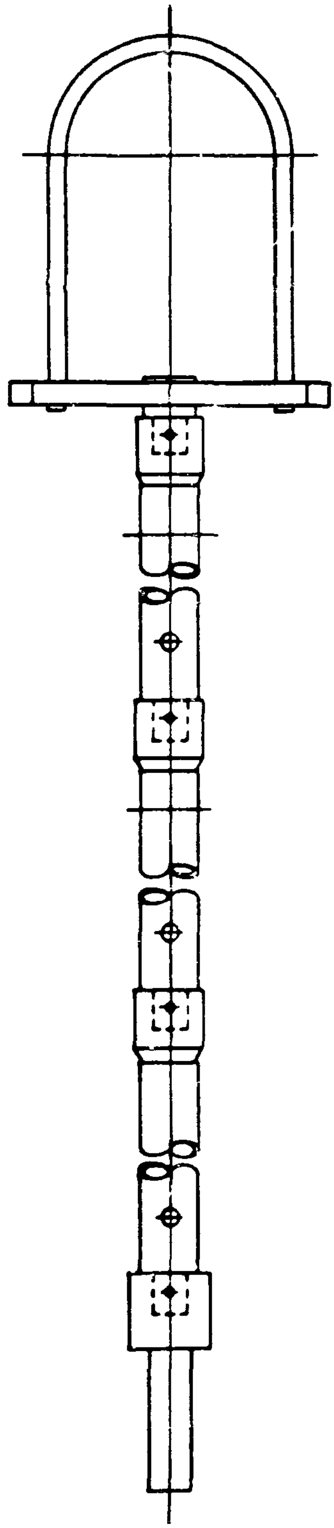
BOLT CUTTERS

FIGURE 9-2



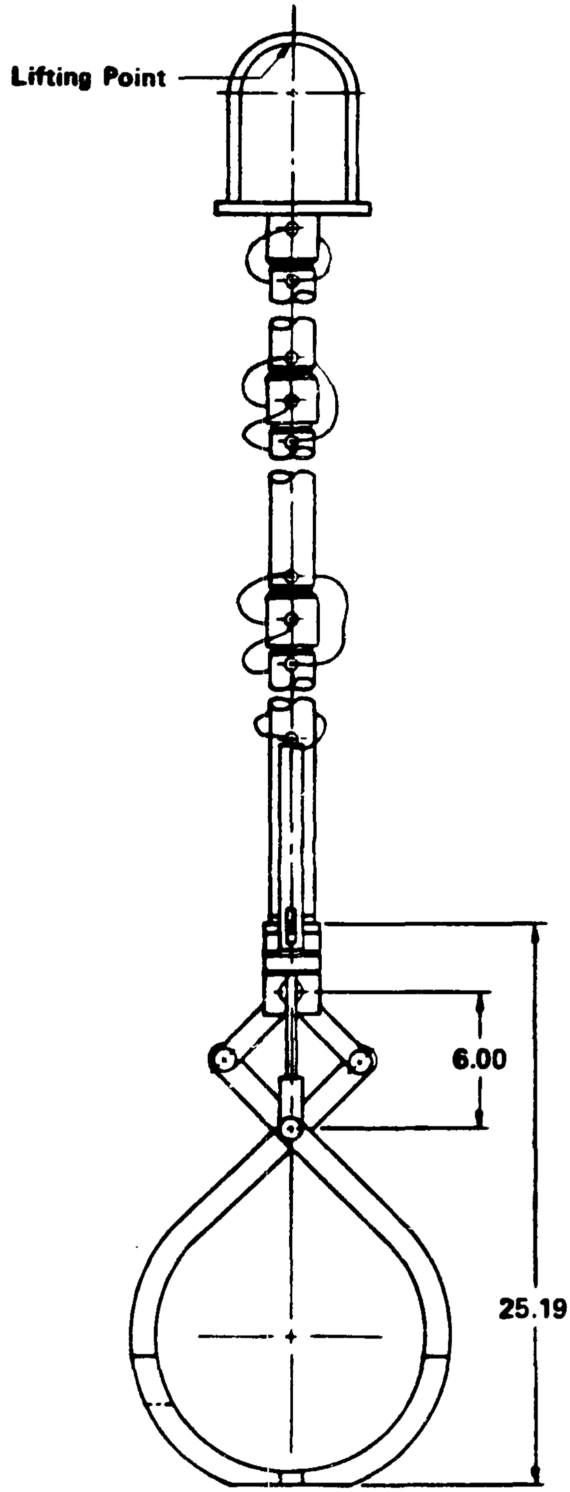
HOOK TOOLS

FIGURE 9-3



SOCKET WRENCH

FIGURE 9-4



LIGHT DUTY TONG TOOL

FIGURE 9-5

Work Platform Debris Bucket Hanger - The work platform debris bucket hanger will be provided for temporary storage of the top loading or side loading debris buckets while the buckets are being filled during early defueling operations when easy access is available. This device will provide the capability of positioning the debris bucket at various elevations ranging from 18 ft to 30 ft below the shielded work platform deck. In addition, the double pivot design of the hanger will allow for positioning a debris bucket adjacent to ongoing defueling activities in virtually any area in the core support assembly below the two shielded work platform tool slots.

When not in use, the debris bucket may be pivoted away from the tool slots and under the work deck for storage. The debris bucket hanger also provides a means of transferring debris between the two tool slots in the shielded work platform. The debris bucket hanger consists of a support post, vertical extension support tubes (central pivot), a radial arm, an outer pivot, and a debris bucket tray.

0 SUMMARY

The design and manufacture of the hardware described in this report represents, in many instances, the product of a multi-prong approach to lower reactor vesse head defueling. The chief reasons for this were:

a. The extent of damage to the lower internals and lower reactor vessel head is and remains spectulative.

b. The corium configuration and the friability of same in the internals and lower head is not known.

c. The fuel rods which fell into the lower internals and lower head greatly complicated the defueling effort because vacuuming was no longer a viable method for their removal.

d. Knowledge relative to the material in the lower internals came late in th planning program because much of the fuel above the LCSA had to be remove first.

However, when it came time to actually cut the LCSA, the program resolved itsel into using both the Core Bore Machine and the plasma torch. As previously stated, the Core Bore Machine would cut all circular cuts, and the Plasma Torch would make straight horizontal or vertical cuts.

.0 SUMMARY

The design and manufacture of the hardware described in this report represents, in many instances, the product of a multi-prong approach to lower reactor vessel head defueling. The chief reasons for this were:

a. The extent of damage to the lower internals and lower reactor vessel head is and remains spectulative.

b. The corium configuration and the friability of same in the internals and lower head is not known.

c. The fuel rods which fell into the lower internals and lower head greatly complicated the defueling effort because vacuuming was no longer a viable method for their removal.

d. Knowledge relative to the material in the lower internals came late in the planning program because much of the fuel above the LCSA had to be removed first.

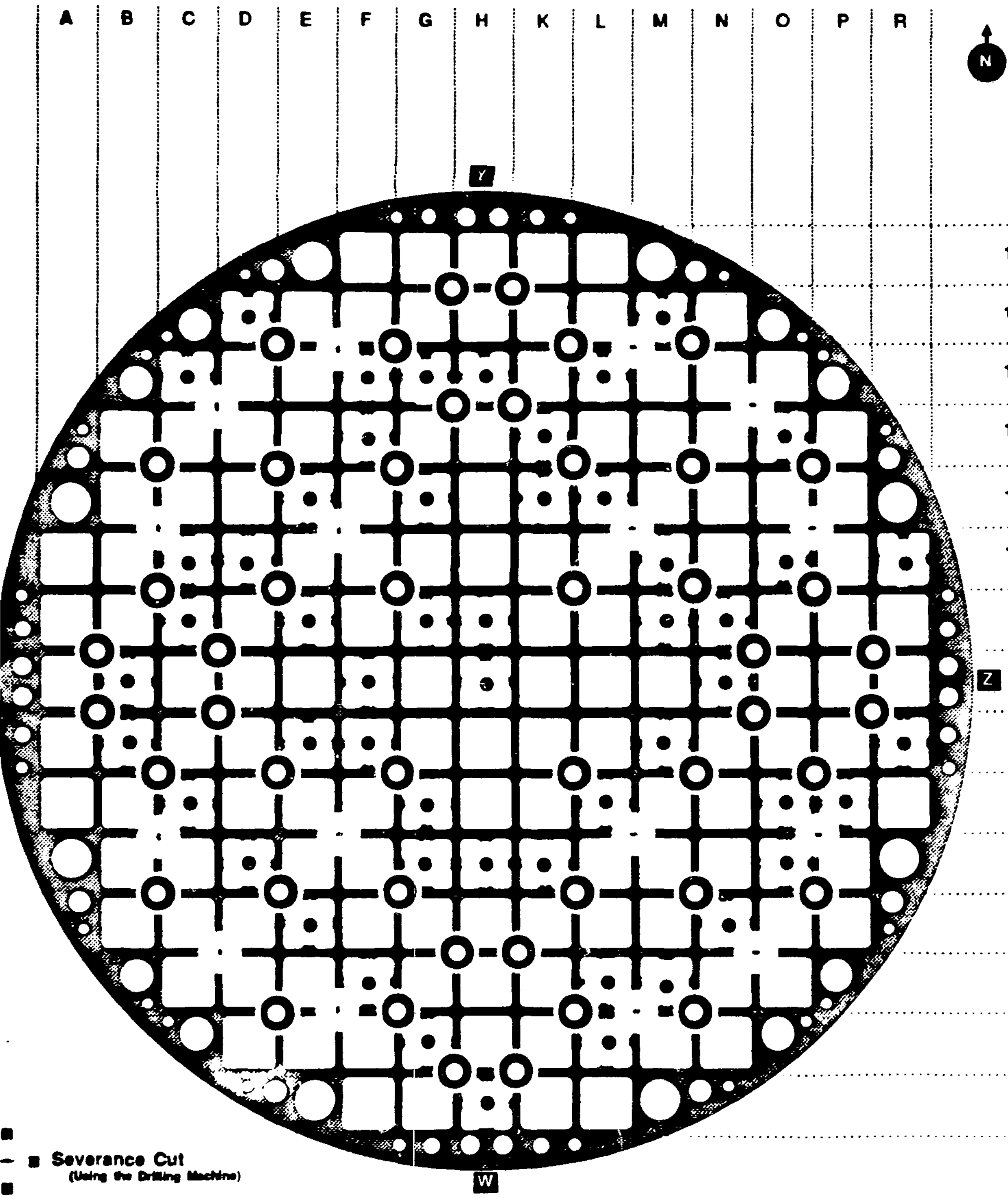
However, when it came time to actually cut the LCSA, the program resolved itself into using both the Core Bore Machine and the plasma torch. As previously stated, the Core Bore Machine would cut all circular cuts, and the Plasma Torch would make straight horizontal or vertical cuts.

