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IN-VESSEL INSPECTION BEFORE HEAD REMOVAL: TMI II
PHASE I
(CONCEPTUAL DEVELOPMENT)

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FOREWORD

(Prepared by EG&G Idaho, Inc.)

The overall objectives for the tasks discussed in this document were recommended by the TMI-2 Examination Planning Group 7.2. The Planning Group was formed to study the unique data available as a result of the March, 1979 accident, and provide recommendations on data acquisition. The results of the study were divided into five major phases; before head removal, before plenum removal, and before, during and after fuel removal. The completed Planning Group report was subsequently published as Section 7.2 of the GEND Planning Report (GEND-001; October, 1980). Subsection 3.1 of that report addresses data acquisition prior to the removal of the reactor vessel head and, in part, forms the planning basis and objectives for this document. The overall objective, that of providing for an internal inspection of the upper reactor vessel (RV) internals and upper fuel assembly end fittings with the RV head still in place, is intended to:

1. Provide information at the earliest possible date on the operational conditions to be encountered, at least between head removal and the initiation of defueling, and possibly in defueling itself. Planning of these evolutions must currently cover a broad spectrum of potential conditions, and this spectrum can only be reduced by actual observation.

2. Provide information to help "benchmark" the range of damage estimates currently in use. The damage estimates, in turn, provide input for (1)

above. At this stage, the "benchmark" would consist of damage assessment (e.g., peak temperatures and effects) of upper core internals, extent of fuel assembly "slumping," and distribution/type/size of core debris in the upper vessel region.

3. Provide information at the earliest possible date on the in-vessel conditions for the technical community.

To develop the initial scopes of work and preconceptual techniques, a working group of technical personnel from EG&G Idaho and Babcock & Wilcox was assembled. The group reviewed the Planning Group 7.2 recommendations, the types of inspection devices applicable, the access routes available, and the kinds of information which could be extracted. Preliminary work scopes defining those results which were considered valuable were then generated. Alternative techniques which were of questionable feasibility or of high risk were deleted at that point.

The tables and figures attached to this Foreword are provided to familiarize the reader with the results of this precontract work. Table i, in conjunction with the figures, outlines the inspection areas, access routes and anticipated information. Table ii briefly reviews alternative inspection techniques and the reasons for deletion from the work scope. For additional background, the reader is referred to Section 7.2 of the GEND-001 report referenced above.

TABLE i

PRE HEAD REMOVAL IN-VESSEL INSPECTION

	Inspection Area	Access Route (See Fig. i &/or ii)	Information Anticipated
1.	Plenum Cover (horizontal top plate that forms top surface of plenum)	#1; typical of several locations; view is essentially straight down or at a slight angle.	Presence, size, and distribution of debris; if debris present, it's indicative of flow paths and velocities (size and distribution) in a normally low-flow region, and potential radiation-field problems for head removal.
2.	Internal Structure of Control Rod Guide Tubes	#2 & #3; typical of several locations; view is essentially straight down while descending longitudinal axis of tubes. Route #3 used in locations where CRDM lead screw cannot be removed.	Presence of distortion of tube and/or release of control rod guide brazements; indicative of thermal distortion of plenum and/or temperatures >2300°F (braze melting point); input for plenum removal task.
3.	Bottom end of CRDM Lead Screws Which Cannot be Removed	#3; as required.	Information on probable cause preventing "delatching" (fused to CR spider, lack of fuel assembly upper structure, jamming); input for both head removal and plenum removal.
4.	Fuel Assembly Upper Structures	#2, #3, & #4; typical of several locations. Route #4 provides access to peripheral fuel assemblies which do not contain control elements; route is between Plenum Cover OD and Plenum Cylinder ID.	Evidence of core "slumping," missing upper structure(s), and/or accumulations of debris above the upper structures; input indicative of flow velocities, inference of core damage severity; input for plenum removal.
4a.	Core Region (possible, probability uncertain)	#2 & #3; available only if fuel assembly upper structure if found to be missing (i.e., has dropped) into core).	Camera lowered into core; the only direct-access route possible.
5.	Internals Vent Valve	#5; as available; route between Plenum Cylinder OD and Core Support Shield ID.	Evidence of jamming or distortion of vent valve; input for plenum removal.
6.	Plenum-to-Core Support Flange	#5; typical of several locations.	Evidence of debris accumulation in flange area, inferrence of size and quantity of debris swept into outlet nozzles; input for plenum removal and later work on primary piping.

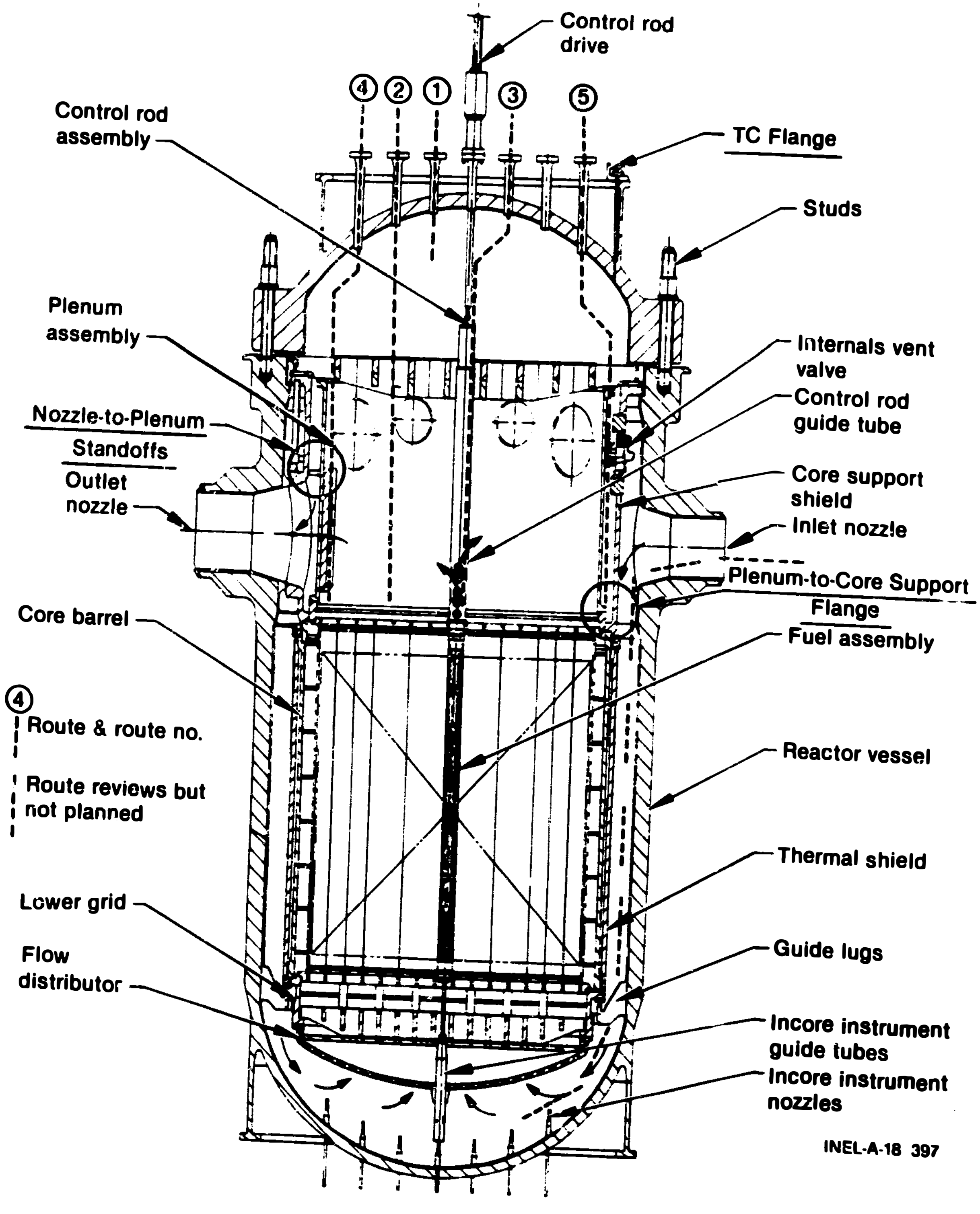

Figure i. Access routes for pre-head removal in-vessel inspection.

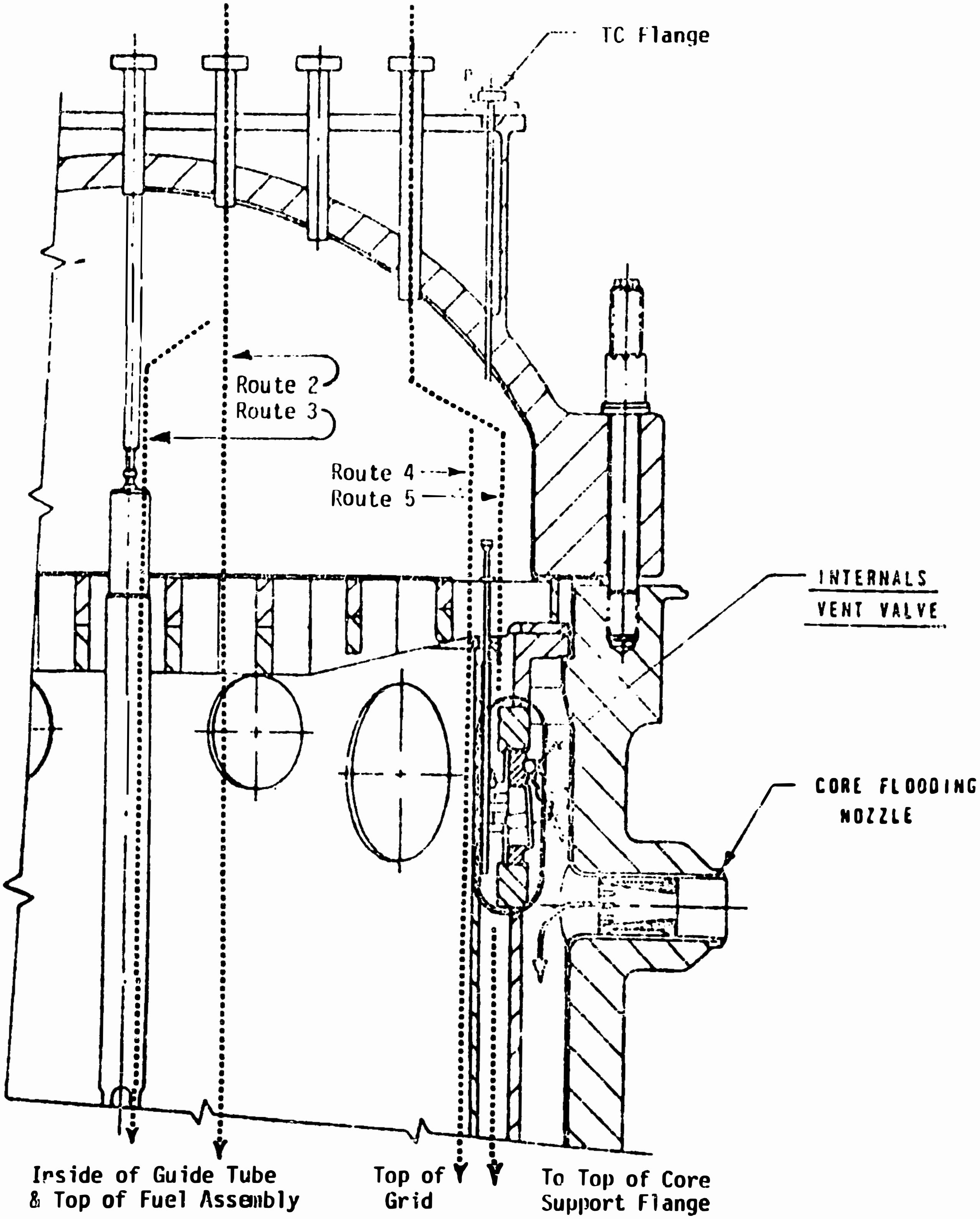

Figure ii

CORE FLOODING ARRANGEMENT

TABLE ii

IN-VESSEL INSPECTION ALTERNATIVES

1.	Use of Thermocouple (TC) Flange for Optical System Access	Access diameter thus provided is too small for commercially-available CCTV cameras and lights; borescope, which would fit access diameter, is very limited in mechanical and visual range, incapable of articulation, and could not see fuel assembly upper structure level; fiber optic system is not commercially available for this range, environment or radiation level.
2.	Cut Additional Openings in Reactor Head	Very limited locations available; high radiation fields for workers; increased manipulative requirements; limited access to CR guide tubes and fuel assembly upper structures.
3.	Cut Access Opening in Primary System Inlet Piping and "Snake" CCTV Camera into Bottom of Pressure Vessel (See Fig. 1)	High risk of CCTV camera "hang up" resulting in loss of camera and complicating removal of vessel internals; view limited to bottom head of vessel because camera cannot be manipulated; opening in primary piping must be made with a substantial head of water in the pipe ($\sim$45 ft) with inherent leak risks and contamination control problems; worker location is in area of potentially high radiation fields.

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1. OBJECTIVE AND SUMMARY

B&W was assigned the task to perform Phase I of the TMI-II Reactor Vessel Inspection Before Head Removal by General Public Utilities Service Corporation on June 9, 1980. The definition of work was outlined in Babcock and Wilcox proposal letter B&W/GPU-80-67 dated May 1, 1980.

1.1 Objective

The objective of the task is to provide for an internal inspection of the reactor vessel and the fuel assemblies prior to reactor vessel head removal. Because the degree of damage to equipment and fuel in the TMI-II reactor is not precisely known, it is important that as much information as possible be obtained on present conditions inside the reactor. This information will serve to benchmark the various analyses already completed or underway and will also guide the development of programs to obtain more information on the TMI-II core damage. In addition, the early look will provide data for planning the reactor disassembly program.

The entire task is divided into three phases: 1. Conceptual Development, 2. Detailed Design, 3. Tooling and

Inspection Equipment Fabrication and Checkout. This report covers the work performed in Phase I, Conceptual Development.

1.2 Summary

Phase I of this task included investigation and conceptual development of designs and procedures for the following areas:

1. Selection of penetrations
2. Selection of any necessary secondary boundary concepts
3. Contingency access tooling
4. Evaluation of available inspection techniques
5. Evaluation of options for manipulating surveillance equipment

The following areas were not included in Phase I, but a conceptual study of these areas was performed and it is recommended that they be included in Phase II.

1. Plenum cover debris sampling
2. (TLD) Thermoluminescent Dosimeter monitoring at various heights above the upper grid
3. Continuous water level monitoring during inspection/ sampling activities

To conclude Phase I, a more detailed cost estimate and schedule including these three options for Phases II, III was prepared.

A summary of the results of Phase I follows. Detailed discussion of each area is covered in the appropriate section of this report.

Penetration Selection - A detailed evaluation of potential access points into the reactor vessel upper head area was performed. The Control Rod Drive Mechanism (CRDM) nozzles were chosen because of their size and location as the primary access point for the inspection equipment, sampling equipment, and radiation monitoring equipment. Contingent upon normal CRDM uncoupling procedures, additional centrally located CRDM(s) will be utilized as inspection access points. The vent valve thermocouple nozzles were chosen because of their accessibility and closure only by a bolted blind flange as a primary access point for a possible reactor vessel water level indication system and for connection of the reactor vessel head purge system. A flow chart of the penetration procedure is shown in Figure 1.2-1.

Secondary Boundaries - An evaluation was made concerning the necessity of secondary boundaries such as glove boxes and gland seals for the different accesses. A current assessment of expected radiation levels inside the reactor vessel has been performed. Further analysis is required to determine the effects of plateout and potential airborne activity inside the drained vessel head, however, it is estimated that secondary boundaries will not be required provided that the following precautions are taken:

1. Prior to any work that breaches the integrity of the vessel, an adequate purge system is established such that there would be a continuous "in flow" of outside air through any "working" penetrations preventing escape of any particulate or gaseous activity.
2. Upon removal of each CRDM, an empty motor tube is placed in position and bolted on the CRDM nozzle to provide a radiological boundary and to serve as a guide tube for the inspection and sampling equipment. After access to a particular CRDM nozzle is not longer necessary, the empty motor tube may be replaced with a blind flange.

Contingency Tooling - In the event of unsuccessful uncoupling and removal of the CRDM via normal procedures, contingency tooling will be necessary to uncouple and remove the CRDM by abnormal means. A flow chart showing the recommended sequence of events for uncoupling and removal of a CRDM after stator removal is shown in Figure 1.2-2 and 1.2-3. The tooling required for abnormal removal is listed in Table 2.3-3. The recommended procedure for abnormal removal of a CRDM is as follows:

1. Establish necessary radiological controls.
2. Cut access into service support structure adjacent to CRDM to be removed.
3. Cut the motor tube and leadscrew at a selected location.

4. Lift off upper cut section of the CRDM and move to the laydown area.
5. Unbolt the flange assembly. Force bolts if necessary.
6. Lift off lower motor tube section with a lifting tool and move to the laydown area.
7. Install the leadscrew push/pull tool and leadscrew lifting tool. Apply force necessary to separate the leadscrew, lift leadscrew, and move to the laydown area. If the leadscrew is highly radioactive, it should be moved to a shielded area such as the deep end of the refueling canal.
8. Position an empty motor tube on the CRDM nozzle and seal.
9. With a CRDM removed, an adjacent CRDM which will not uncouple can be removed by severing the leadscrew below the leadscrew support and unbolting the nozzle flange.

If difficulties are encountered with unbolting the vent valve thermocouple nozzle flange, tooling capable of forcing or breaking the bolts will be required.

Inspection Technique - For the internal vessel inspection, both ultrasonics and video technology were reviewed and compared. In this comparison the video systems proved superior to ultrasonic system both in results and cost. The video systems give real-time results, need no positive position control, can inspect a greater area at one time, give more interpretative results (such as shadow effects and surface features) and are of a proven design. The only real advantage that the ultrasonic system would have is its ability to provide imaging in murky water. The problems associated with murky water can be overcome to some degree with a properly modified video system. Three ideas to compensate for murky water conditions were tested. The most successful system will allow viewing of single objects at a distance up to approximately one foot. The system uses a clear plastic "bag" which is slipped over the front of the camera and inflated with clear water in.

Manipulators - Various conceptual designs were developed for use with the inspection and lighting equipment. These concepts use the thermocouple and CRDM nozzle as penetrations. These manipulators are manually operated and can be controlled from the top of the service support structure. Also, a conceptual design was developed for the optional sampling system.

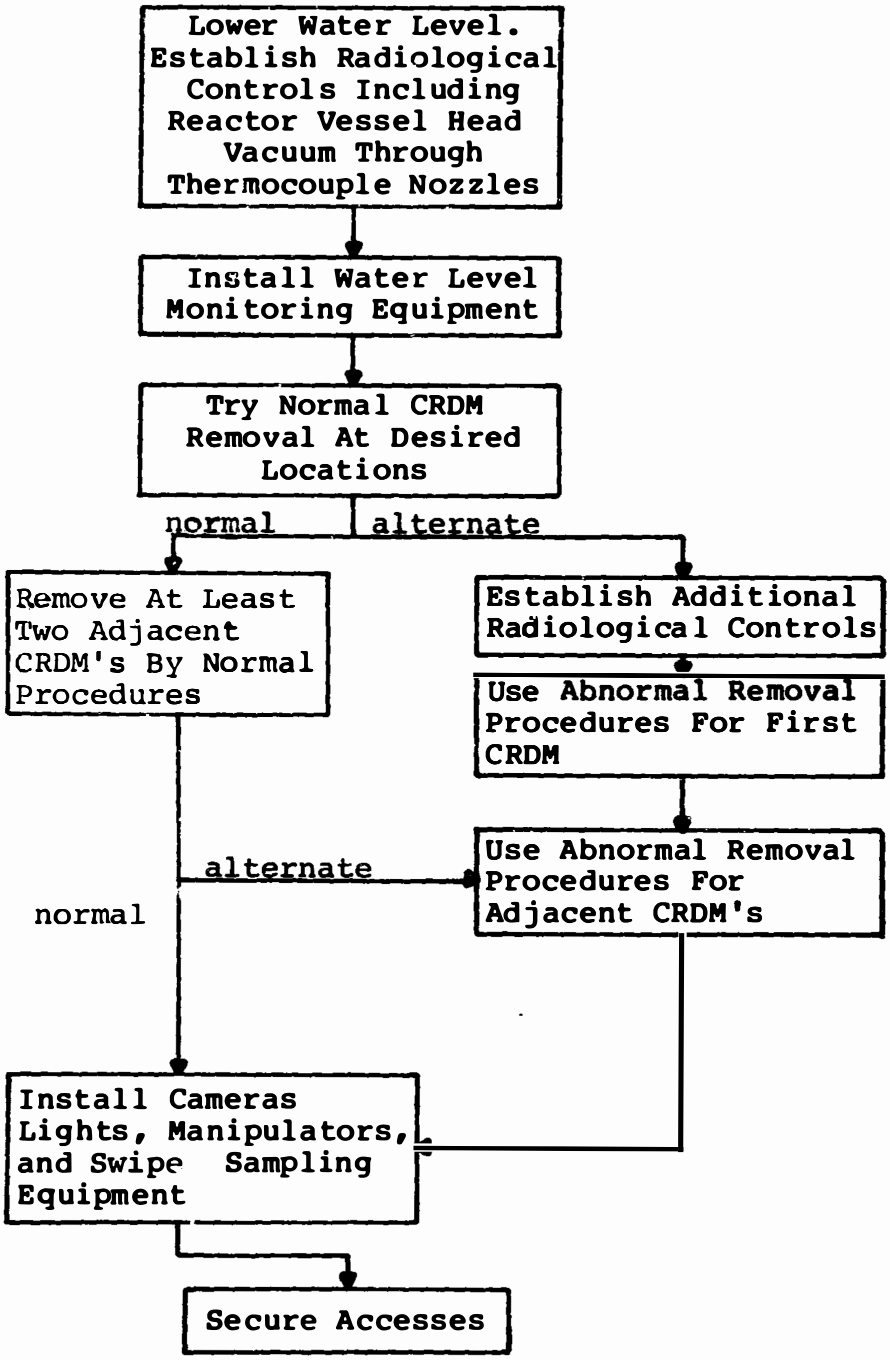


FIGURE 1.2-1 - General Approach

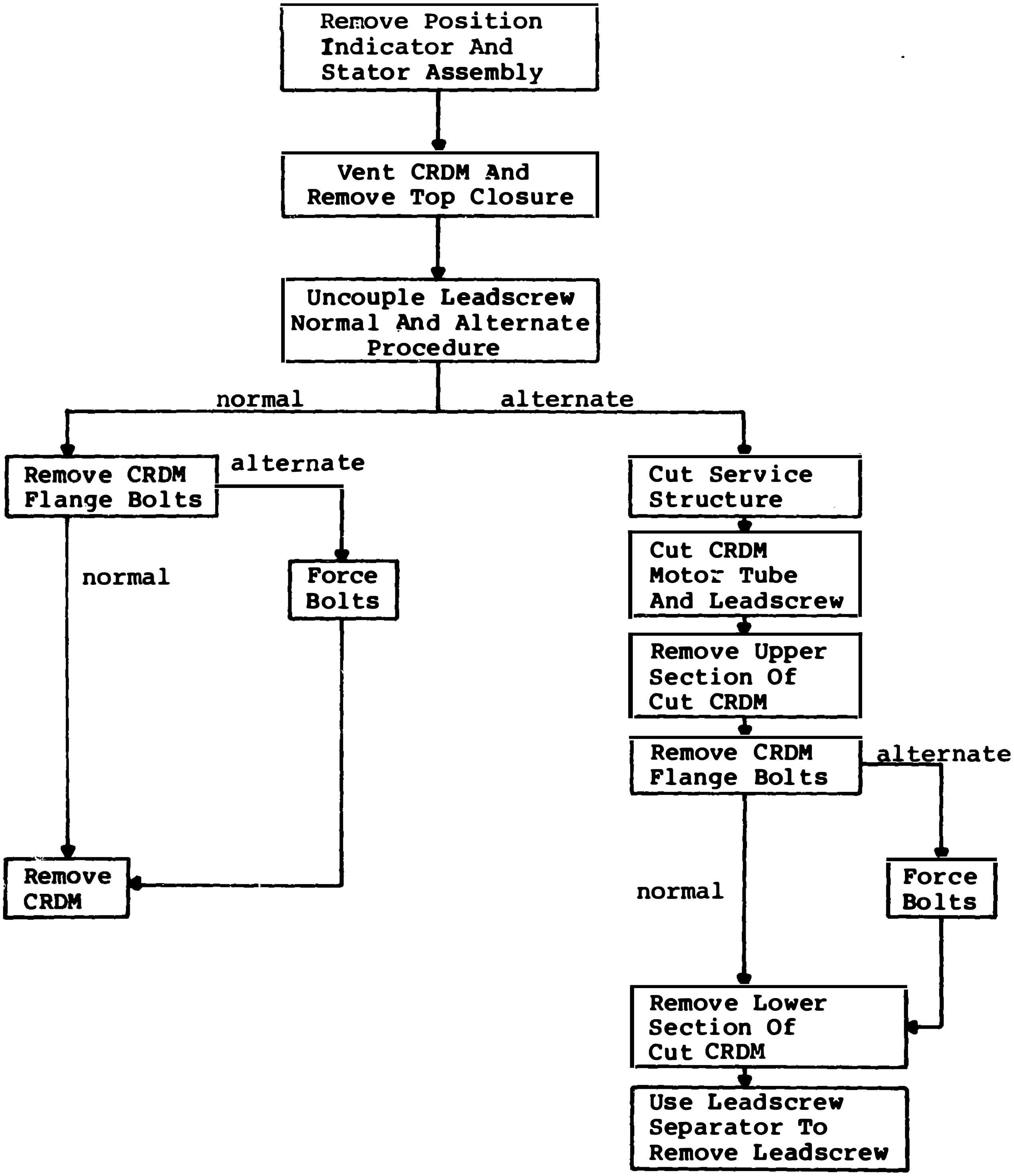


FIGURE 1.2-2 Contingency Procedure For First CRDM Removal

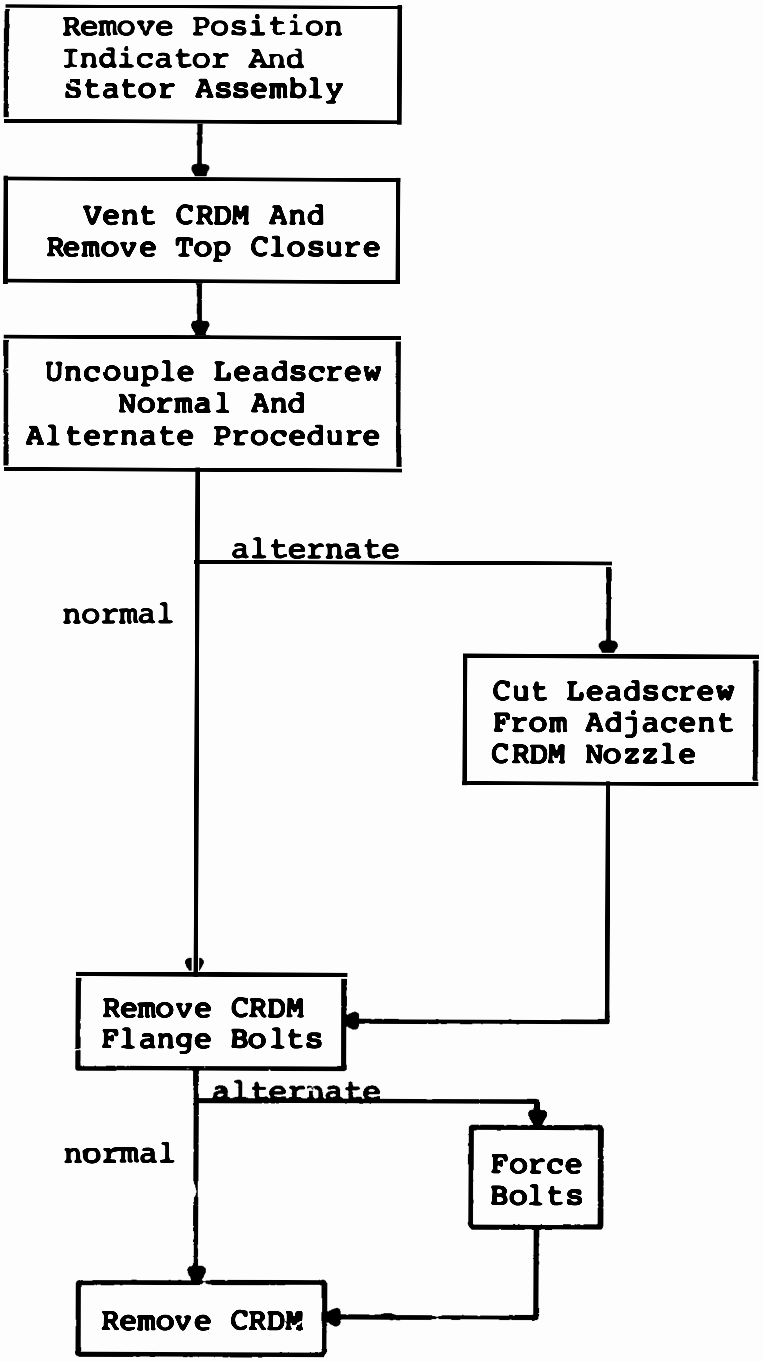


FIGURE 1.2-3 Contingency Procedure For Adjacent CRDM Removal

2. DISCUSSION

2.1 Penetration Selection

A detailed access evaluation of the potential access points into the reactor vessel was performed. The evaluation was limited to access points into the upper head of the reactor vessel.

The primary objectives considered in performing the access evaluation are:

1. Allow access for manipulated inspection equipment including auxiliary lighting.
2. Allow access for attachment of a reactor vessel head purge system to provide an inflow of air through all other penetration.

Optional objectives were also considered in performing the access evaluation and are:

1. Allow access for primary water level sensing equipment.
2. Allow access for radiation monitoring equipment.
3. Allow access for sampling equipment.

For each of these objectives, criteria were established as a basis for penetration selection. Each of these criteria is listed below:

1. Manipulated inspection equipment must be capable of viewing the following areas as a minimum:

a. General area in the upper head including the plenum cover and control rod guide tubes.

b. Inside the plenum between the plenum wall and control guide tube down to and including the upper grid assembly in one quadrant of the vessel.

c. Outside the plenum cylinder and inside the core support shield at one location.

d. Vertically down through a control rod guide brazement to the top of the fuel assembly.

2. The reactor vessel head purge system must be attached to a head penetration such that a continuous "air in-flow" is monitored through the working penetrations at all times.

3. The primary water level sensing system monitors the primary water level directly through a penetration (Optional).

4 The radiation monitoring equipment must be lowered through the head down to the upper grid to provide a "map" of internal radiation levels (Optional).

5. The sampling equipment must be capable of collecting swipe samples from the plenum cover.

Three penetration locations in the upper head were considered for each objective. These penetrations are the CRDM vessel nozzle, the vent valve thermocouple nozzle, and a special hole cut through the reactor vessel head.

A new hole cut through the head was considered as an option in the event of unsuccessful access attempts through the other penetration location. The drawbacks of such a cut are discussed in Chapter 2.3 and it is not considered a viable option at this point. Emphasis was placed on conceptual development of contingency tooling required for gaining access through the CRDM nozzles and vent valve thermocouple nozzles.

The CRDM nozzles have a 2.765" inside diameter and are considered the first choice penetration location for the following equipment:

1. Inspection equipment
2. Sampling equipment (Optional)
3. Radiation measuring equipment (Optional)

For inspection equipment, 12 primary locations on the periphery as shown in Figure 2.1-1 are chosen for the following reasons:

1. Provides minimum offset required to lower inspection probes past the plenum cover and into the plenum.
2. Provides minimum offset required to lower inspection probes between the plenum cylinder and core support shield.
3. Access down the periphery of the plenum will allow viewing the maximum number of fuel assemblies.
4. In the event of unsuccessful leadscrew uncoupling and CRDM removal, these CRDM's are accessible by cutting through the service support structure wall.

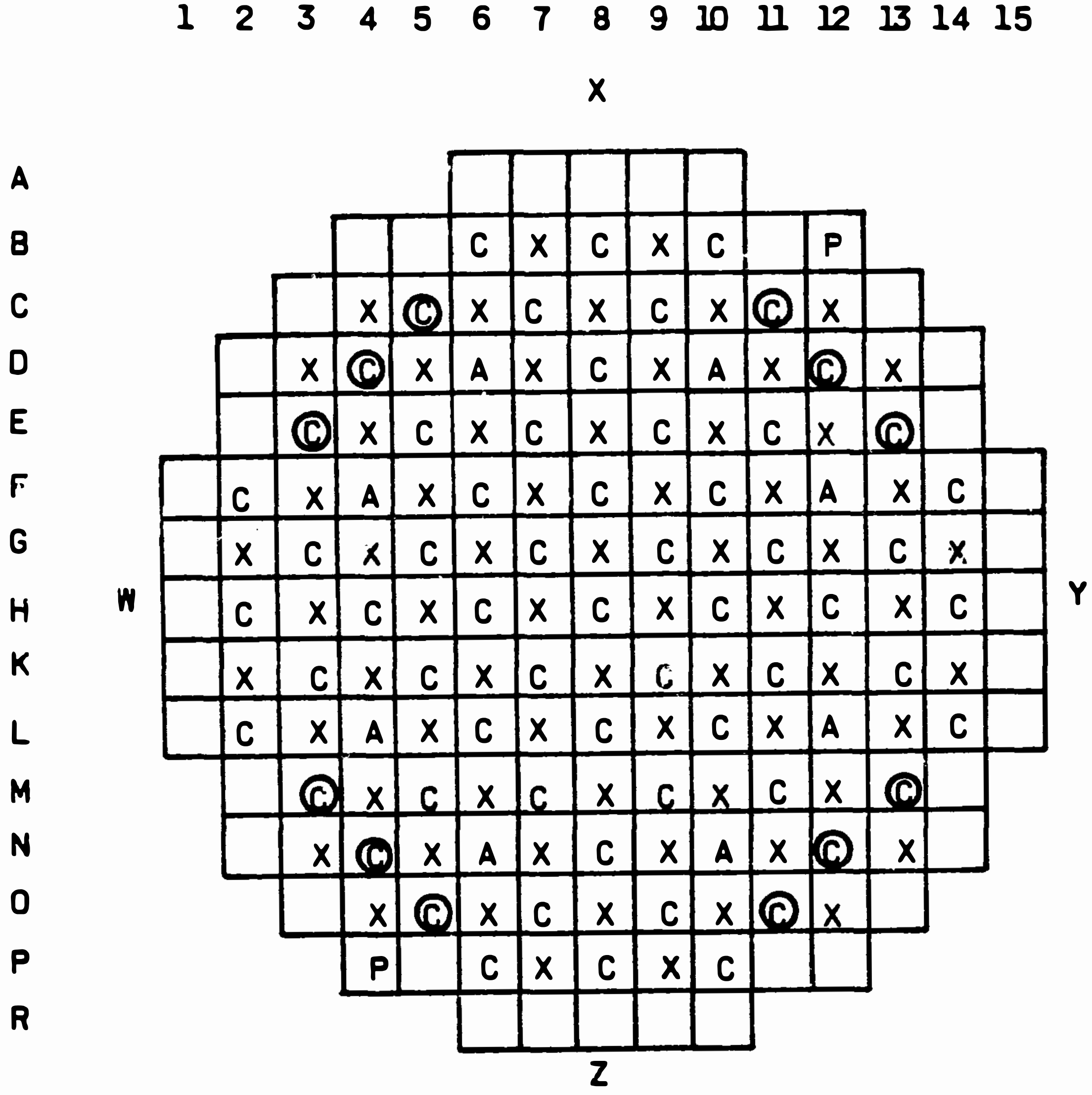
Access through any one of these 12 locations would, with the equipment provided, ensure access to any CRDM location by successively removing adjacent assemblies if necessary. Additionally, contingent upon normal CRDM uncoupling methods, centrally located CRDM(s) will be utilized as access points for inspection.