Each of the fifty-two incore spiders has been drilled out to free the lower grid rib section from the incore guide tubes. In addition, the forty-eight support posts have been separated from the lower grid rib section and the lower grid distributor plate by drilling out the ribs and plate surrounding the posts. Finally, drilling of sixteen locations to completely sever the lower grid rib section pieces has been completed. The resulting thirteen pieces of lower grid rib section were removed from the vessel for storage (see Figure 10-1).

At fourteen of the fifteen non-gusseted incore locations, the drilling was extended through the lower grid distributor plate. At twelve of these locations, the drilling was further extended through the incore guide support plate, and two support posts were partially drilled through the forging.

In general, the complete severance of the support posts from the forging did not occur. The prime reason appears to be that it was not possible to defuel the volume at and below the forging before drilling began. Consequently, there was no open space below the drill into which the cut chips could fall. Therefore, the drill chocked in its own cuttings, cutting rate decreased to zero, and the cutting teeth broke. The use of the Core Bore Machine was, therefore, stopped after the cuts mentioned above were made.

The grid rib sections were then successfully removed and stored in the core flood tank. The top of the flow distributor was then cleaned.



Severance Cut
(Using the Drilling Machine)

Drilled Support Posts

Incore Instrument Guide Tube
(Spiders Drilled Out)

STATUS AS OF 4/11/88

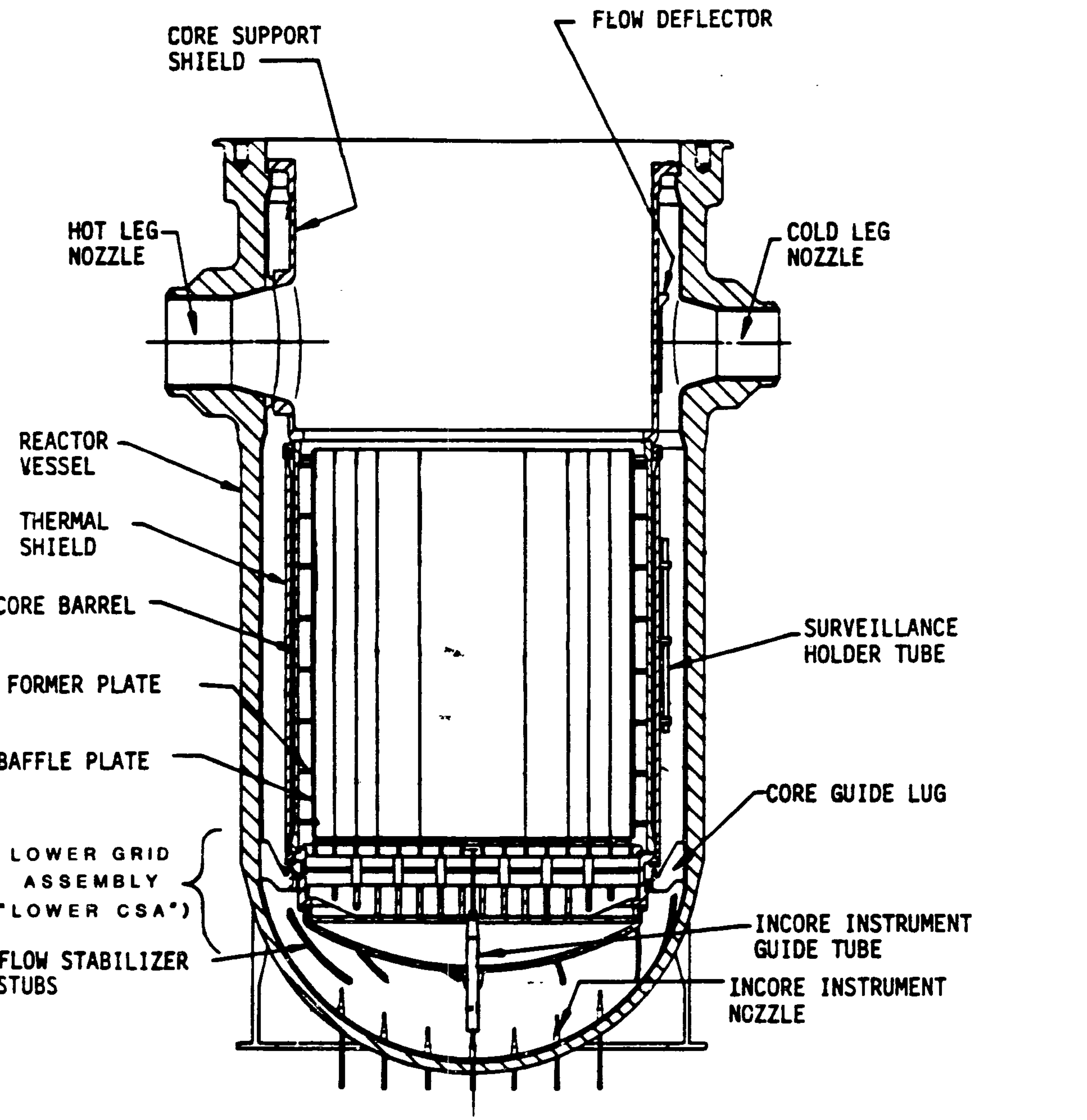
LOWER GRID RIB SECTION

FIGURE 10-1

In its first eight weeks of operations, which included installation, refining safety procedures, and several maintenance tasks, ACES made over 70 cuts through 1-inch-thick, 7-1/4-inch-long grid rib sections to the periphery of the top plate of the LCSA, and then over 80 cuts to section the 1-inch-thick distributor plate into four large pieces, which were removed from the vessel.

Torch replacement has been required frequently due to burnout (average torch life is about 10 cuts), arc starting problems, and mechanical damage in low visibility/restricted access areas. A common failure is loss of electrical conductivity caused by heavily borated vessel water leaking into the torch head. When failure occurs, the entire torch assembly is raised from the vessel and reconstructed on the shielded work platform. Torch burnouts and other problems (e.g., electronics failures, a seal failure on a servo-motor housing, a transformer failure, feedback circuitry difficulties, and [position] limit switch failures) have made ACES a frequent, but not excessive, maintenance system. With the on-going efforts to improve performance, it is anticipated the maintenance requirements will be reduced as experience with the system increases.

After completion of LCSA and lower head defueling, the ACES manipulator arm will be remounted on a manual tool positioner (MTP) and Thompson rail assembly. This deployment scheme, which continues to provide 5-axis torch manipulation and will allow ACES to dismantle the core baffle plates.



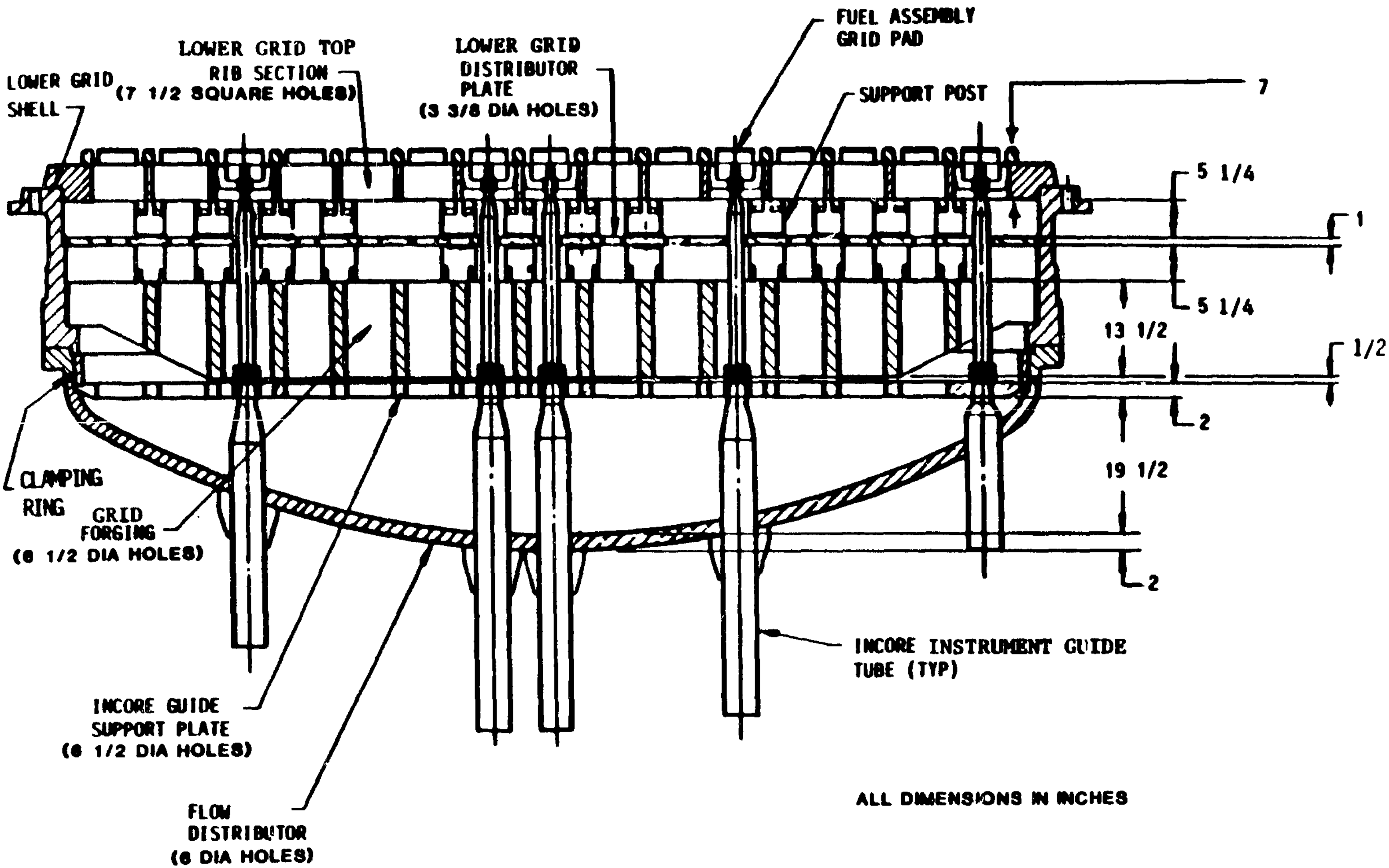
NOT SHOWN:

— VENT VALVES IN CORE SUPPORT SHIELD

— LOCA RESTRAINTS AT HOT LEG NOZZLE ON CORE SUPPORT SHIELD

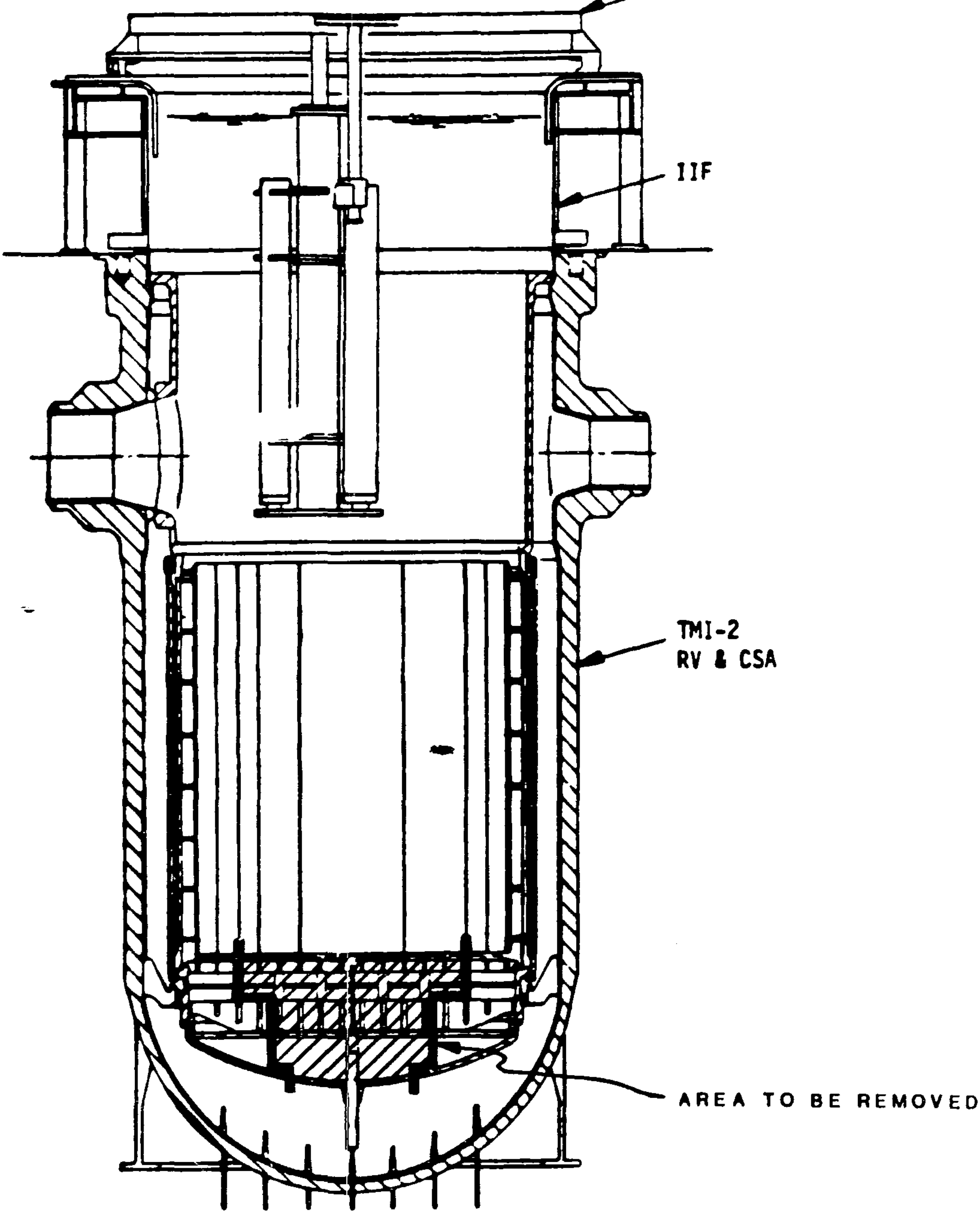
CORE SUPPORT ASSEMBLY IN REACTOR VESSEL

FIGURE 2-1



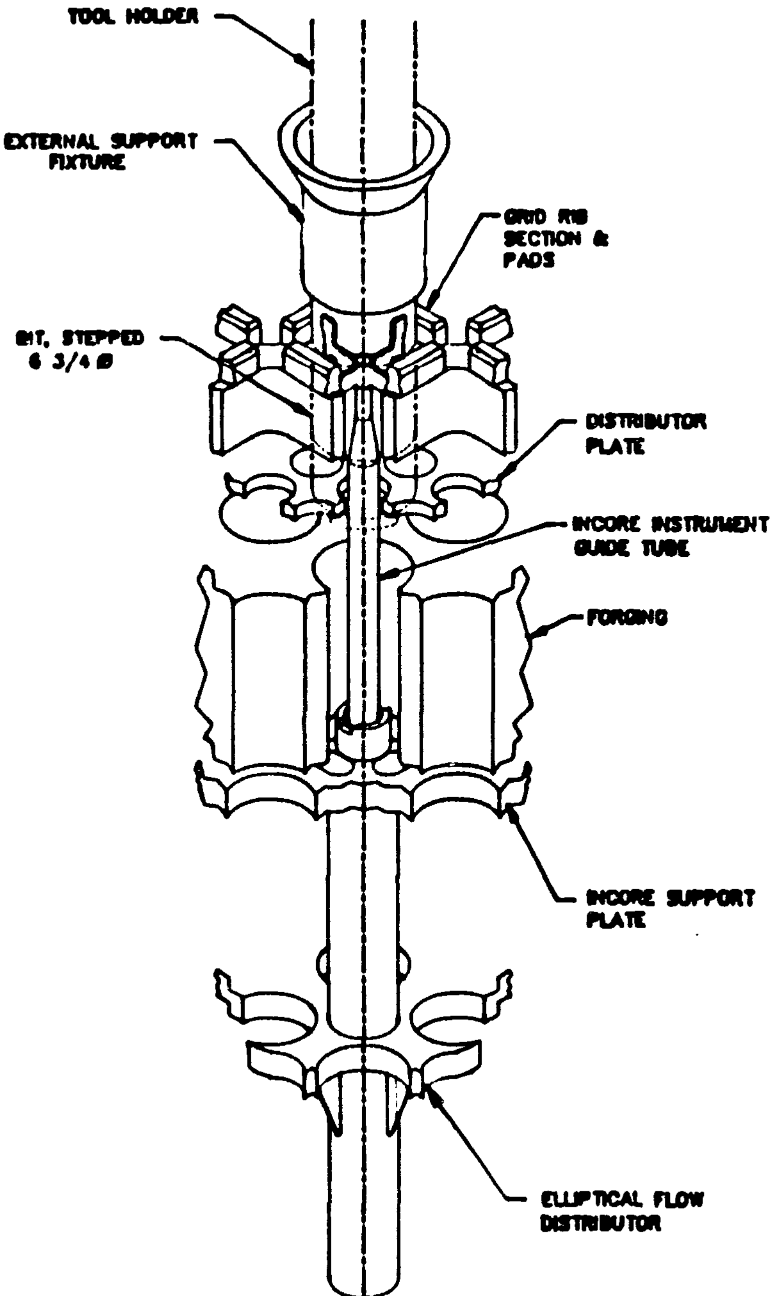
CROSS SECTION OF LOWER GRID ASSEMBLY
("LOWER CSA")