Up to three CRDM nozzles in one quadrant will be required to perform all of the recommended inspections, optional sampling, and monitoring procedures. Sampling equipment, radiation measuring equipment, and inspection devices can be inserted through these penetrations as well as CRDM nozzles closer to the pattern center if CRDM removal does not require motor tube cutting. The normal procedures for removal of a CRDM are outlined in Appendix I.

The vent valve thermocouple nozzles have a 0.614" inside diameter and are considered the first choice penetration location for the following equipment:

1. Reactor vessel head purge system
2. Primary water level indication system (Optional)

The vent valve thermocouple nozzle shown in Figure 2.1-2 is the best penetration location for these prerequisite systems because they are accessible outside the service support structure and are closed only by a bolted blind flange. With appropriate radiological controls, these systems can be established at the thermocouple nozzles after head venting but prior to breaching a CRDM with minimum man-rem exposure.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A															
B						C	X	C	X	C		P			
C				X	Ⓒ	X	C	X	C	X	Ⓒ	X			
D			X	Ⓒ	X	A	X	C	X	A	X	Ⓒ	X		
E			Ⓒ	X	C	X	C	X	C	X	C	X	Ⓒ		
F		C	X	A	X	C	X	C	X	C	X	A	X	C	
G		X	C	X	C	X	C	X	C	X	C	X	C	X	
H		C	X	C	X	C	X	C	X	C	X	C	X	C	
K		X	C	X	C	X	C	X	C	X	C	X	C	X	
L		C	X	A	X	C	X	C	X	C	X	A	X	C	
M			Ⓒ	X	C	X	C	X	C	X	C	X	Ⓒ		
N			X	Ⓒ	X	A	X	C	X	A	X	Ⓒ	X		
O				X	Ⓒ	X	C	X	C	X	Ⓒ	X			
P				P		C	X	C	X	C					
R															

☐ CONTAINS NO CONTROL COMPONENT

C CONTROL ROD ASSEMBLIES

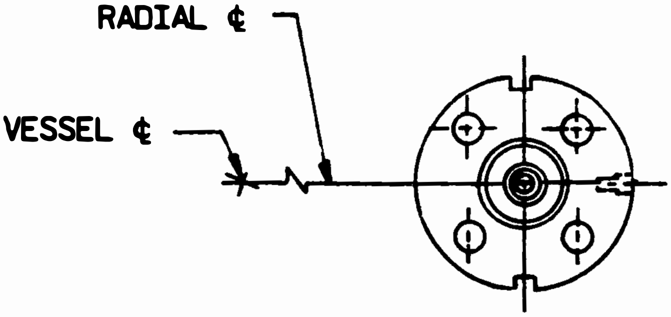
A AXIAL POWER SHAPING ROD ASSEMBLIES

X BURNABLE POISON ROD ASSEMBLIES

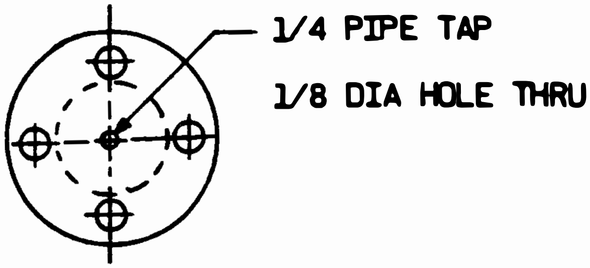
P PRIMARY NEUTRON SOURCES

Ⓒ DESIRABLE LOCATIONS FOR CRDM REMOVAL

Figure 2.1-1 LOCATION OF CONTROL ASSEMBLIES



THERMOCOUPLE NOZZLE



BLIND FLANGE

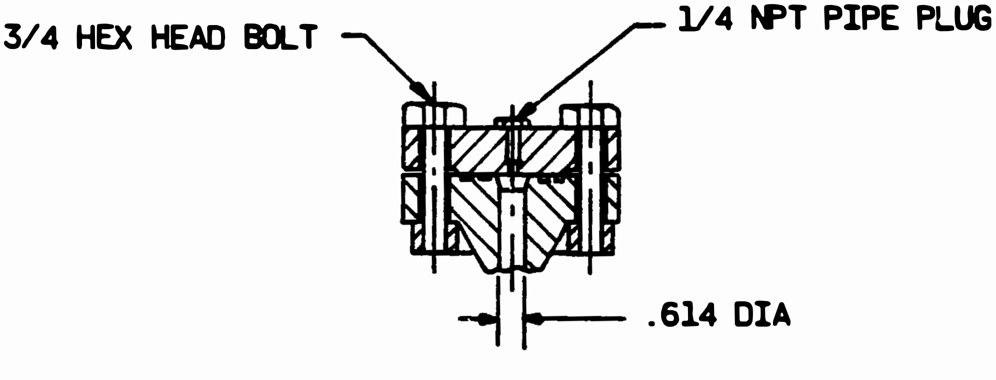


Figure 2.1-2 THERMOCOUPLE NOZZLE ASSEMBLY

2.2 Secondary Boundary

The necessity of secondary boundaries such as glove boxes and gland seals for the accesses to be used has been evaluated. This assessment has been based on two assumptions:

1. Prior to any work that breaches the integrity of the vessel, a purge would be established in the reactor vessel head such that there would be a continuous "in flow" through any open penetrations preventing the release of any particulate or gaseous activity.
2. Upon removal of each CRDM, a guide tube similar to an empty motor tube is placed in position and bolted on the CRDM nozzle to provide a radiological boundary when the penetration is not in use and to serve as a guide tube for the inspection equipment. After access to a particular CRDM nozzle is no longer necessary, the empty motor tube may be replaced with a blind flange.

A conceputal design of a purge system to be used is shown in Figure 2.2-1. This system requires the lowering of the primary water level to a point below the bottom of the vent valve thermocouple nozzle, its suction point.

Current estimates of radiation levels inside the reactor vessel are as follows:

1. Inside the reactor vessel head near the top, assuming a maximum contribution by the noble gas inventory, 300-500 R/hr is expected before purge.
2. Inside the reactor vessel head near the top, assuming no contribution of gaseous activity, 100-300 R/hr is expected after purge or if no noble gases are encountered.

Assuming a worst case estimated radiation level, inside the reactor vessel head near the top, of 500 R/hr; the radiation level at the top of an empty motor tube due to streaming is estimated to be 2-3R.

General area radiation levels on the working platform of the service structure due to sources inside and outside the primary system are estimated to be 500-700 mR/hr unshielded.

These estimates do not account for any possible plateout of radioactive materials on the reactor internal surfaces or potential airborne particulate activity that could be produced during drying of the drained upper head region. The airborne particulate contribution will be removed once the purge system becomes operational.

Further analyses are required to determine the gas production rate resulting from the possible release of bubbles originating within the vessel and the effects of plateout and potential airborne particulates. These analyses are necessary to conclusively determine the adequacy of a purge system in preventing a release of particulate and gaseous activity through open penetrations.

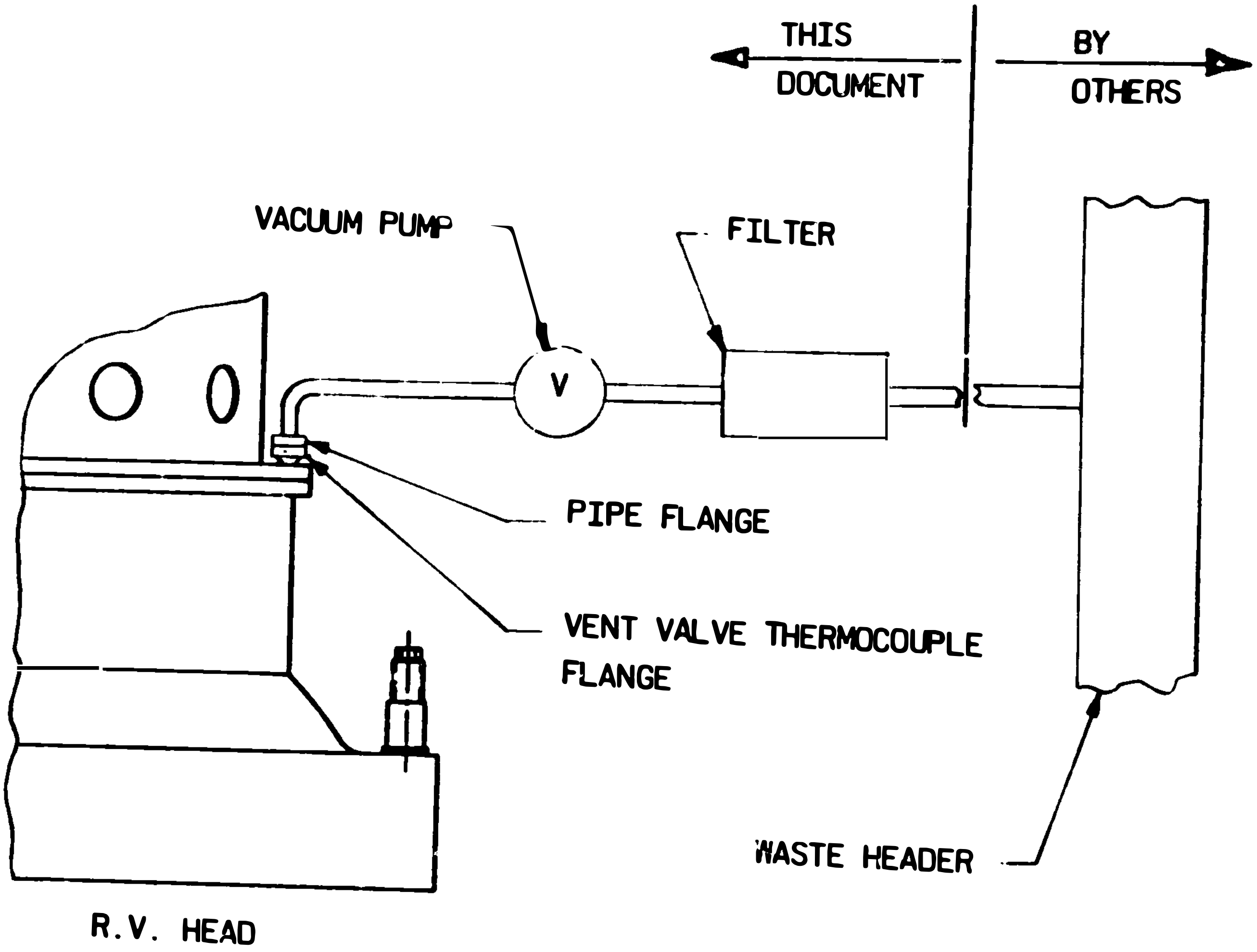


Figure 2.2-1 PURGE SYSTEM

2.3 Contingency Tooling

An evaluation was performed to assess the potential problems in obtaining access into the reactor vessel by unbolting existing flanges. Contingency tooling has been identified which will be necessary as a backup method for gaining access through these existing flanges. Additionally, the cutting of a special hole in the reactor vessel head was evaluated.

Contingency tooling and procedures have been conceptually developed for use in the event of unsuccessful leadscrew uncoupling, CRDM removal, or vent valve thermocouple nozzle blind flange removal.

In developing this alternate procedure, the properties of the CRDM were considered and are outlined in Figures 2.3-1 and 2.3-2.

Thermocouple Blind Flange - The thermocouple blind flange is secured by four 3/4" diameter bolts. Should they fail to come free using standard procedures and tooling a larger wrench will be utilized to apply more torque. If the bolts are still frozen they will be cut off. Tooling design and development would be minimal due to the accessibility of the flange.

CRDM - Standard tooling and procedures for leadscrew uncoupling and CRDM removal may prove to be inadequate due to conditions imposed during and since the TMI-II incident. Possible complicating conditions considered are:

1. Corrosion of bolts and fittings
2. Melting/fusing of leadscrew to the control rod spider
3. Warpage of leadscrew or CRDM due to thermal stresses.
4. Melting or warpage of the quide tube brazements.

It has been estimated that the leadscrews in the peripheral CRDM's experience a minimum of 1500°F for a period of approximately one hour before being quenched. Although this by itself would not have significantly changed the metallurigical properties of any of the key components, it could have been sufficient to cause degree of warpage. If the temperature reached as high as 2100°F, the rod guide brazements could have begun to melt. It is possible that the male coupling on the end of the leadscrew assembly was fused or deformed and will not uncouple from the spider. Some degradation of both components is expected due to the initial thermal gradients and subsequent environment.

An alternate procedure for removing a CRDM is outlined in Figures 1.2-2 and 1.2-3. A list of tooling which was considered is listed in Table 2.3-3. The PI is attached at the bottom by a single stud and nut and at the top by a clamp. Should these fail to come off utilizing standard procedures and tooling, they could be broken off, either by prying or direct lifting with a strong puller. The stator should then be lifted off, using either the standard tool or a heavier version (see Figure 2.3-4) which grabs it at the bottom and is able to exert much more lifting force. In the unlikely event that the stator still fails to lift off, it may be bypassed by using a double offset flange bolt removal tool (Figure 2.3-5) specifically designed for that purpose.

An access hole would now be cut in the service structure as shown in Figure 2.3-6. This is not a stress relieved structure. The structural aspects of cutting such an opening have been evaluated and no strength or stability problems would exist. The material is 3/4" carbon steel and would lend itself quite well to gas torch or abrasive disc cutting. Both of these methods would be both fast and relatively easy, but the potential airborne contamination is considered undesirable. A power reciprocating hacksaw would reduce potential airborne contamination but would take much longer to cut.

Once an access hole is established, the motor tube and leadscrew could be cut. Two possible cut locations have been identified. The upper cut location is between the top of the rotor assembly and the bottom of the torque tube assembly. The lower cut location is between the bottom of the rotor assembly and the top of the thermal barrier assembly.

The upper cut location has the following advantages over the lower cut location:

1. Thinner motor tube wall, 0.3" versus 0.5"
2. More leadscrew would be exposed, 2' versus 6"
3. Rotor assembly would require anchoring or capturing before cut section could be lifted away.

A disadvantage of the upper cut location is that the stator must first be removed or cut.

Possible cutting methods are shown in Figures 2.4-7 and 2.3-8. Cutters considered are power reciprocating hacksaw, power bandsaw, and abrasive disc. As with the service structure cut, the abrasive disc is expected to be the quickest and easiest method, with airborne contamination again a concern. A power bandsaw or hacksaw would reduce the potential airborne contamination but the work hardening of the metals must be considered. After the cut is complete, the upper portion would be carried to a designated lay down area. The flange bolts would then be loosened using appropriate tooling. Although it is assumed that the torque necessary to strip the threads can be generated by the special tooling, cutting or breaking of the bolts may be required. The remainder of the CRDM would then be removed.

At this point, it would be necessary to separate the leadscrew assembly at a controlled location down inside the head. The access is limited by the 2.765" inside diameter of the CRDM nozzle and the 1-1/2" outside diameter of the remaining leadscrew. Numerous leadscrew assembly separation options were investigated and are listed below:

1. Torch cut - gas

2. Electric ARC cut, Electron Discharge Machining
3. Mechanically cut - cutting tools, hydraulic shear
4. Chemically cut - acid, etc.
5. Chemically machine
6. Hydrogen embrittlement
7. Thermal Shock
8. Freeze - nil ductility
9. Heat soften
10. Twist apart
11. Pull apart

As shown in Figure 2.3-1, the leadscrew assembly consists of four sections connected at three locations by pairs of stainless steel pins held in place by sleeves. The relative material strengths of the components are listed in Table 2.3-9. Based on the geometric and structural considerations all but two of the eleven options investigated were discarded as impractical. The following corresponding list briefly summarizes the reasons for rejection:

1. Geometric constraints limit the size of the torch and stainless steel does not burn, it requires flux or powder injection.

2. Power levels required coupled with geometric constraints of tooling make impractical.
3. Geometric constraints on tooling and the difficulty in accurately controlling the feed speed.
4. Would take too long. Time needed is estimated to be one month.
5. It is impractical to establish anodic-cathodic reaction since all metal structures in the reactor vessel and the reactor vessel itself are electrically connected to the leadscrew.
6. Hard to maintain hydrogen environment, explosive, too slow, unreliable results.
7. Would at best make brittle, still need impact to break, hard to apply.
8. Essentially no nil ductility temperature.
9. Conceivably could heat to reduce stress flow, however, problems in heating the leadscrew inside the reactor vessel make this impractical.

The last two options, numbers 10 and 11, were investigated further and the results of several calculations performed appear in Table 2.3-10. The 500ft-lbs of torque necessary to shear the pins would not be hard to generate, however, due to the uncertain condition of the spider and brazement it was considered not posssible to predict where breakage would occur.

The best method for obtaining a controlled separation would be shearing the connecting pins by pulling the leadscrew assembly apart. The magnitude of the force necessary would be approximately six tons. In order to insure that the control rods are not pulled out of the fuel assembly, a thick walled pipe would be slipped down around the leadscrew to the hub of the spider assembly as a hold down while a jacking force was applied. A block clamp would be placed on top of the leadscrew to transmit force to the leadscrew. Separation of the leadscrew assembly upon the application of force would take place at either one of the remaining two pinned connections or at the conceptual design of the push/pull tool as shown in Figure 2.3-11.

Once an initial CRDM penetration has been completed using the preceeding methods then subsequent leadscrews which fail to uncouple could be cut in the head using remote tooling. A saw type or hydraulic shear cutter could be lowered through an open nozzle and used to cut adjacent leadscrews below the leadscrew support.

Tooling would have to be designed which would fit through a CRDM nozzle and reach over to an adjacent leadscrew located approximately 12" away. This would replace the hydraulic jack method of separation and probably reduce separation time and man-rem exposure. A conceptual design of this in-head leadscrew cutter is shown in Figure 2.3-12.

The cutting of a special hole in the reactor vessel head, either by enlarging the existing thermocouple hole or making a separate penetration was evaluated.

The reactor vessel head is made of 7" thick carbon steel clad with 0.125" minimum 3/16"nominal stainless steel. The existing thermocouple penetration is a 0.614" diameter hole drilled vertically through the head.

The enlarged hole would follow the existing vertical path. The new penetration would be made radially in order to reduce stress concentrations. The necessary size of each penetration would depend on the exact locations of the holes and would be on the order of 2 to 4 inches in diameter. Tooling would consist of boring equipment mounted on a template. The template would be bolted to the head using drilled and tapped holes. In the case of the new penetration, a pilot hole would first be made using a magentic base drill. In both instances, the hole would be cut using progressively larger boring bars. The cutting of the hole would present no real problem in itself other than being a time consuming process. However, the subsequent repair of such a hole would present problems in three major areas:

1. Stress relief around hole
2. Protection of exposed carbon steel surfaces
3. Structural integrity of pressure vessel following repair.

Investigation into these problem areas has resulted in the opinion that although such a penetration could conceivably be made and repaired it would be done only as a last resort and would be further evaluated at that time. Alternate access routes other than existing CRDMs and thermocouples are considered impractical at this time.

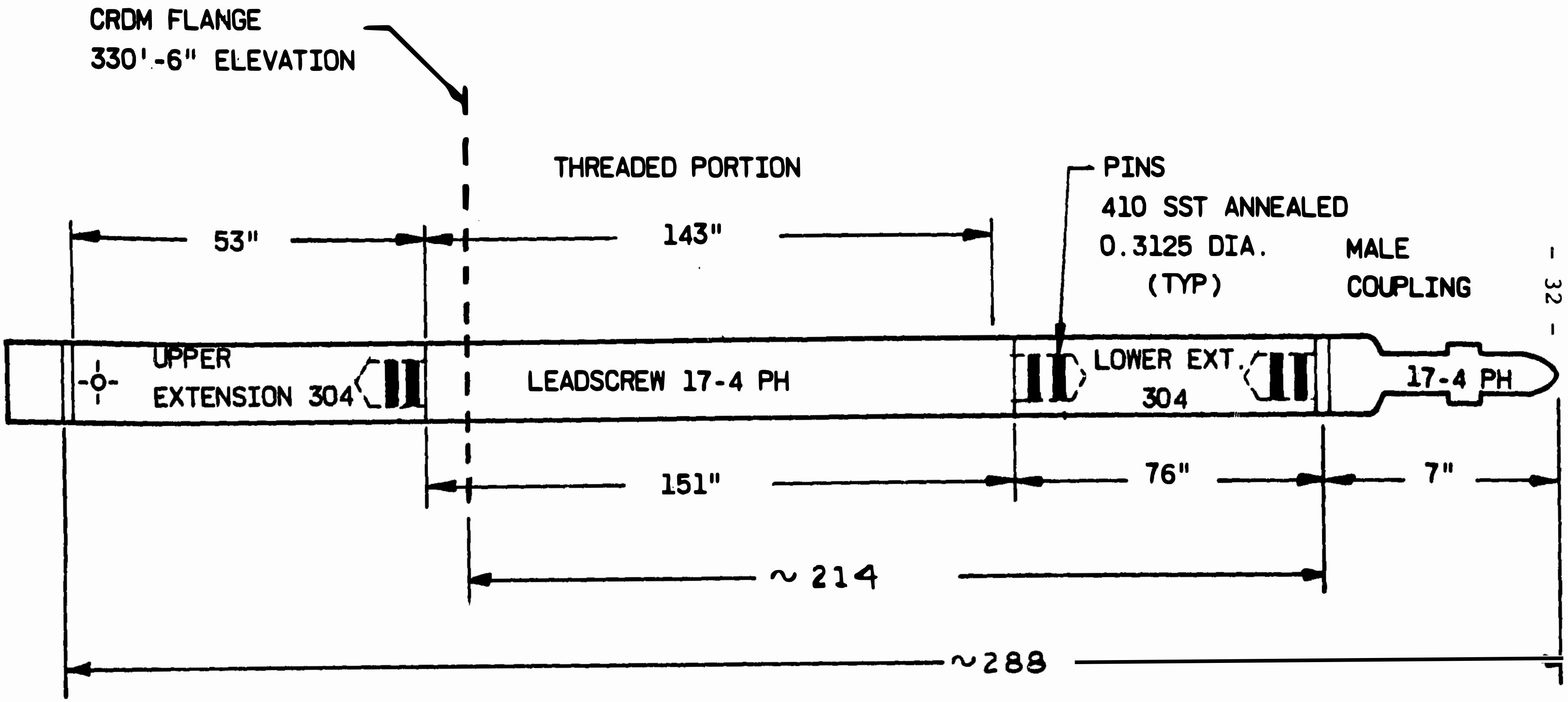


Figure 2.3-1 LEADSCREW ASSEMBLY

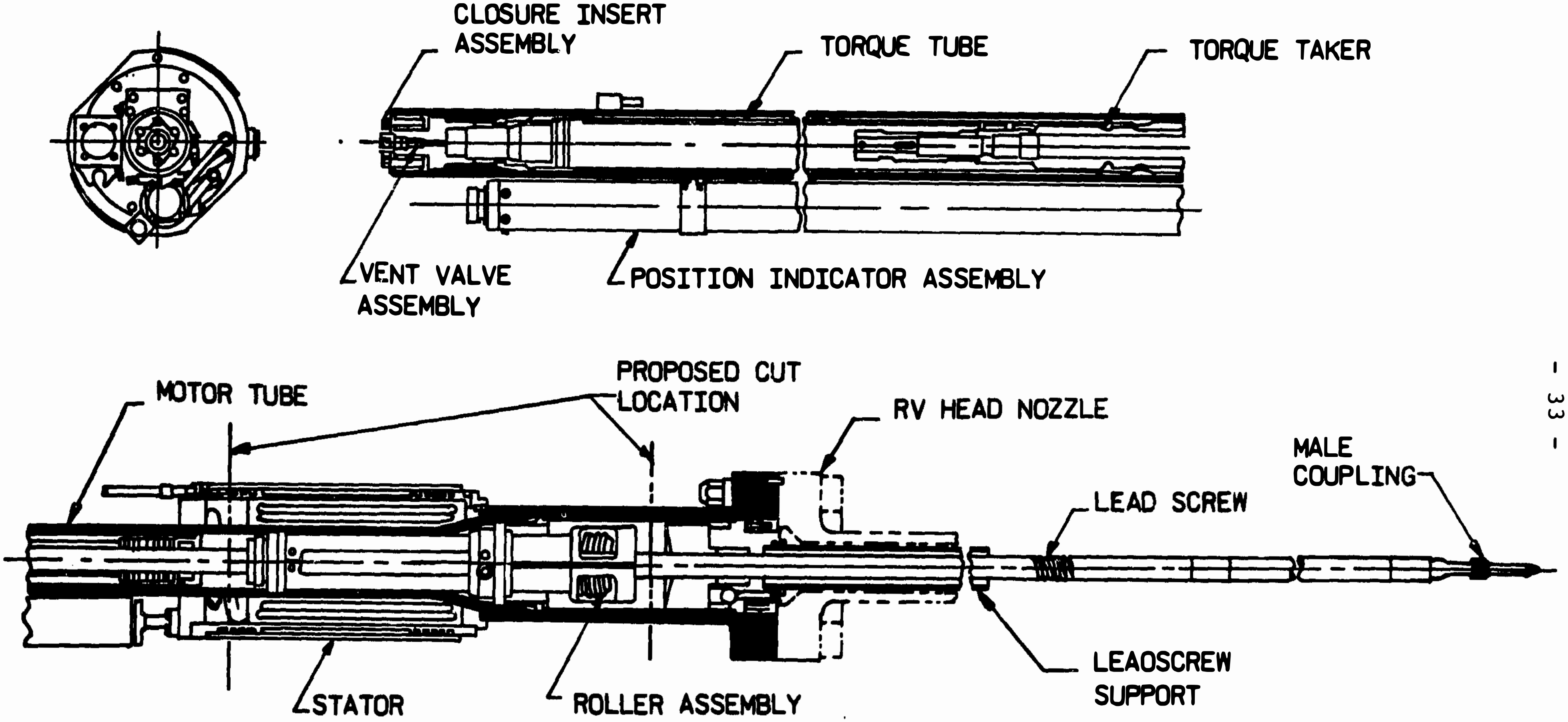


Figure 2.3-2 CONTROL ROD DRIVE MECHANISM

Table 2.3-3

TOOLING SUMMARY

Purpose	Notes	Tooling Considered
Remove PI	Hose type clamp and stud and nut engagement	Pry bars, long handled cutters, lifters
Remove Stator	Lift and Remove	U-shaped hook to lift at bottom
Cut through service structure	3/4" thick carbon steel not stress relieved	Cutting torch, abrasive disc reciprocating hacksaw
Cut through motor tube and leadscrew	Motor tube - app. 1/2" thick stainless steel Leadscrew - 1 1/2" dia. threaded shaft, 17-4 Ph H-1100 condition	1. Reciprocating hacksaw 2. Power bandsaw 3. Abrasive disc
Pull apart leadscrew assembly	Shear two 0.3125" dia. SS pins/pull coupling out of spider	Hydraulic hollow - cylinder jack, long thick walled pipe. Glycerogen to be used as hydrolic fluid.
Remove CRDM holddown bolts	1" bolts (8)	1. Heavy duty socket wrench with lever arm 2. Saw 3. Double offset wrench
Remove T/C flange holddown bolts	3/4" bolts (4)	Same as 1 & 2 above
Cut adjacent leadscrew	Reach through CRDM nozzle and cut adjacent leadscrew in the head	Saw type cutter, Hydraulic