FIGURE 2-2



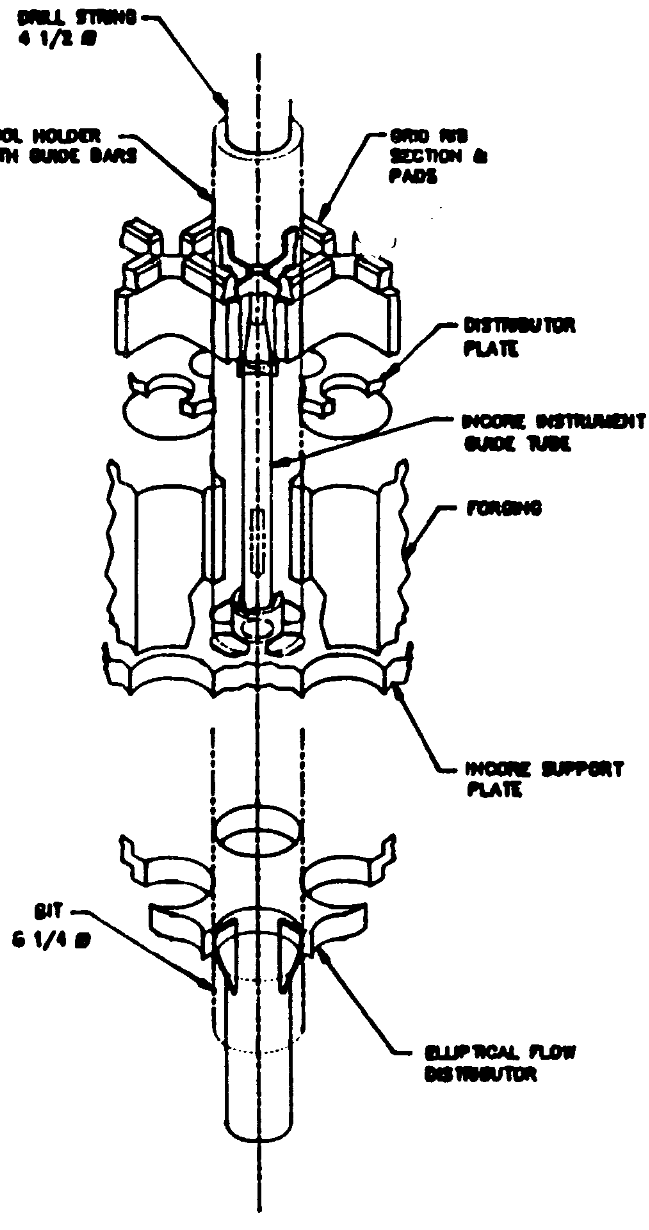
LOWER CSA DISMANTLEMENT

FIGURE 2-3



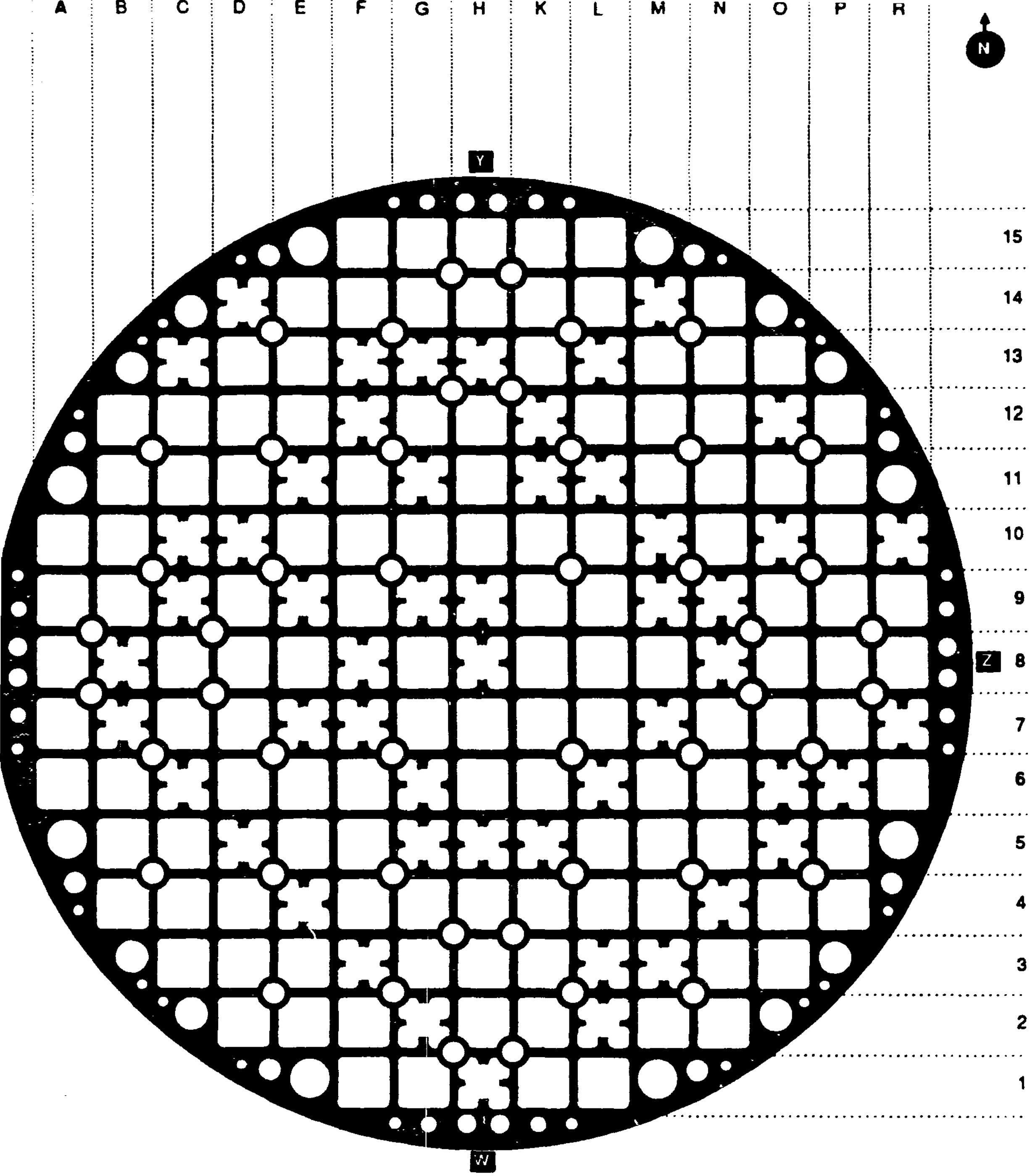
INSTRUMENT GUIDE TUBE CUT

FIGURE 3-1



INSTRUMENT GUIDE TUBE CUT THROUGH
ELLIPTICAL FLOW DISTRIBUTOR

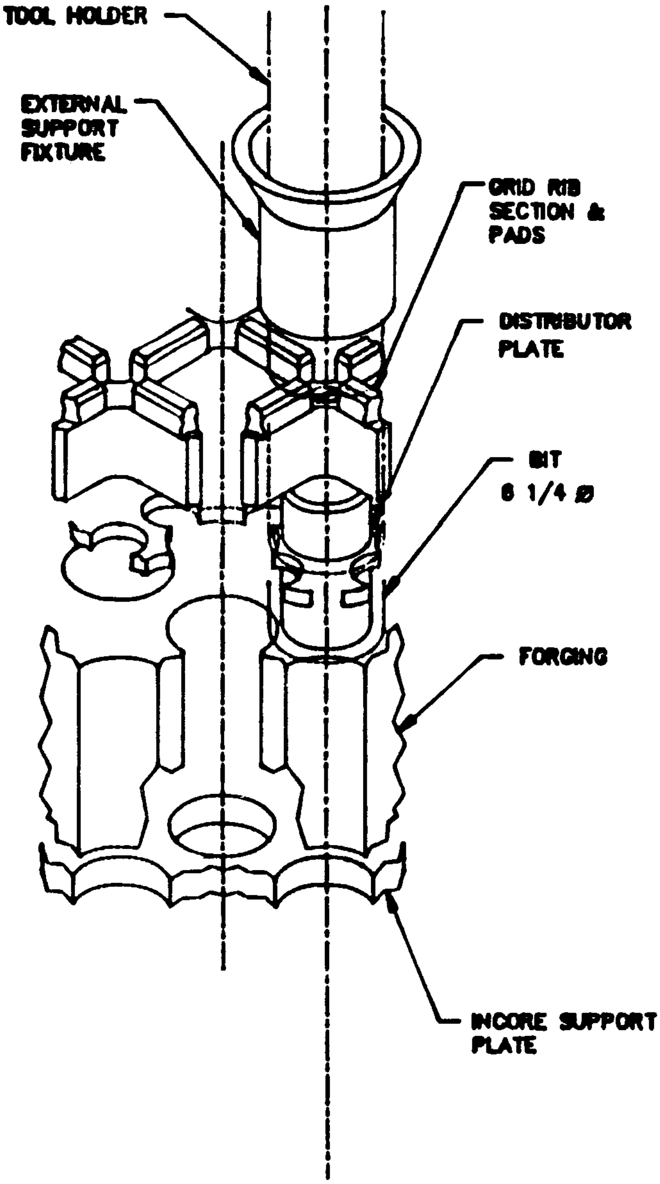
FIGURE 3-2



Lower Grid Rib Section