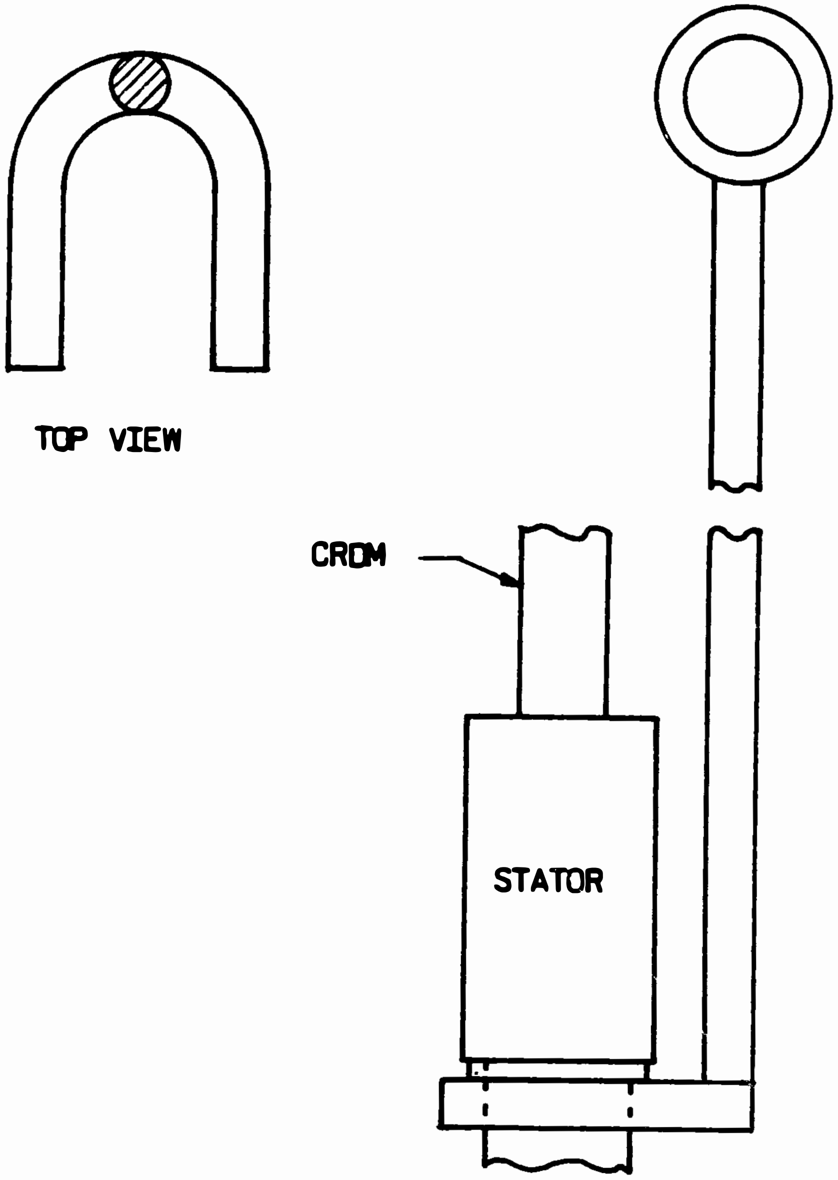


Figure 2.3-4 STATOR LIFTING TOOL

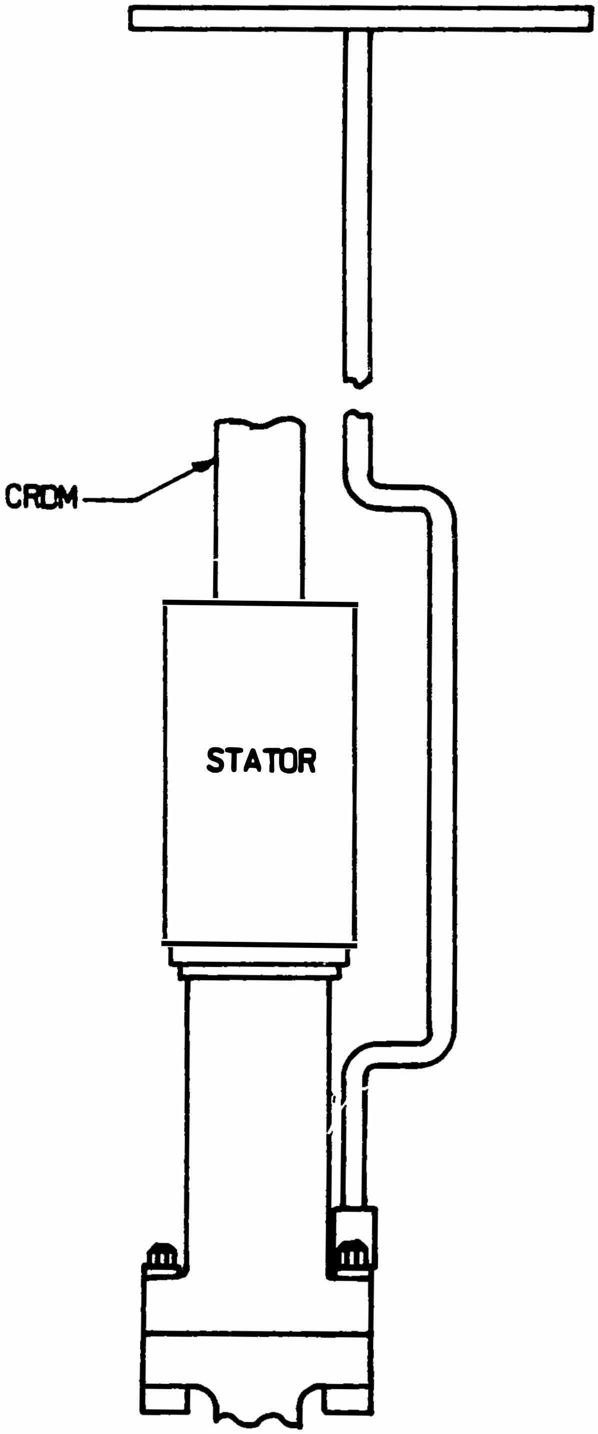


Figure 2.3-5 DOUBLE OFFSET FLANGE BOLT TOOL

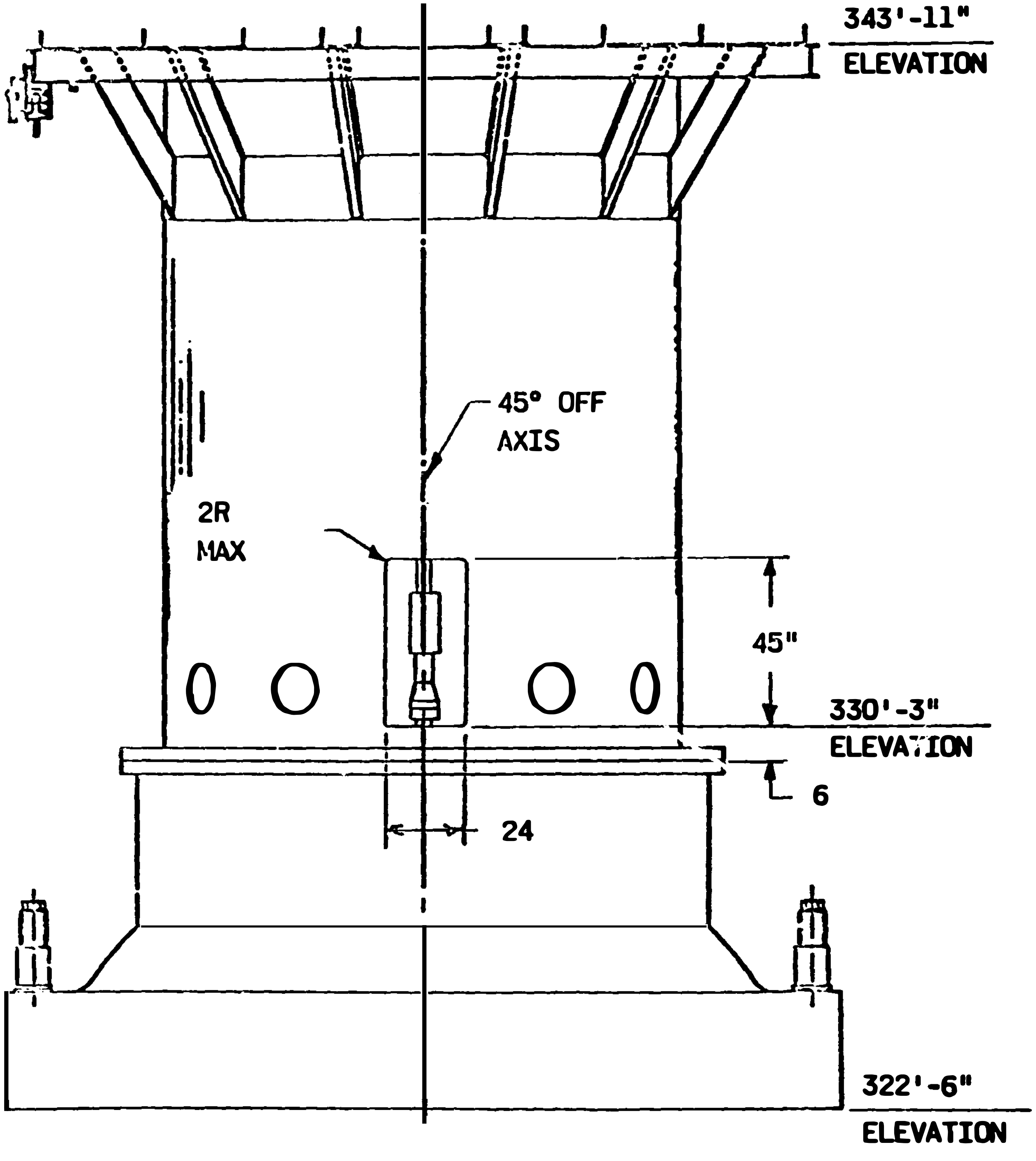


Figure 2.3-6 CRDM ACCESS HOLE IN SERVICE STRUCTURE

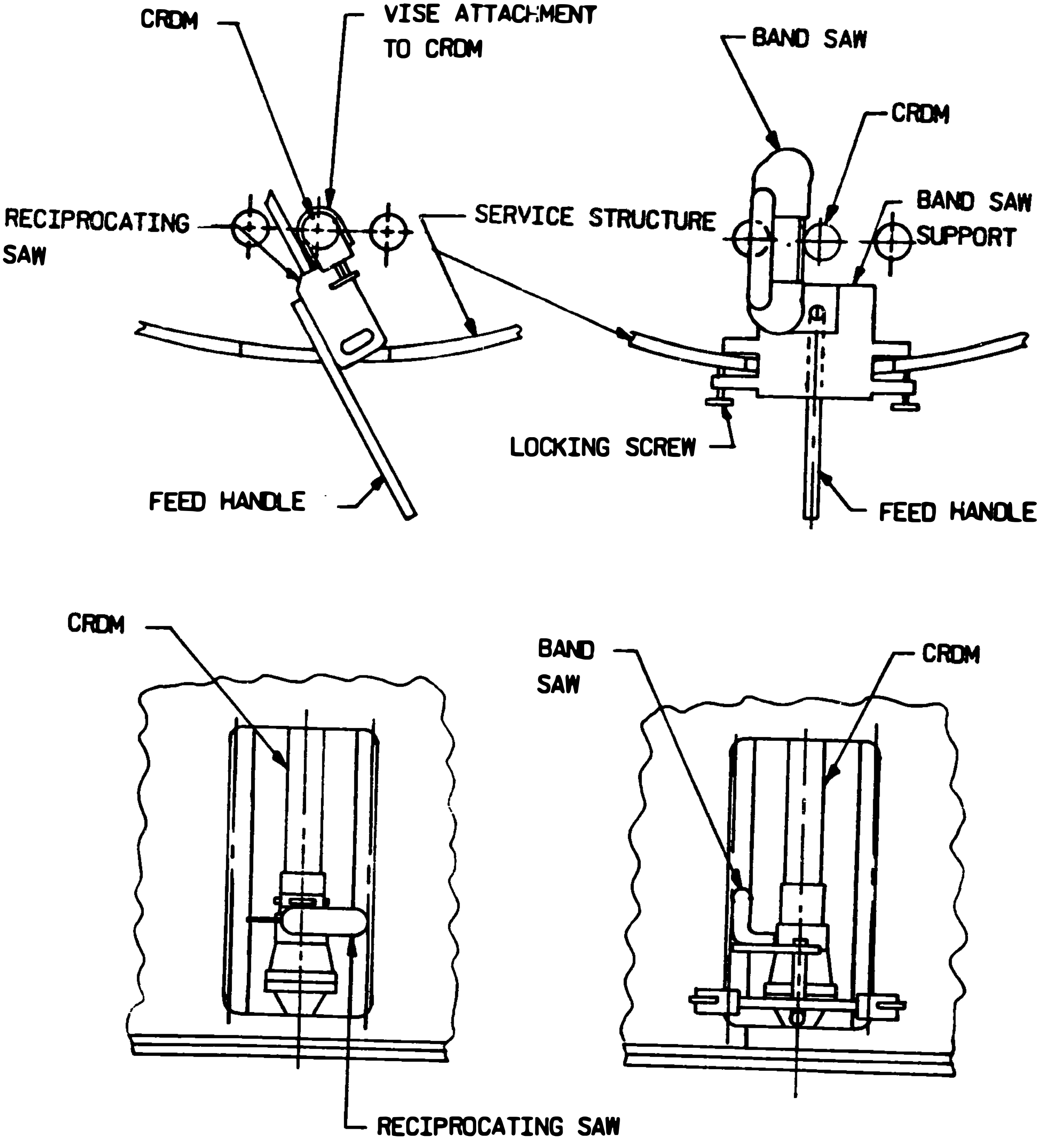


Figure 2.3-7 MOTOR TUBE/LEADSCREW CUTTING CONCEPT

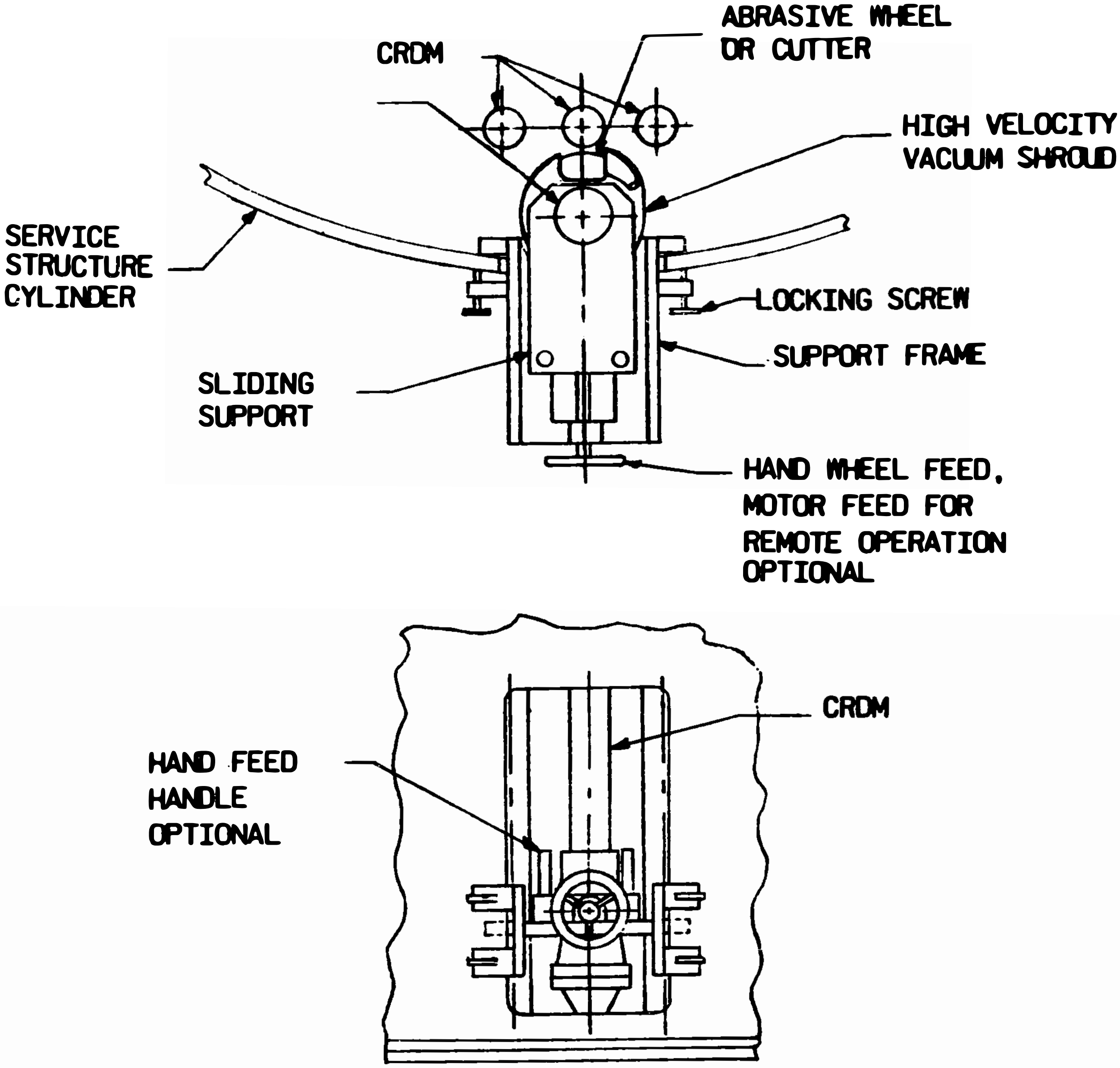


Figure 2.3-8 CRDM CUT-OFF CONCEPT

Source: Mark's Handbook

Material	**Ultimate (PSI)**	**Yield (PSI)**
304 Annealed	85,000	35,000
410 Annealed	75,000	40,000
17-4 PH H-1100	140,000	115,000

Best Estimate Of Current Properties:

No Significant Change Due To Transient

Figure 2.3-9 Relative Strengths

Torque To Shear Pins	500 Ft-Lbs
Lifting Force To Shear Pins	11,500 Lbs
Torque To Shear Off Teeth On Coupling	> 3,000 Ft-Lbs
Torque To Twist Off Shaft (304 Annealed)	> 1,900 Ft-Lbs

Assuming No Significant Change In Metalurgical Properties Due To Transient

Figure 2.3-10 Forces Necessary To Separate Leadscrew

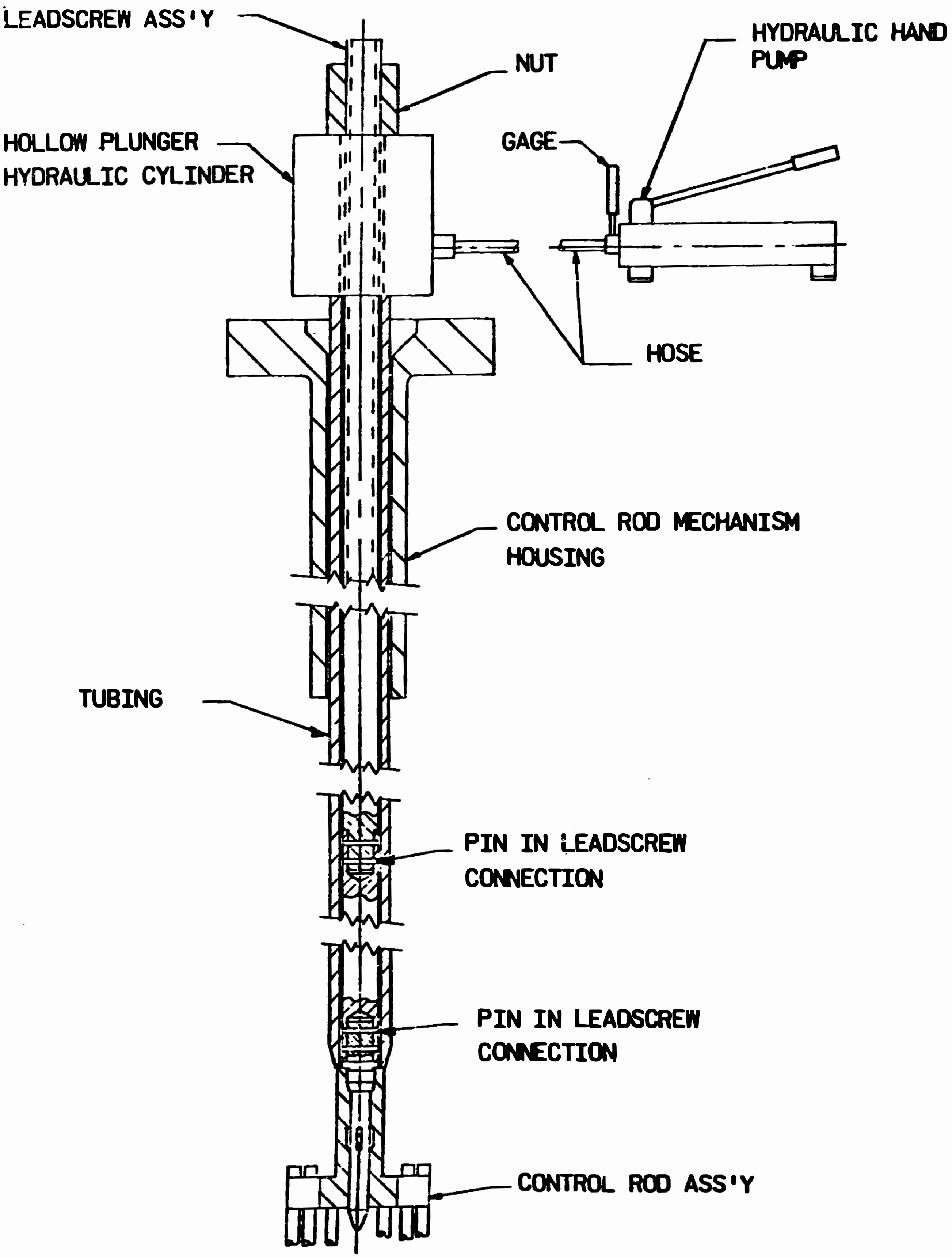


Figure 2.3-11 LEADSCREW PULLER/SEPARATOR

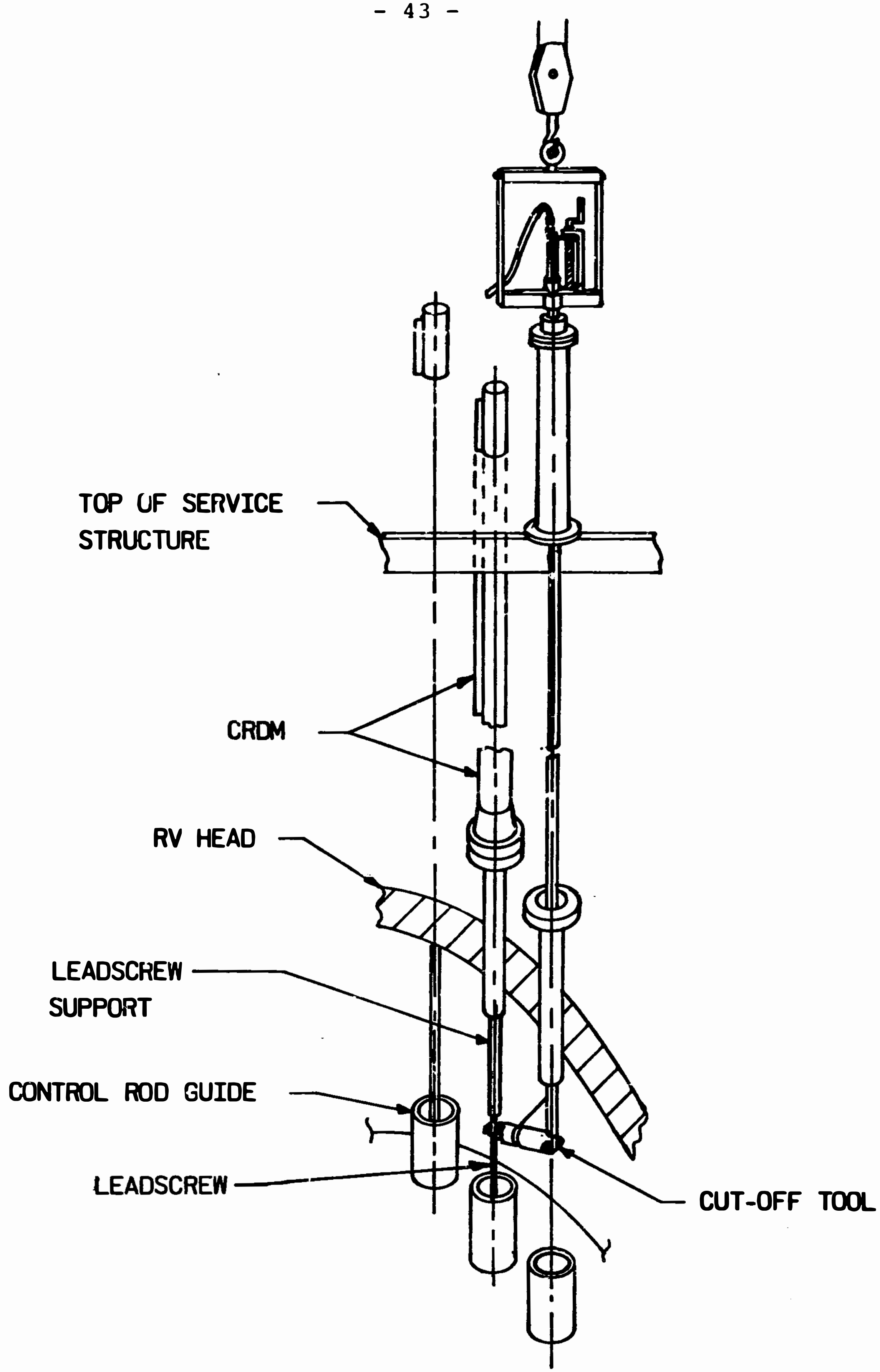


Figure 2.3-12 IN HEAD LEADSCREW CUTTER

2.4 Inspection Technique

The objective of this inspection is to obtain a geometrical representation of the reactor internals down to and including the top of several fuel assemblies.

The criteria used in evaluating different inspection techniques are divided into three areas: Results, Physical limitations, and Environment.

Under results, the following characteristics were considered:

1. Resolution - the system must have sufficient resolution to accurately represent complex shapes of any damage or unusual findings.
2. References - the inspection system must be position referenced, either through a positive position control system or have a "field of view" sufficiently large so that enough points of reference are included to define the location.
3. Recordable Output - the inspection results must be accurately recorded either by a hard copy output, photographs, or video tapes.

Under physical size limitations, the following characteristics were considered:

1. The inspection probe must operate at a minimum of 40 feet from the control unit.
2. The inspection probe must be capable of passing through a 2.765" diameter opening.
3. The rigid length of the probe should be minimized to facilitate ease of entry via a complex entry path.

Under environment, the following conditions were considered:

1. Maximum underwater depth of 40'
2. Maximum water temperature 150°F
3. Radiation levels up to 1000 R/hr.
4. No light
5. Possible opaque water

Two types of systems were considered in meeting the above criteria, video and ultrasonics. An example of ultrasonic system was conceptualized after researching the present ultrasonic market and determining that no current system was available which could meet the inspection criteria. This system would include a foldable transducer array, control unit, and a computer for processing the returning information and providing an output to a graphic display or hard copy unit. The ultrasonic system would require positive array positioning. This positive positioning of the array would be required since ultrasonic transducers can transmit and sense at only one point at any particular time. To build an image, the transducer array must be moved in a controlled path to trace out a line of data. This controlled path can be designed such that an orderly scan of the desired object is traced out. In the conceptual system outlined previously, the control system would have to position and unfold the probe, then be able to move the transducer array accurately enough to obtain a fine resolution scan. The control system which would accomplish this would be complex and would have to be developed along with the overall ultrasonic system. The image is constructed by sound reflected from perpendicular surfaces only. The image would be topographic and would not show shadow effects or surface apprearance. A finite period of time would be required for this imaging process. The principal advantage of the ultrasonic system would be its ability to operate in an opaque liquid.

Three video systems were compared and the results of this comparison are shown in Table 2.4-1. The video systems were all capable of meeting the criteria established for the inspection system with the exception of operation in opaque water. As a contingency in the event of a murky water situation, some conceptual designs of murky water viewing sytems were tested. These designs were tested on an actual underwater camera (the Westinghouse ETV 1250) in a mixture of tap water and common soil. Visibility was measured at about 2". The first idea tested was the use of a fresh water jet intended to provide a constant flushing in front of the camera with a clear water viewing plume. As tested, the flushing action sucked debris into the plume and the turbulence in the water caused the effectiveness of the camera lights to be reduced. The end result of using the plume was decreased not increased viewing capability.

The second concept tested employed bright lights near the camera. This method was unsuccessful because the light reflected off of the suspended particles creating glare.

The third and only successful design tried was an inflatable bag. In this system, a clear plastic bag is slipped over the front of the camera and inflated with a constant supply of fresh water to provide a viewing space of clear water between the camera lens and the object viewed. Vent holes are placed around the bag for discharge of the clear water. The bag tested provided clear viewing as long as the bag was in contact with the viewing surface. A conceptual sketch of the inflating bag system is shown in Figure 2.4-2.

Demonstrations of the Westinghouse ETV-1250 and the Diamond ST-6 were conducted at B&W in Lynchburg. The Westinghouse system proved to be the better system during the demonstrations. The integral lighting system was judged superior in both right angle and straight ahead viewing. The Westinghouse system also has a better arrangement for changing viewing accessories, (threaded connections versus set screws). The Diamond camera has a higher resolution specification, 800 vs 550 lines for the Westinghouse; however, the Westinghouse produced a much clearer picture during the demonstrations. Unlike the Westinghouse system, the right angle viewing attachments for the Diamond system have not yet been fully developed and tested.

Other differences between those cameras were minor. The FERNSEH System was eliminated early in the selection process because of larger camera size, larger size of the forward viewing attachment, and discontinuities in the surface of the right angle viewing attachment which would cause the camera to hang up.

No system considered would have sufficient lighting integral with the camera. Auxiliary lighting will be necessary for general area coverage. These lights can be fabricated from existing components to meet the access and environmental requirements of the inspection process.

Table 2.4-1

CAMERA SPECIFICATION TABLE

	Diamond ST-6	Fersneh R-93 TM	Westinghouse ETV 1250
Dia X length (with connector)	1-1/8 X 14.5"	1-19/32 X 11-5/6" without connector	1-1/4 X 13-2/5"
Resolution	800 lines	550 lines	550 lines
Gray Scale	10 shades	10 shades	10 shades
Focus Range	1/2" to	13mm to	1" to
Remote Focus	Yes	Yes	Yes
Automatic Light Compensation	Yes	Remote Iris Control	Yes
Straight Ahead Lighting Power	<20 watts	150 watts	40 watt integral
Right Angle Lighting Power	20 watts	150 watts	150 watt
Newvicon Tube Available	Epicon	Yes	Yes
Maximum Radiation Field	5 X 10^6 R/hr	Unknown	2 X 10^6 R/hr
Cumulative Exposure Limit	10^8 R	1.6 X 10^8 R	10^8 R
Temperature Range	-20°C to +70°C	-25°C to +60°C	+60°C
Lens	16mm	11mm	16mm
NOTES:	Right angle viewing attachments not developed and tested		Camera system and all attachments first marketed May 1977

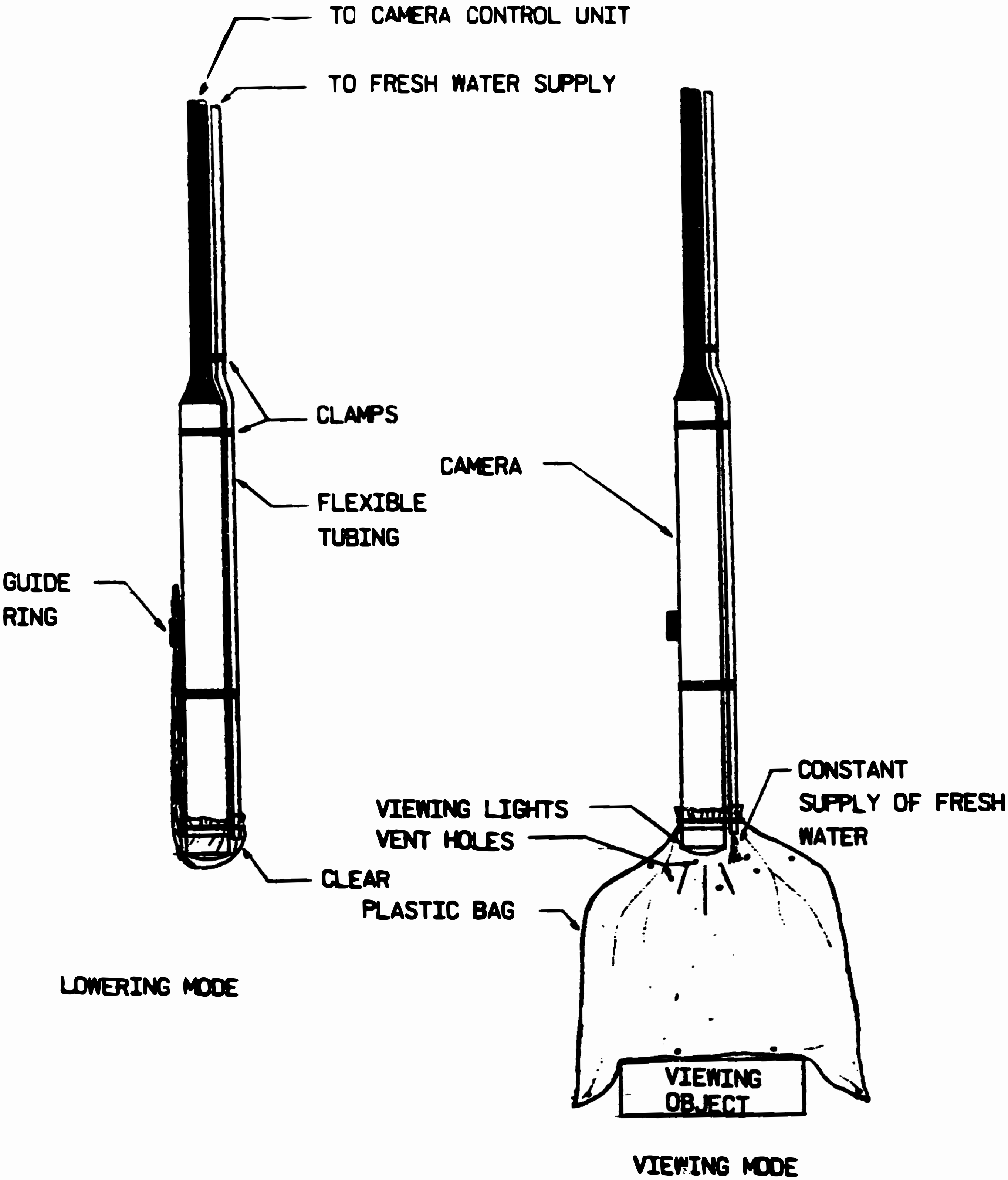


Figure 2.4-2 CONCEPT FOR MURKY WATER VIEWING

2.5 Manipulators

Manipulators must be designed to maneuver three types of devices within the reactor vessel during inspection operations:

1. Cameras - Manipulator must be able to move a camera to four desired points of observation:
    a. Tops of peripheral fuel assemblies.
        - To reach this area camera must travel from point of entry, around the edge of the plenum cover then down along the inside of the plenum cylinder to a point directly above the peripheral fuel assemblies.
    b. The area between the core support shielding and the plenum.
        - The camera must travel from point of entry to the gap between the core support shield and the plenum, then down into this gap as far as possible.
    c. The interior of the control rod brazements.
        - The camera will be lowered straight down from the control rod drive mechanism nozzle into the guide tube brazements.
    d. The area on top of the plenum cover.

- The camera will be swept over the plenum in the available open area below the entry point.

2. Auxiliary Lighting - Manipulator must be able to position the auxiliary lighting in the upper head region for general illumination. It must be also capable of positioning auxiliary lighting down inside the plenum cylinder to a point above the fuel assemblies and down between the plenum cylinder and core support shield.
3. Sampling Equipment (Optional) - This manipulator must carry the swipe system over a section of the plenum cover to collect swipe samples of the plenum cover.

In addition to maneuvering its particular device to a desired location, each manipulator must also:

1. Be able to fit through the available penetration in the closure head.
2. Not encounter interference from existing structures within the closure head.
3. Allow the connecting cable for the device to feed freely for both entry and exit operations.
4. Operate reliably.

5. Allow manipulator control from outside of penetration in vessel head.
6. Allow coordination with visual observation equipment for placement, sample gathering, etc.
7. Be salvagable if camera or lighting gets stuck beyond removal.

The following options were considered for manipulators:

1. A hinged arm shown in Figure 2.5-1.
2. A hinged tube shown in Figure 2.5-2.
3. A hinged tube with provision for housing the camera shown in Figure 2.5-3.

In each case, the lower arm of the manipulator is raised and lowered by a deployment cable. The camera or light would be lowered through the manipulator by handling its electrical cables.

Based on the established criteria and an evaluation of the advantages and disadvantages of each type manipulator, a conceptual design was chosen for each operation.

Camera - A hinged tube with a camera recess, which allows a maximum length of the lower manipulator arm, was chosen. This longer lower arm allows the greatest lateral movement and gives a larger angle for a given offset. This larger angle reduces cable drag and allows a more controlled playout of the camera cable.

A method for canting the camera at a slight angle (0-30°) in a given direction is required. By use of a draw cable attached to the camera head and by rotation of the camera cable, this manipulation could be achieved. A conceptual design is shown in Figure 2.5-4. Specific designs will require extensive mock-up testing.

Auxiliary Lighting - A hinged tube with or without the recess capability (Figure 2.5-5) would be used for the auxiliary lighting. A tube was chosen over a closed hinged arm because by enclosing the electrical cable in a tube, there is a reduced risk of fouling in the manipulators.

Debris Sampling/Swipe Sampling (Optional) - For this operation, a hinged tube with an additional weighted arm connected at the bottom of the lower arm would be used (Figure 2.5-6). This arrangement will allow movement over the plenum cover in the vicinity of the CRDM nozzle (approximately 25" radius). The weighted arm which will hang vertically, will allow controlled positioning of the swipe sampler over desired areas of the plenum cover.