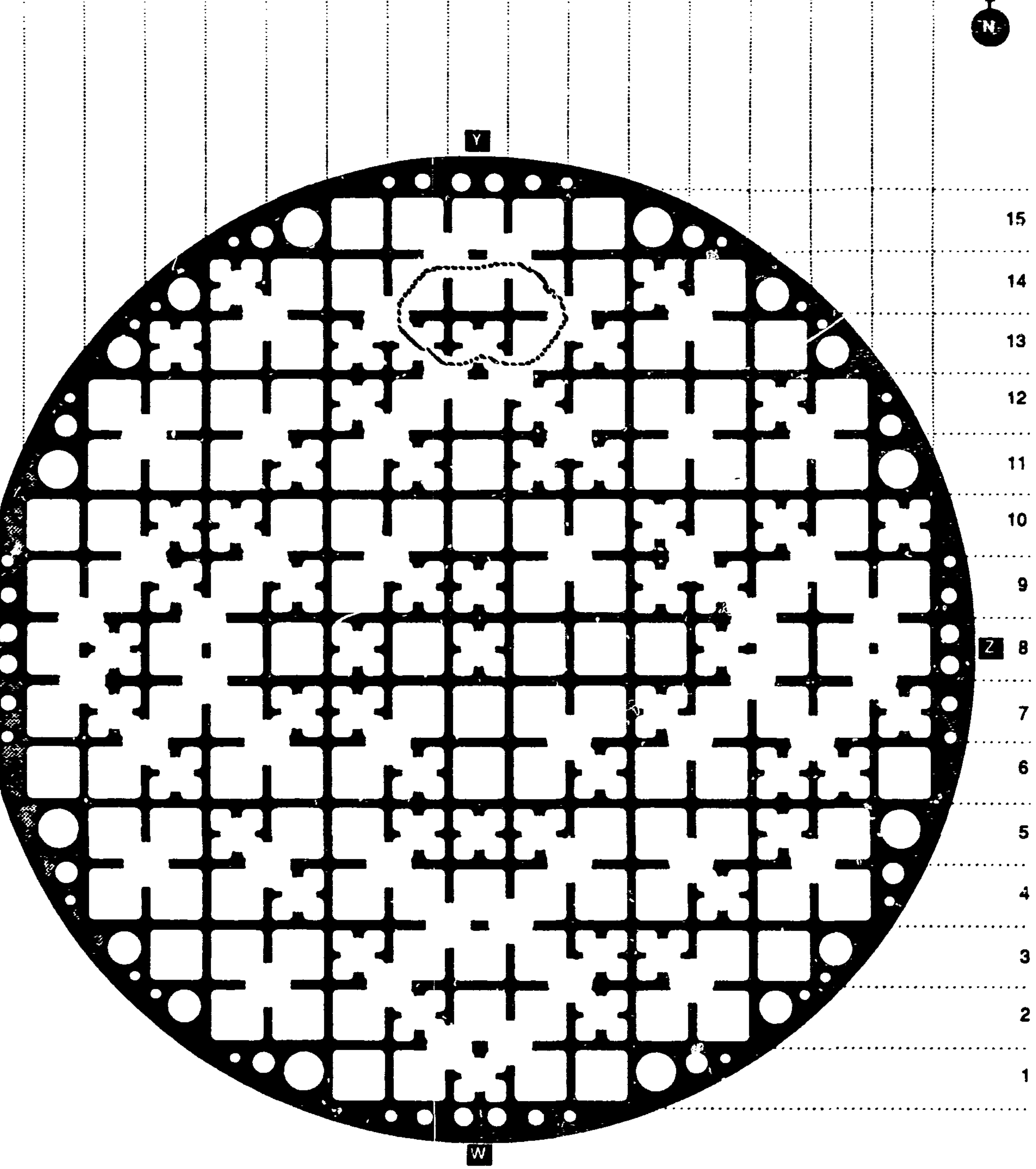
After Drilling Out Incore Guide Tubes

FIGURE 3-3



SUPPORT POST CUT

FIGURE 3-4

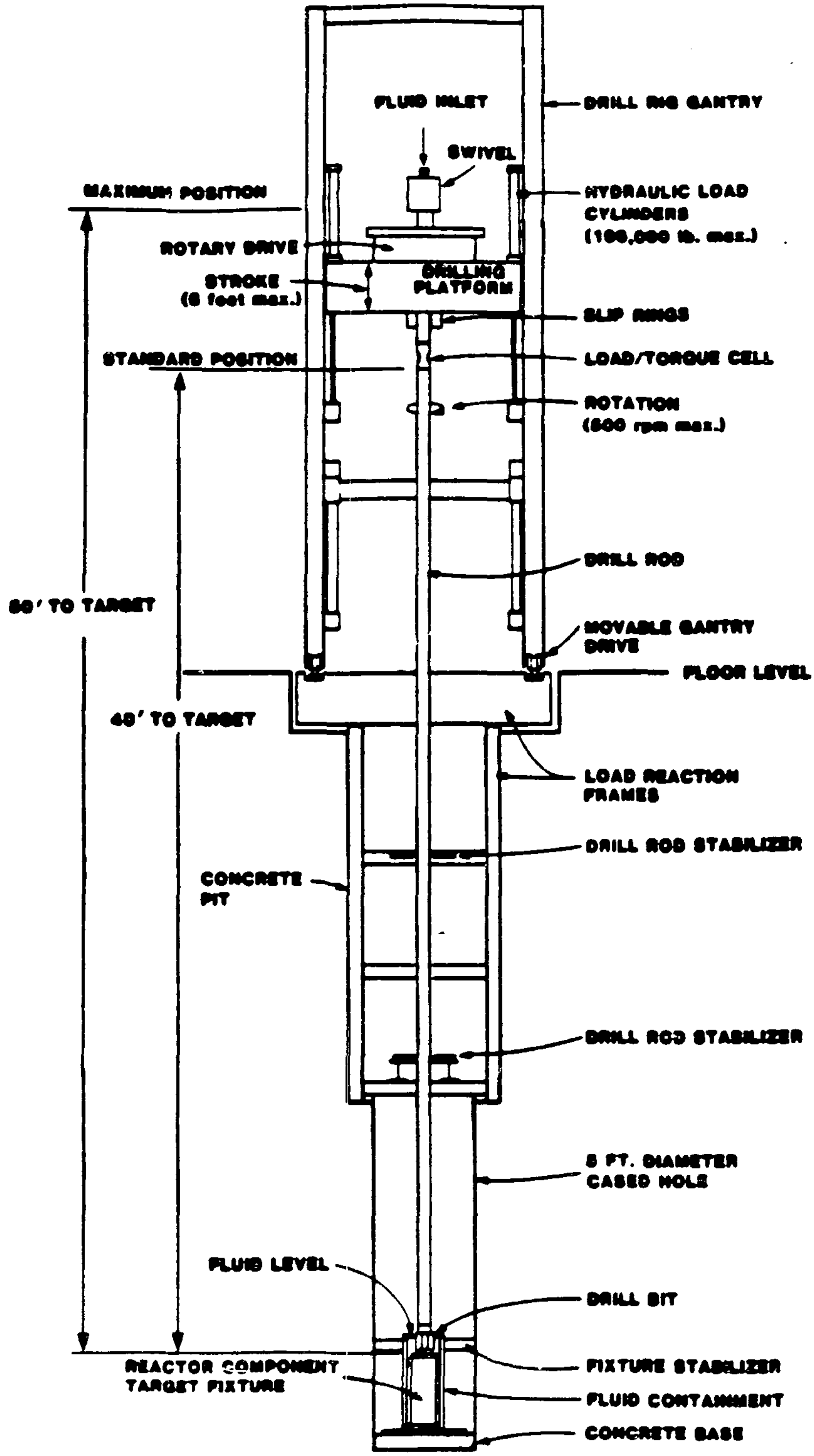


Lower Grid Rib Section

After Drilling Out Incore Guide Tubes And Support Posts

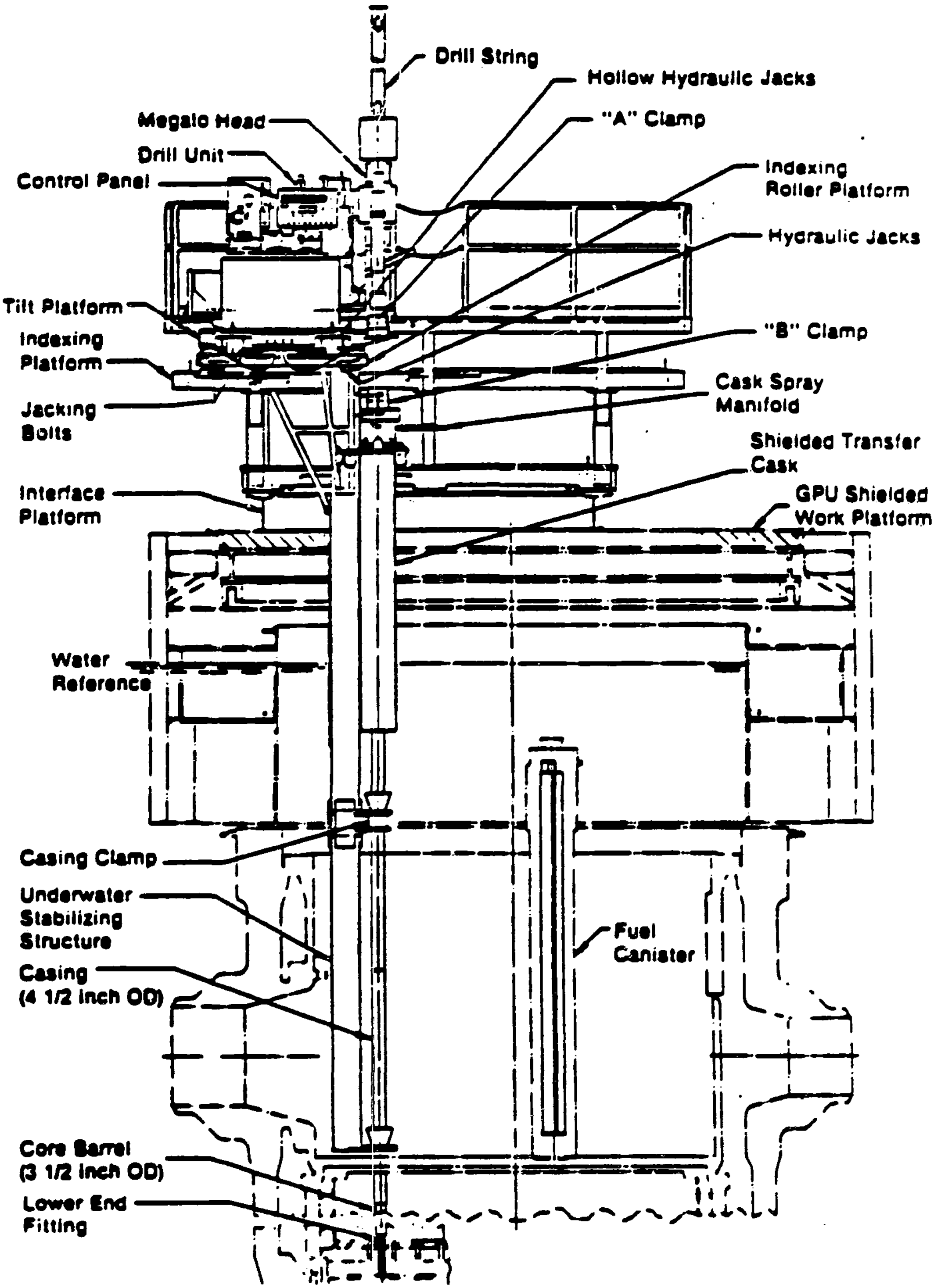
Note: Four H-Section dropouts (one at each axis)

FIGURE 3-5



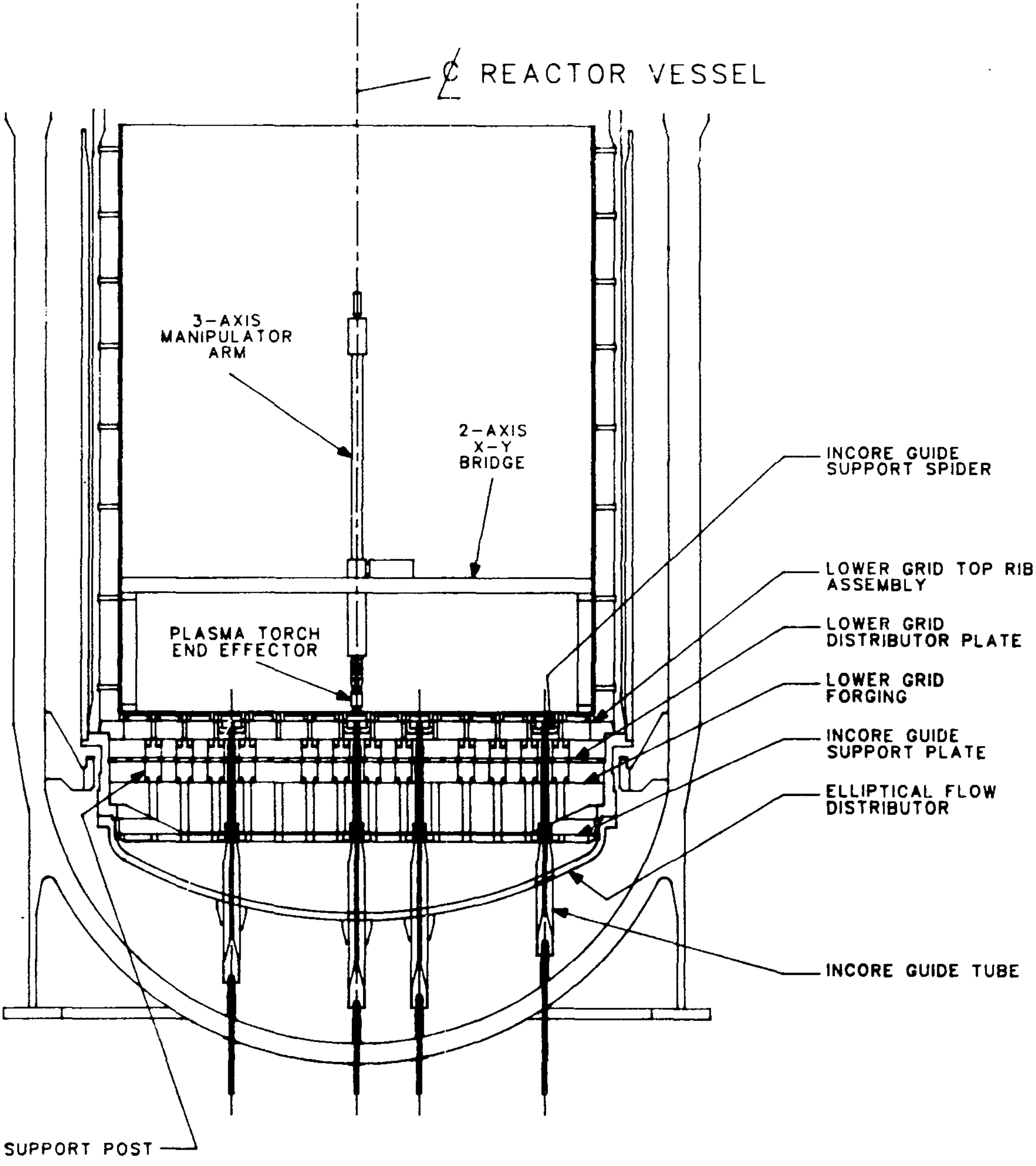
TEST FACILITY SET-UP

FIGURE 4-1



ELEVATION VIEW OF THE DRILL UNIT
WITH ITS SUPPORTING STRUCTURES AND EQUIPMENT

FIGURE 4-2

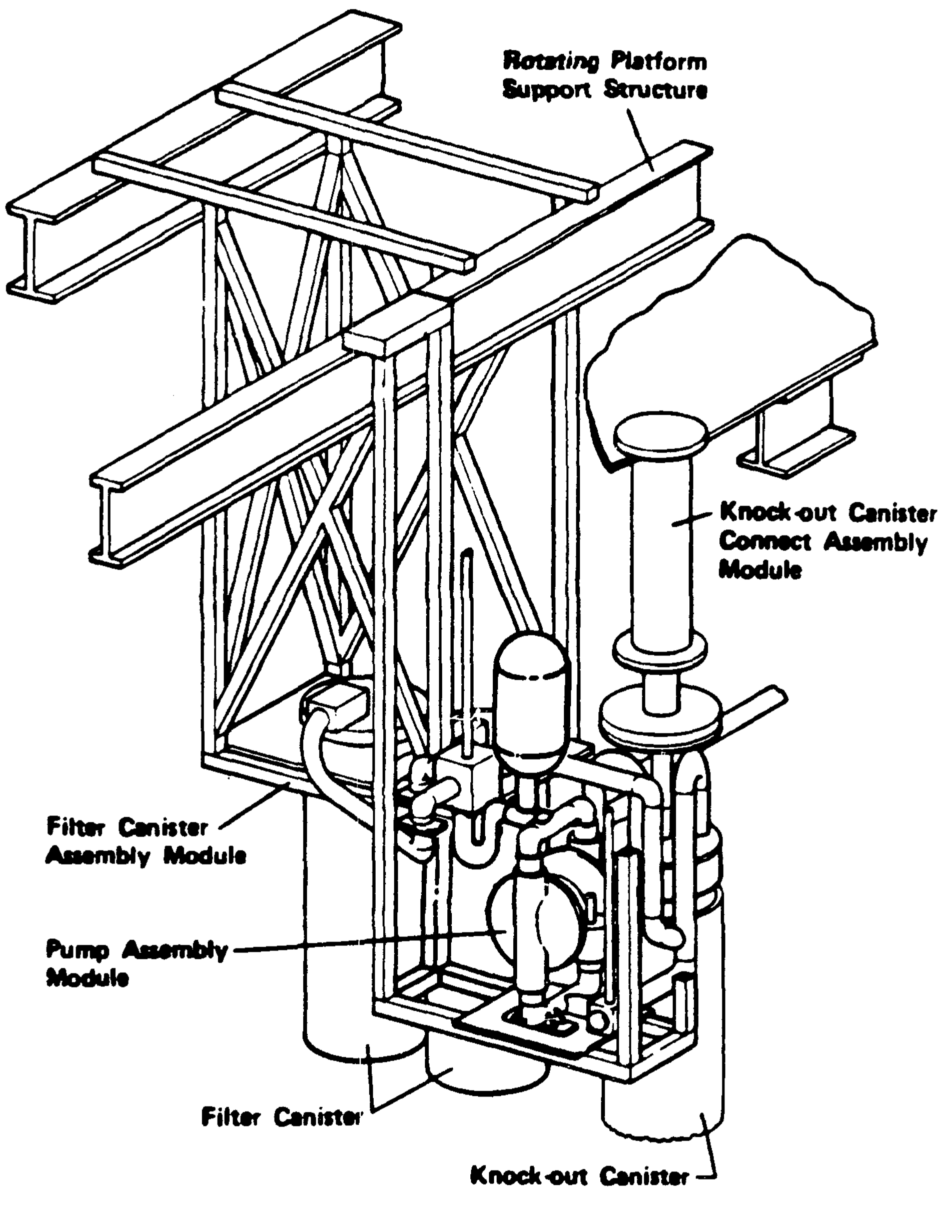


ELEVATION VIEW OF LCSA

AND

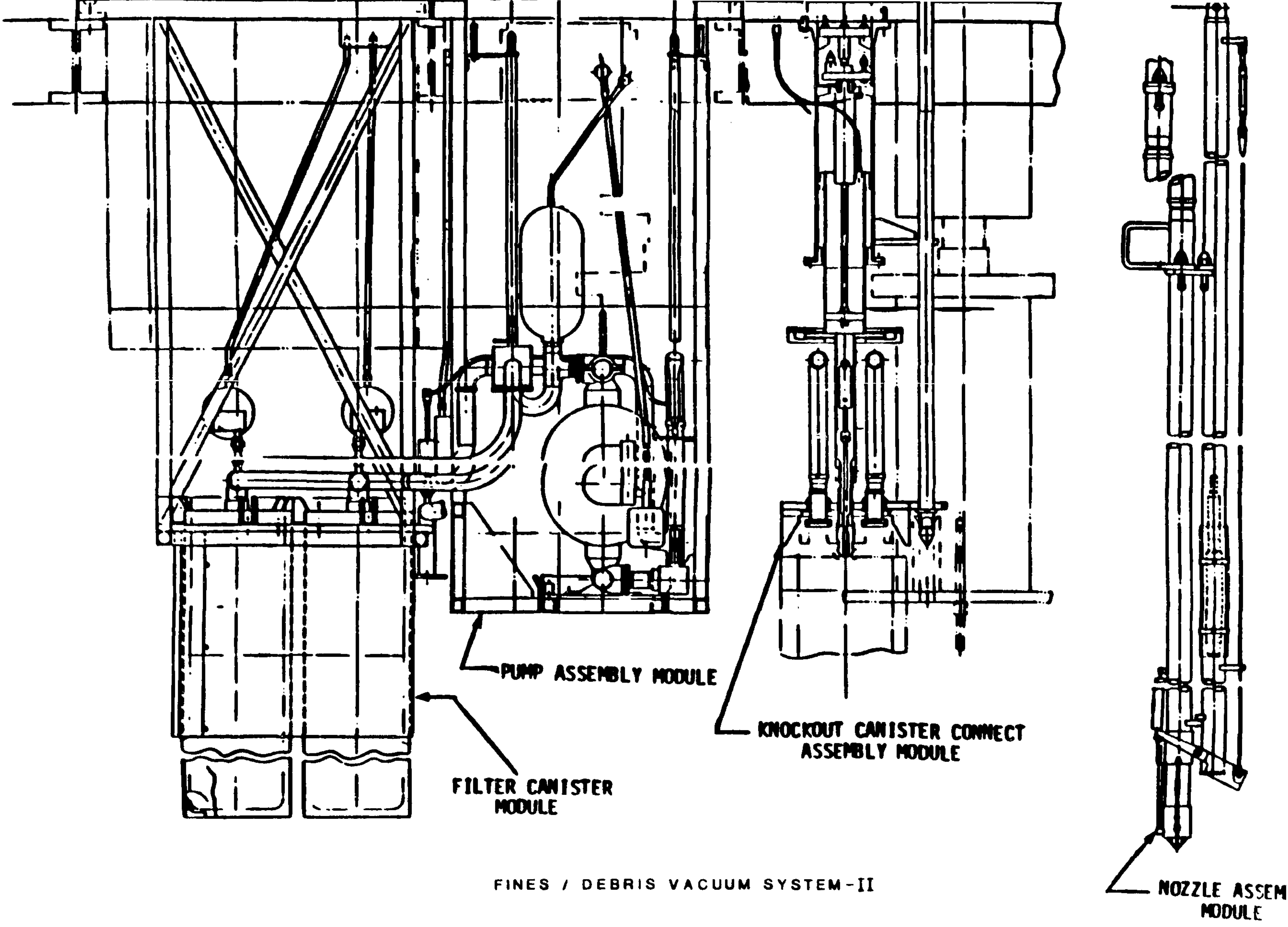