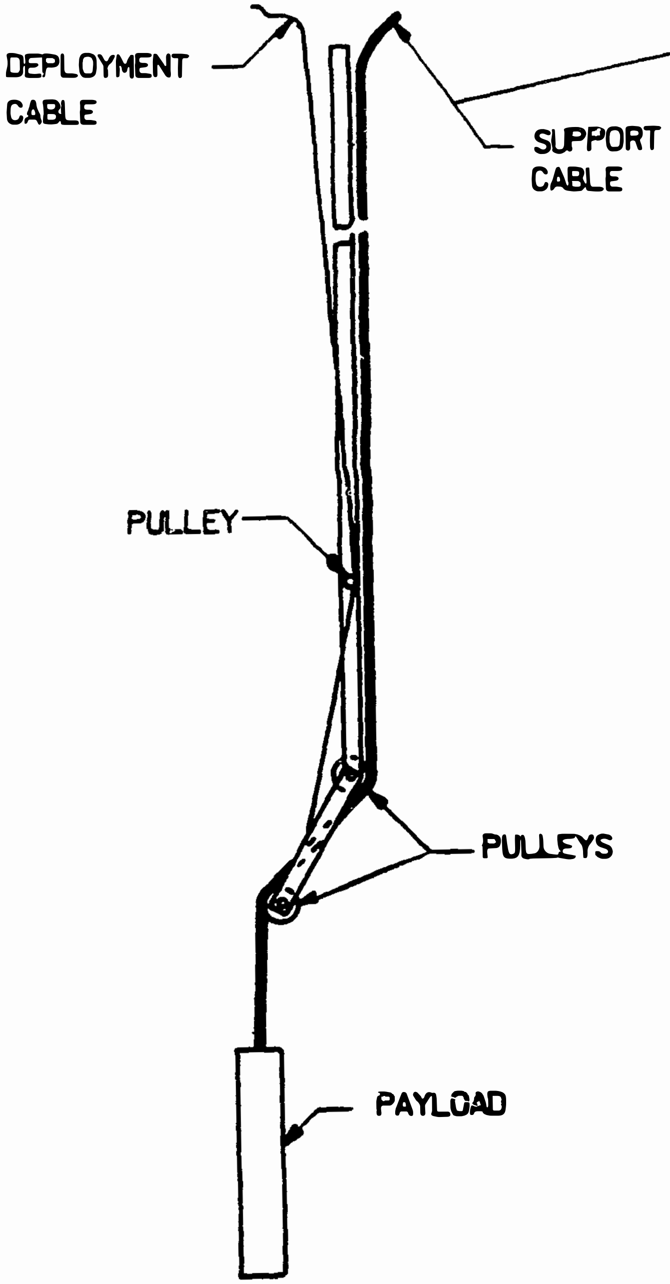


Figure 2.5-1 SIMPLE HINGED ARM MANIPULATOR

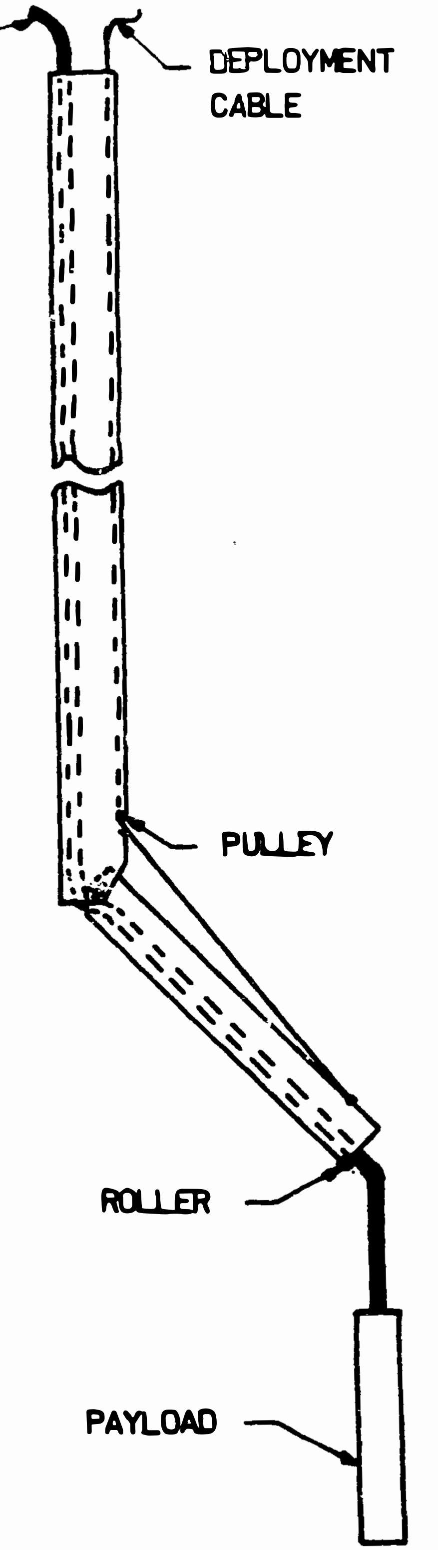


Figure 2.5-2 HINGED TUBE MANIPULATOR

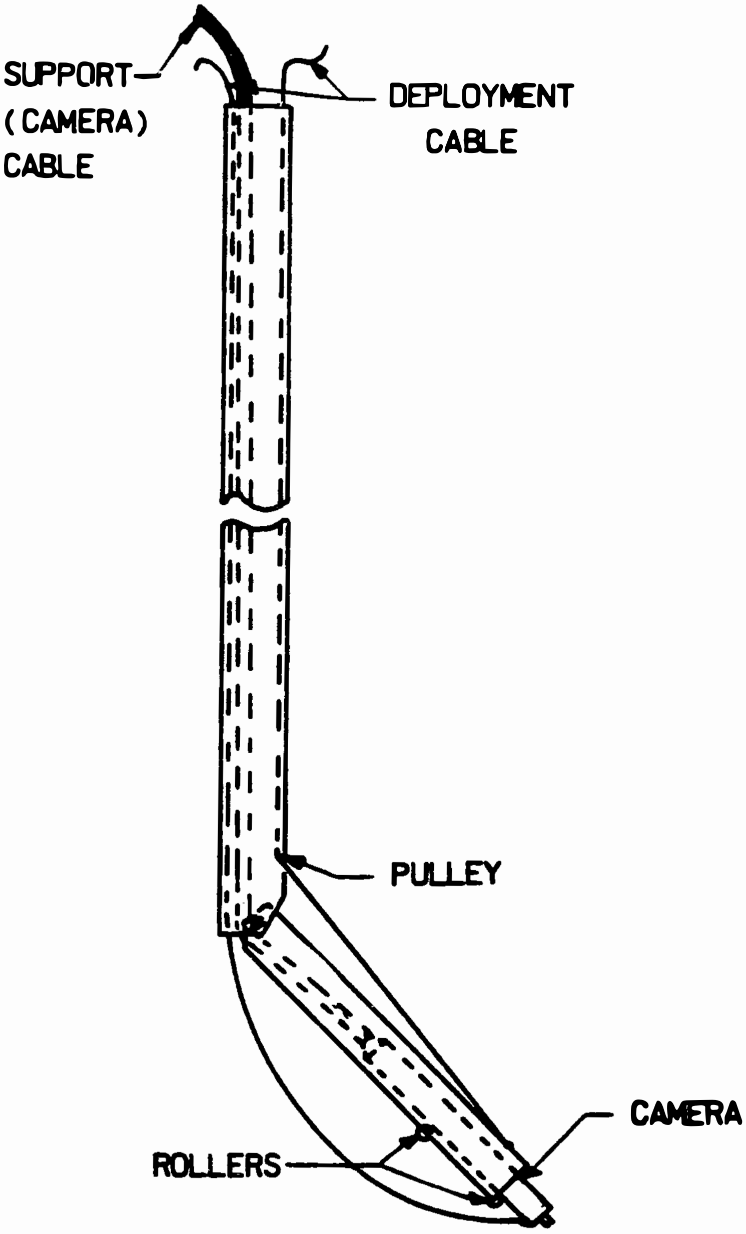


Figure 2.5-3 HINGED TUBE WITH RECESS FOR CAMERA WITHDRAWAL

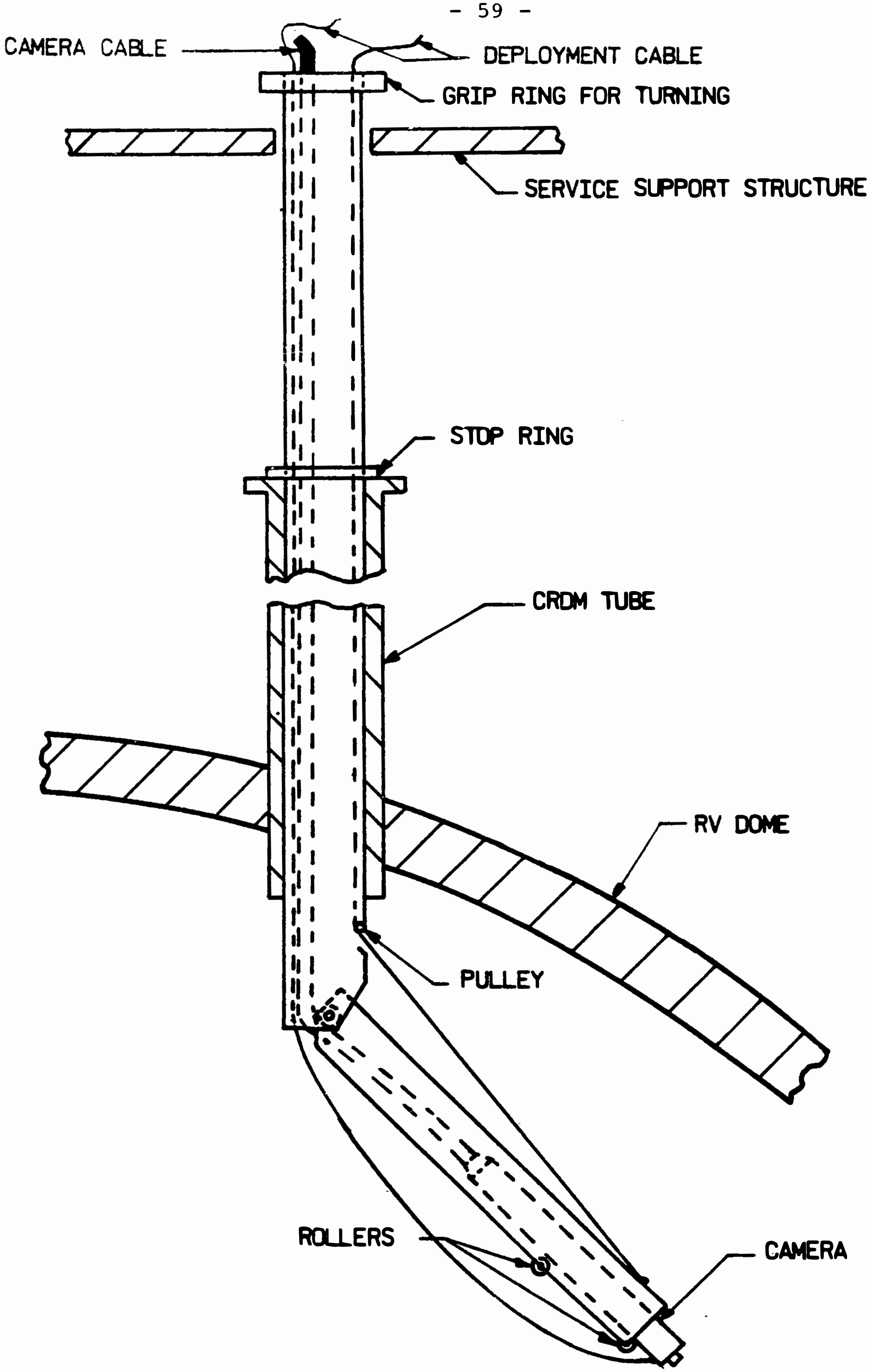


Figure 2.5-4 OPTION USING CRDM TUBE FROM SSS

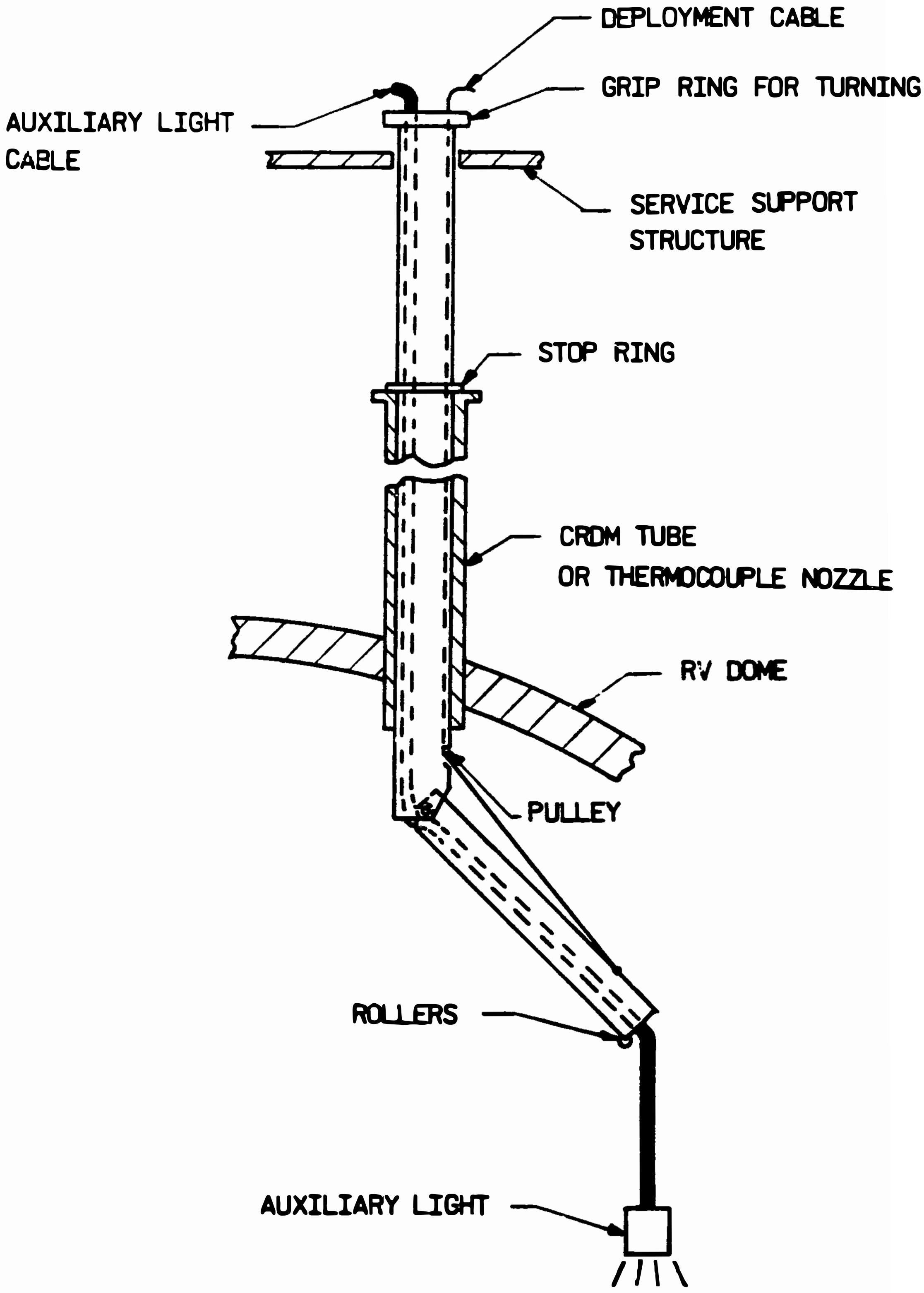


Figure 2.5-5 HINGED TUBE MANIPULATOR FOR AUXILIARY LIGHTS

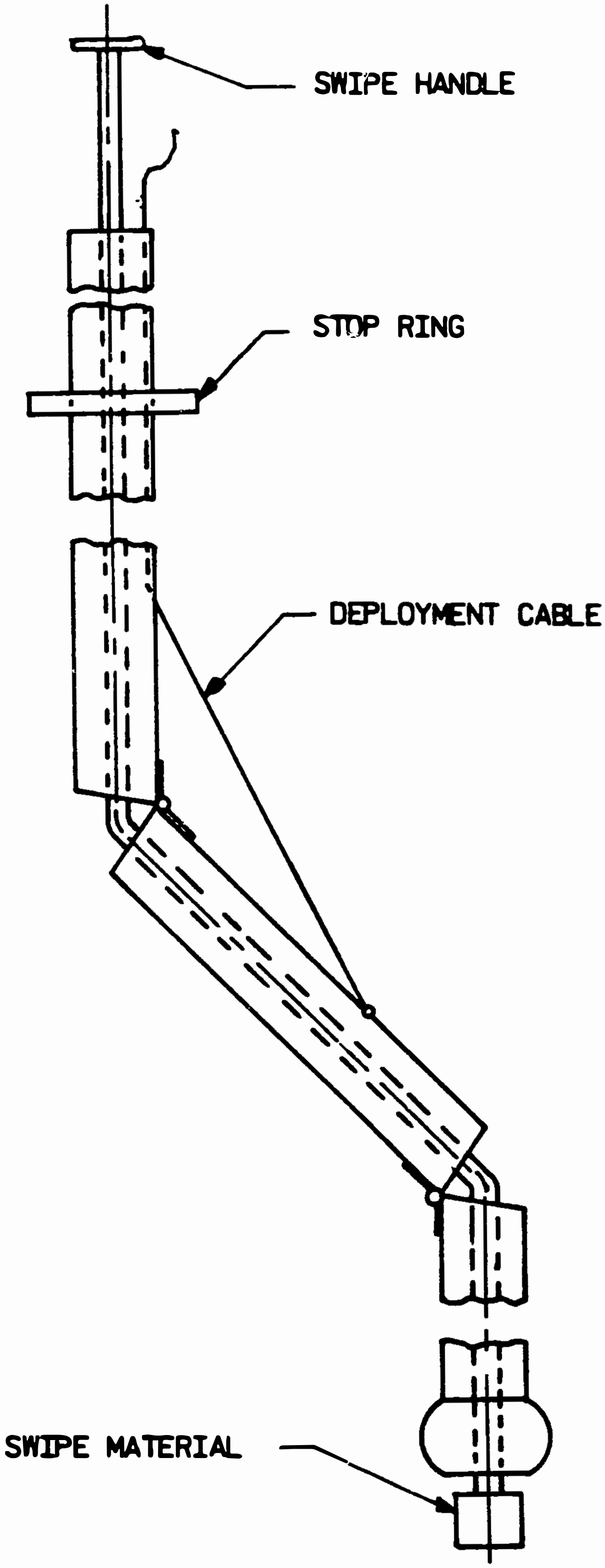


FIGURE 2.5-6 MANIPULATOR FOR SWIPE SAMPLING

2.6 Swipe Sampling (Optional)

Once access is obtained into the reactor vessel head, special sampling equipment could be used to collect swipe samples of part of the plenum cover in the vicinity of the access. Collection of particulate material could be achieved through use of a swipe system conceptually shown in Figure 2.6-1. Analysis of this would be extremely beneficial in further evaluation the consequences of the incident.

2.7 TLD Sampling (Optional)

Measurement of radiation levels at specific heights above the upper grid could be achieved by lowering a TLD "tree" vertically down through a control rod guide brazement to designated positions for calculated stay time. A map of radiation levels inside the upper vessel could then be developed and used to benchmark other analysis performed and underway.

2.8 Water Level Monitoring (Optional)

A primary water level indicator system should be established through a vent valve thermocouple nozzle. This system, if continously monitored, would serve as a back-up for existing systems thus assuring early warning of any water level changes.

2.9 Mock-ups

Mock-ups will be required for checkout and testing of the special tooling and procedures developed in Phase II. These mock-ups will also be necessary for training of personnel in the use of the tooling and procedures. The Diamond Power Specility Co. (DPSC) has been selected as the primary site for building a mock-up of the reactor vessel and CRDM arrangement. The DPSC has a test facility which includes several full scale CRDM's used for operational testing. Other smaller mock-ups will also be required to test specific tools. Conceptual designs of these mock-ups are shown in Figures 2.9-1, 2.9-2, and 2.9-3.