PLASMA ARC CUTTING EQUIPMENT

FIGURE 5-1

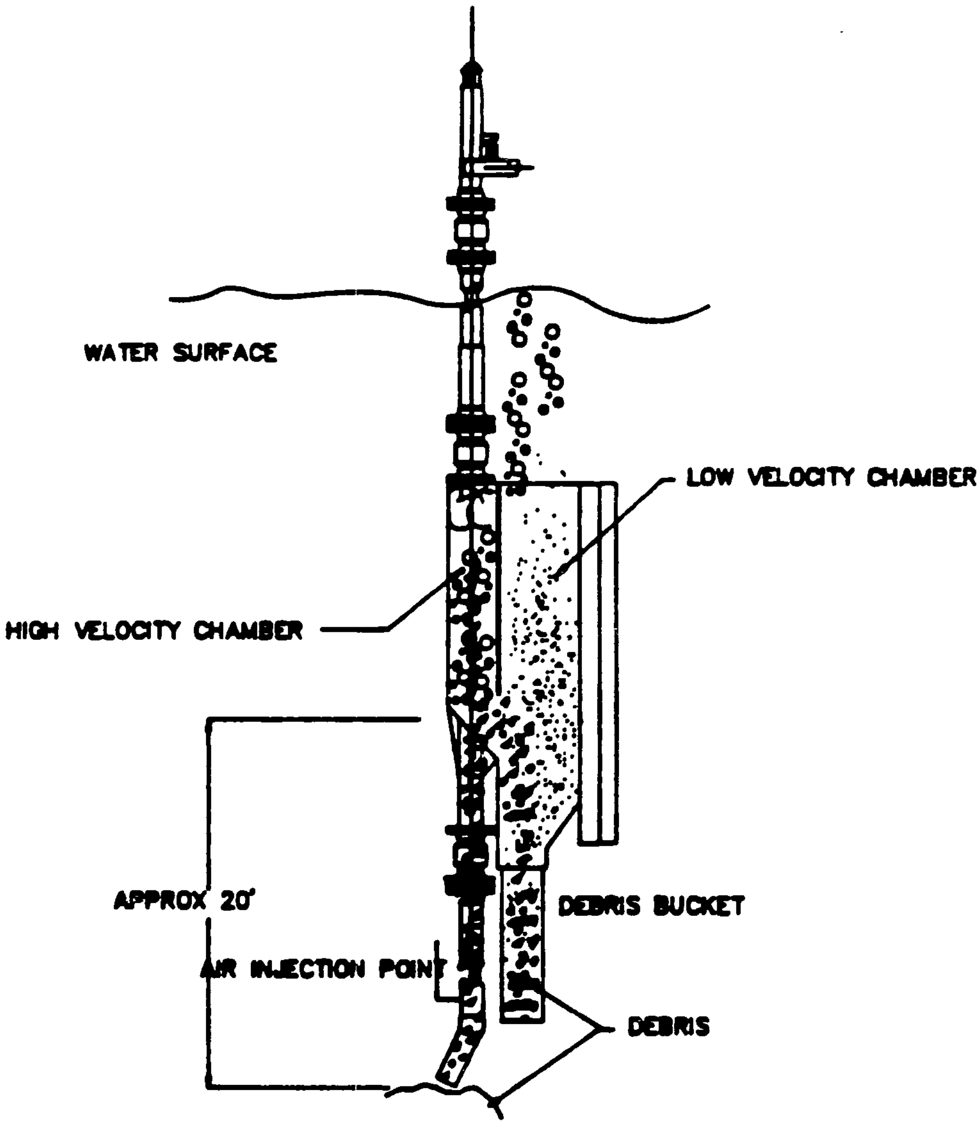


FINES / DEBRIS VACUUM SYSTEM - I

FIGURE 7-1



FINES / DEBRIS VACUUM SYSTEM-II



AIR LIFT

FIGURE 7-3

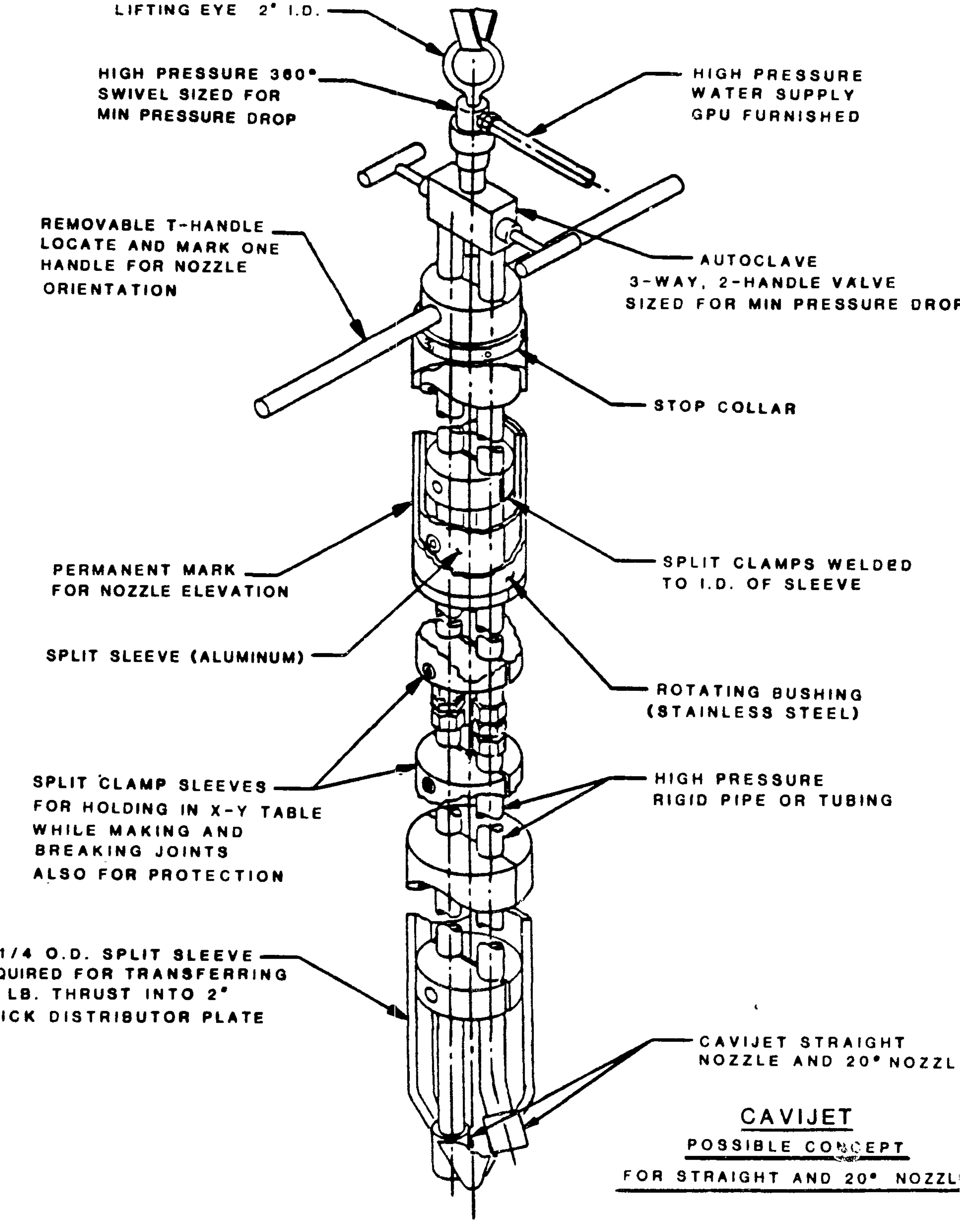
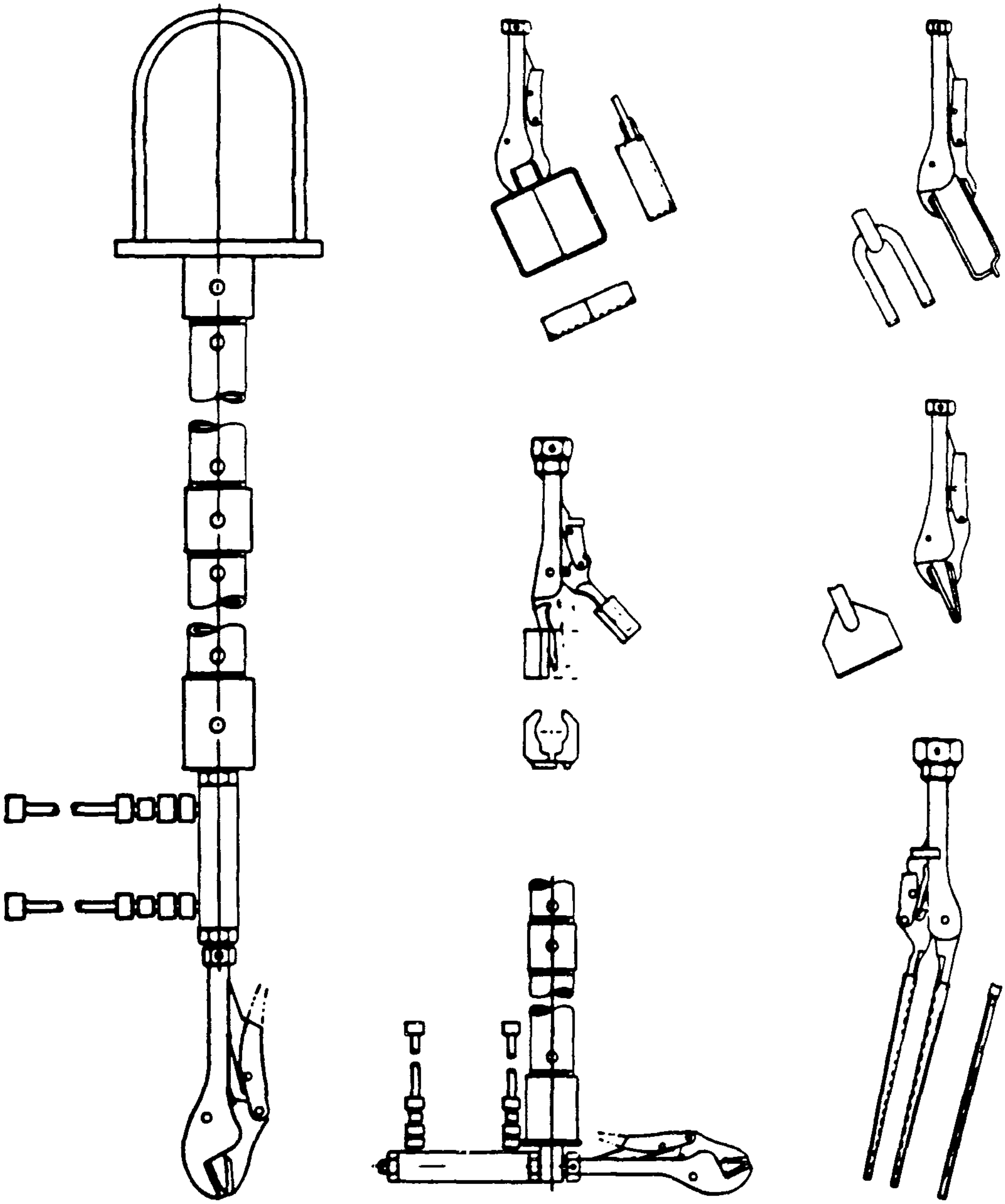
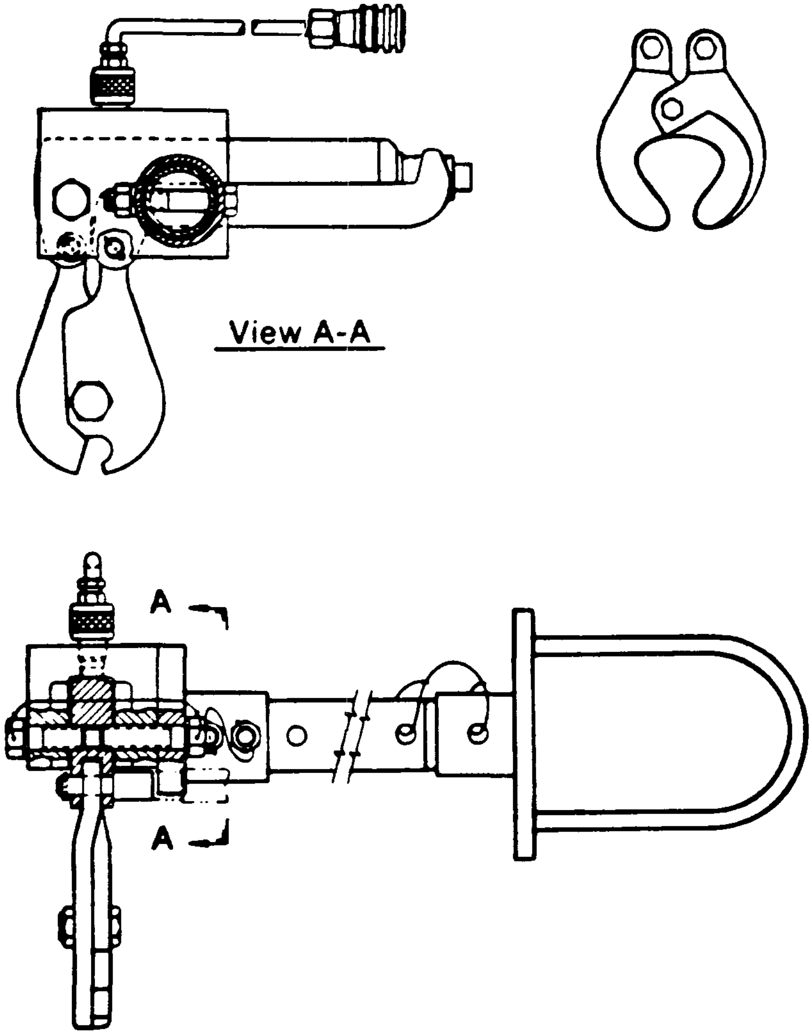

LIFTING EYE 2" I.D.
HIGH PRESSURE 360° SWIVEL SIZED FOR MIN PRESSURE DROP
HIGH PRESSURE WATER SUPPLY GPU FURNISHED
REMOVABLE T-HANDLE LOCATE AND MARK ONE HANDLE FOR NOZZLE ORIENTATION
AUTOCLAVE 3-WAY, 2-HANDLE VALVE SIZED FOR MIN PRESSURE DROP
STOP COLLAR
PERMANENT MARK FOR NOZZLE ELEVATION
SPLIT CLAMPS WELDED TO I.D. OF SLEEVE
SPLIT SLEEVE (ALUMINUM)
ROTATING BUSHING (STAINLESS STEEL)
SPLIT CLAMP SLEEVES FOR HOLDING IN X-Y TABLE WHILE MAKING AND BREAKING JOINTS ALSO FOR PROTECTION
HIGH PRESSURE RIGID PIPE OR TUBING
1/4 O.D. SPLIT SLEEVE
QUIRED FOR TRANSFERRING
LB. THRUST INTO 2"
ICK DISTRIBUTOR PLATE
CAVIJET STRAIGHT NOZZLE AND 20° NOZZL
CAVIJET
POSSIBLE CONCEPT
FOR STRAIGHT AND 20° NOZZL

FIGURE 7-4



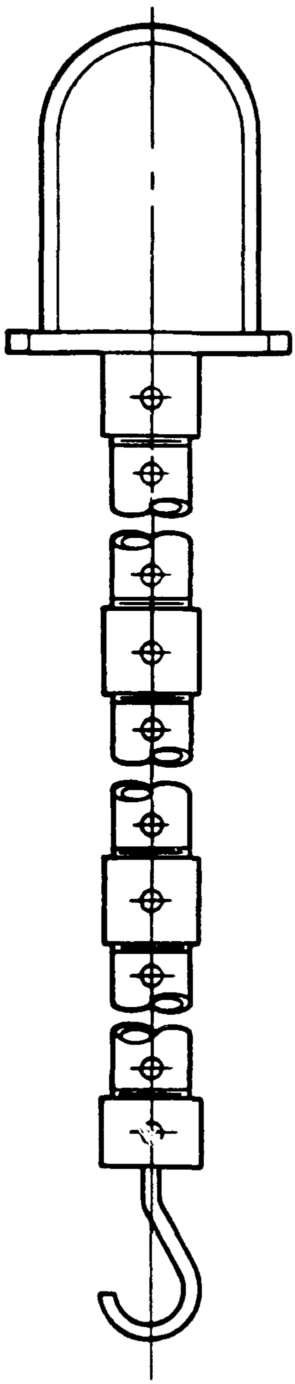
VISE GRIPS

FIGURE 9-1



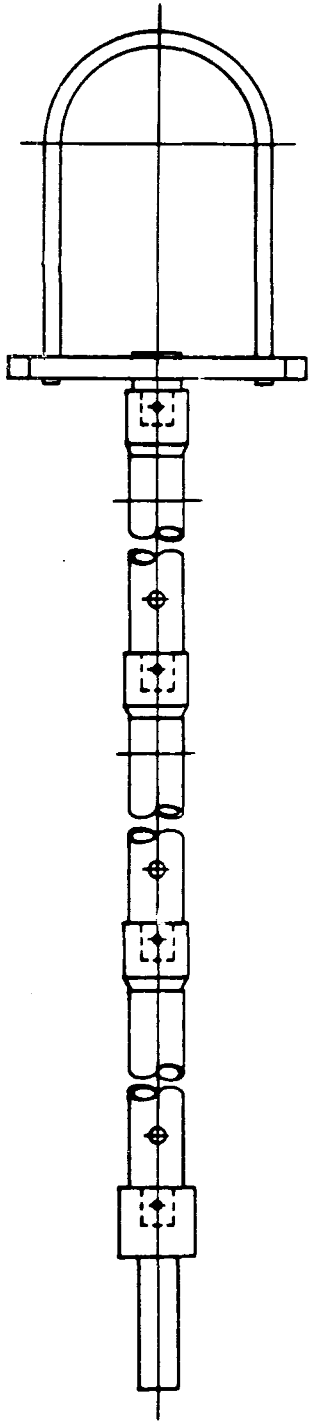
BOLT CUTTERS

FIGURE 9-2



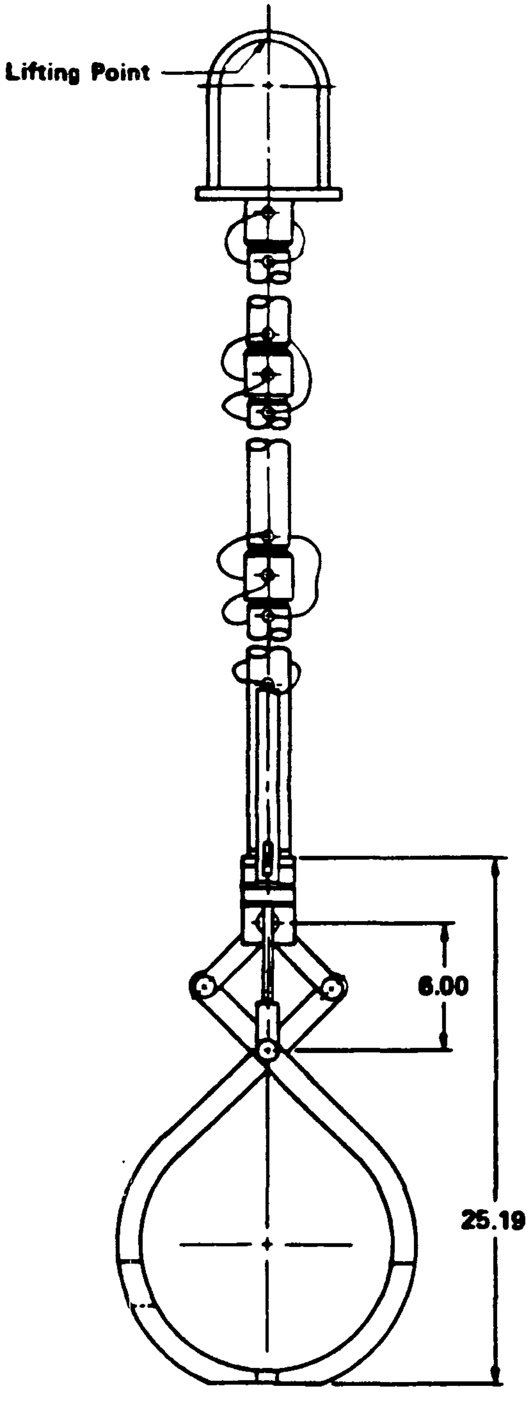
HOOK TOOLS

FIGURE 9-3



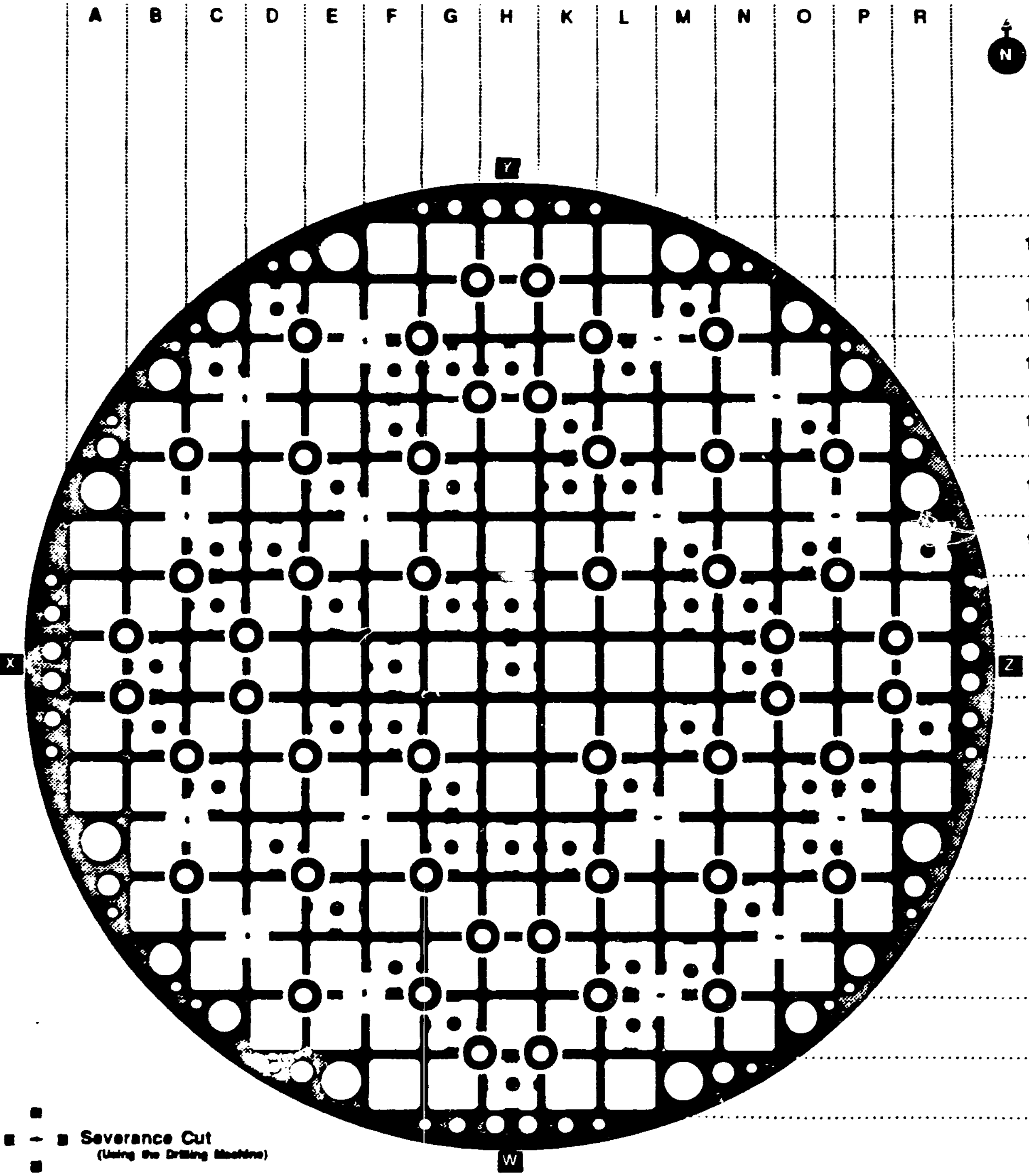
SOCKET WRENCH

FIGURE 9-4



LIGHT DUTY TONG TOOL

FIGURE 9-5



Severance Cut
(Using the Drilling Machine)

Drilled Support Posts

Incore Instrument Guide Tube
(Spiders Drilled Out)

STATUS AS OF 4/11/88

LOWER GRID RIB SECTION

FIGURE 10-1