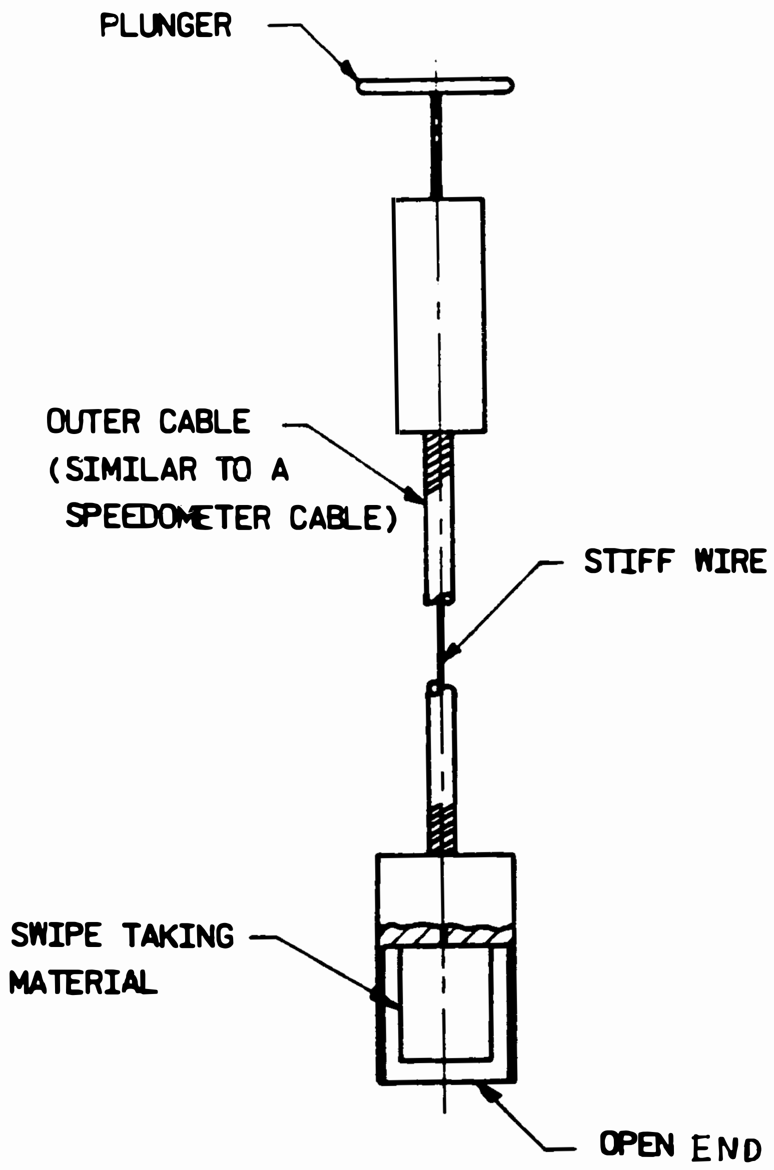


Figure 2.6-1 SWIPE SAMPLER

TO TEST NORMAL & CONTINGENCY TOOLING, MANIPULATORS, CAMERAS AND LIGHTING DEBRIS SAMPLING TOOLS

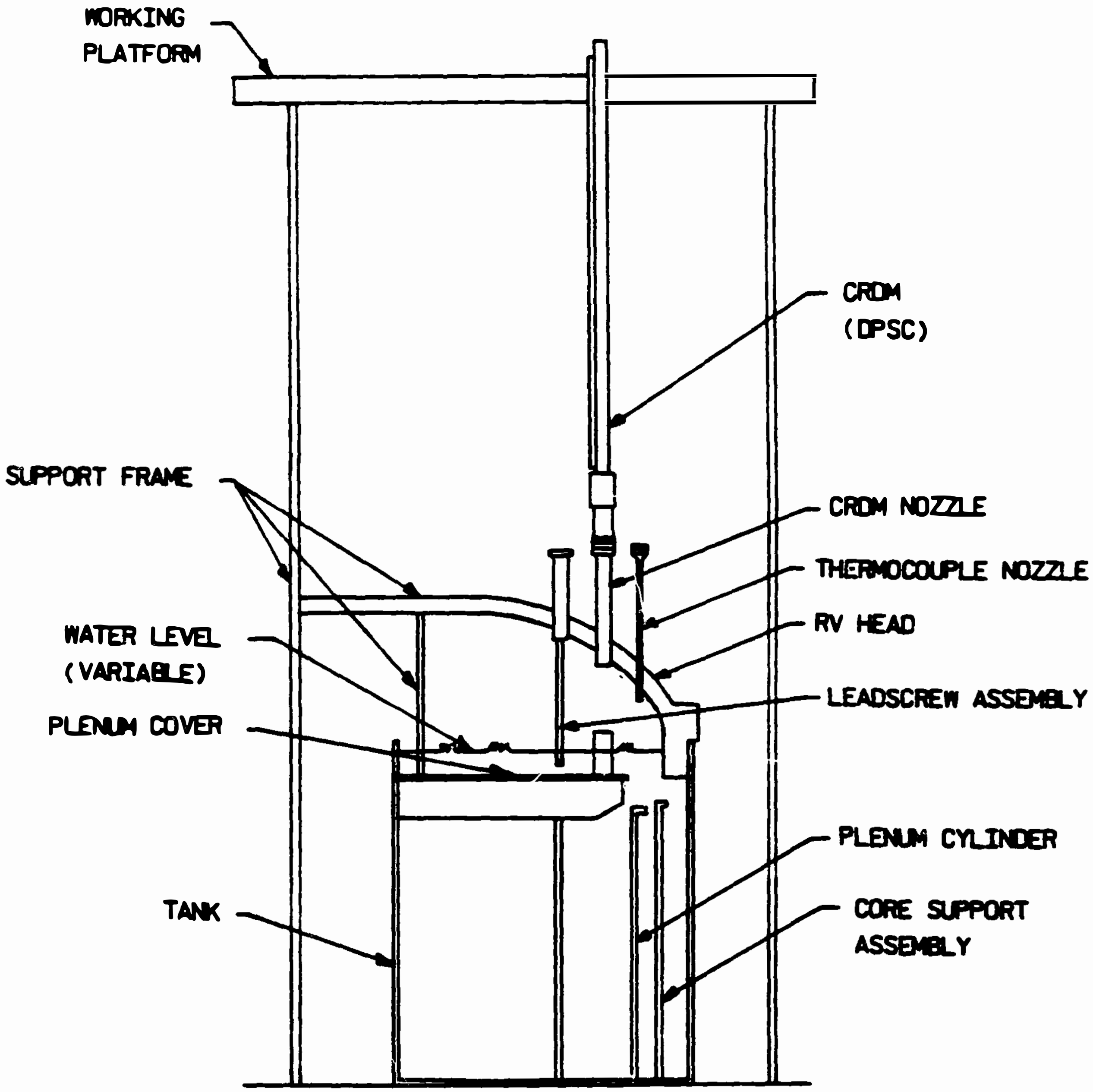


Figure 2.9-1 TEST FACILITY MOCK-UP

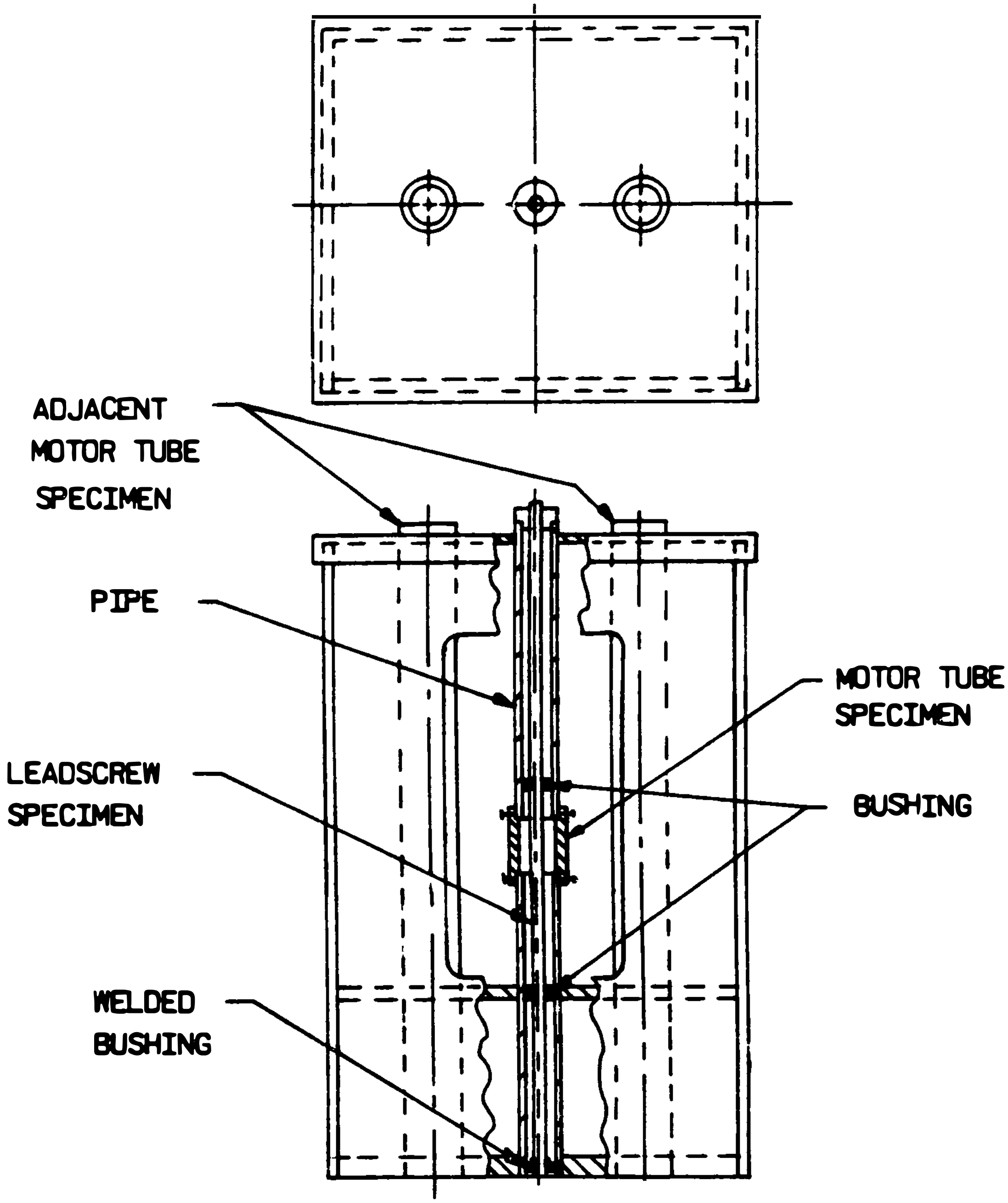


Figure 2.9-2 MOTOR TUBE/LEADSCREW CUTTING MOCKUP

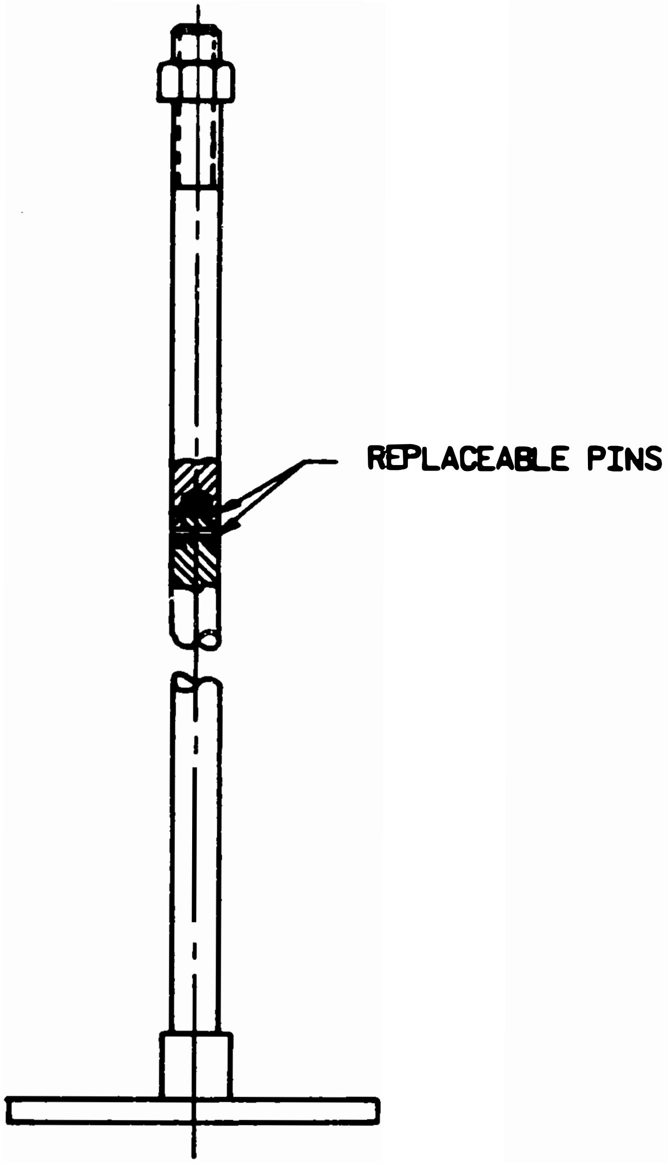
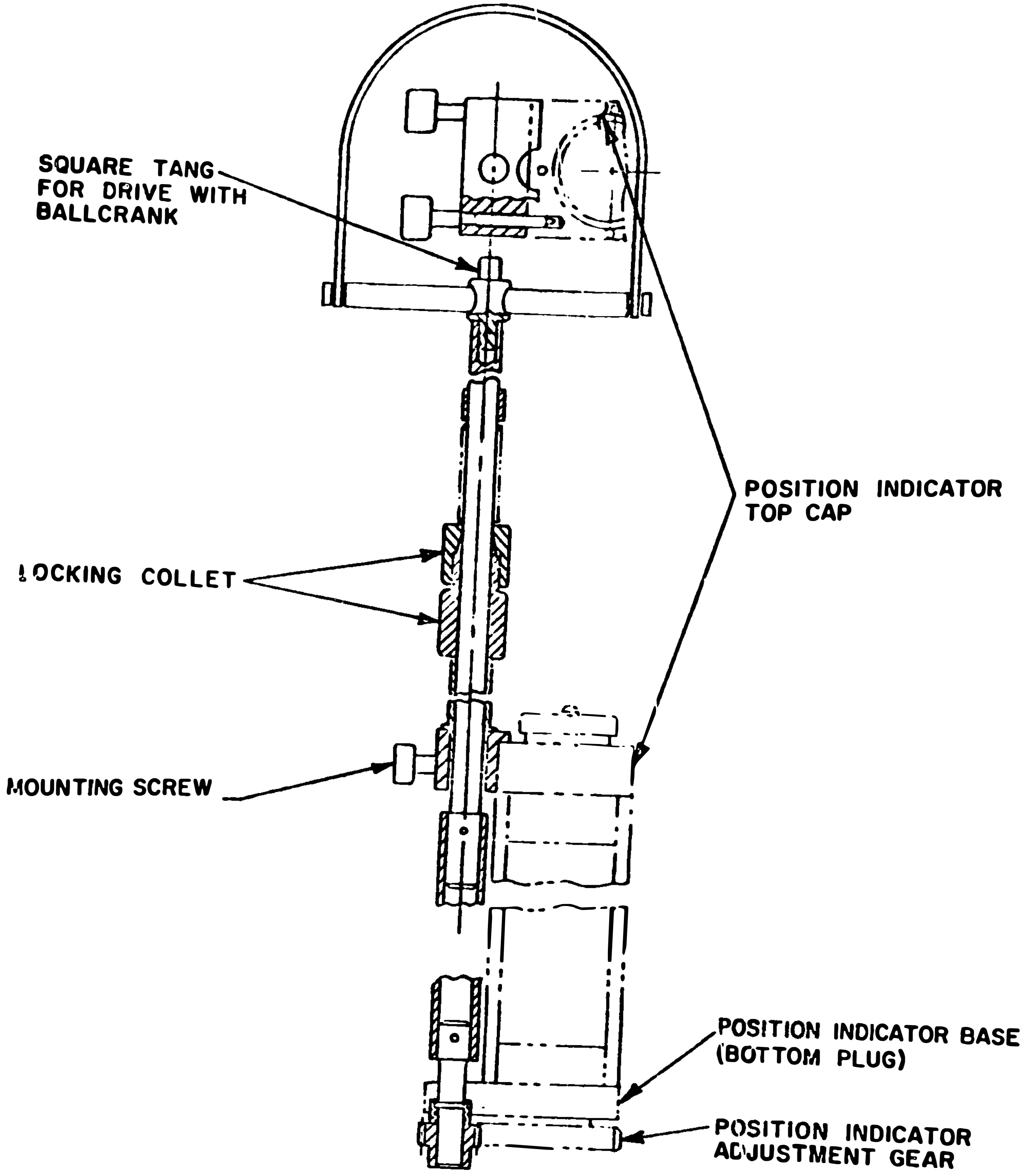


Figure 2.9-3 LEADSCREW MOCK-UP

APPENDIX I

OUTLINE OF NORMAL CRDM REMOVAL

1. Loosen seismic clamp.
2. Using the position indicator (PI) adjustment tool, Figure I-1, unthread the P.I. (Figure 2.3-2).
3. Remove the seismic clamp.
4. Using the P.I. lifting tool, Figure I-2 remove the P.I.
5. Using the stator installation/removal tool, Figure I-3, remove the stator and water jackets.
6. Remove the CRDM vent plug and by using the venting tool, Figure I-4, vent the drive.
7. Remove the CRDM top closure.
8. Use the 0 ring removal tool Figure I-5, to remove the drive.
9. Uncouple and park the leadscrew using either the leadscrew installation/removal tool, Figure I-6, or the alternate uncoupling tool, Figure I-7.
10. Remove the leadscrew from the drive using the leadscrew lifting tool, Figure I-8.
11. Unbolt the CRDM using the holddown bolt installation/removal tool Figure I-9.
12. Remove the CRDM using the CRDM lifing tool Figure I-10.



APPROXIMATE TOTAL LENGTH 196"

FIGURE I-1 P.I. ADJUSTMENT TOOL, 706508-1049

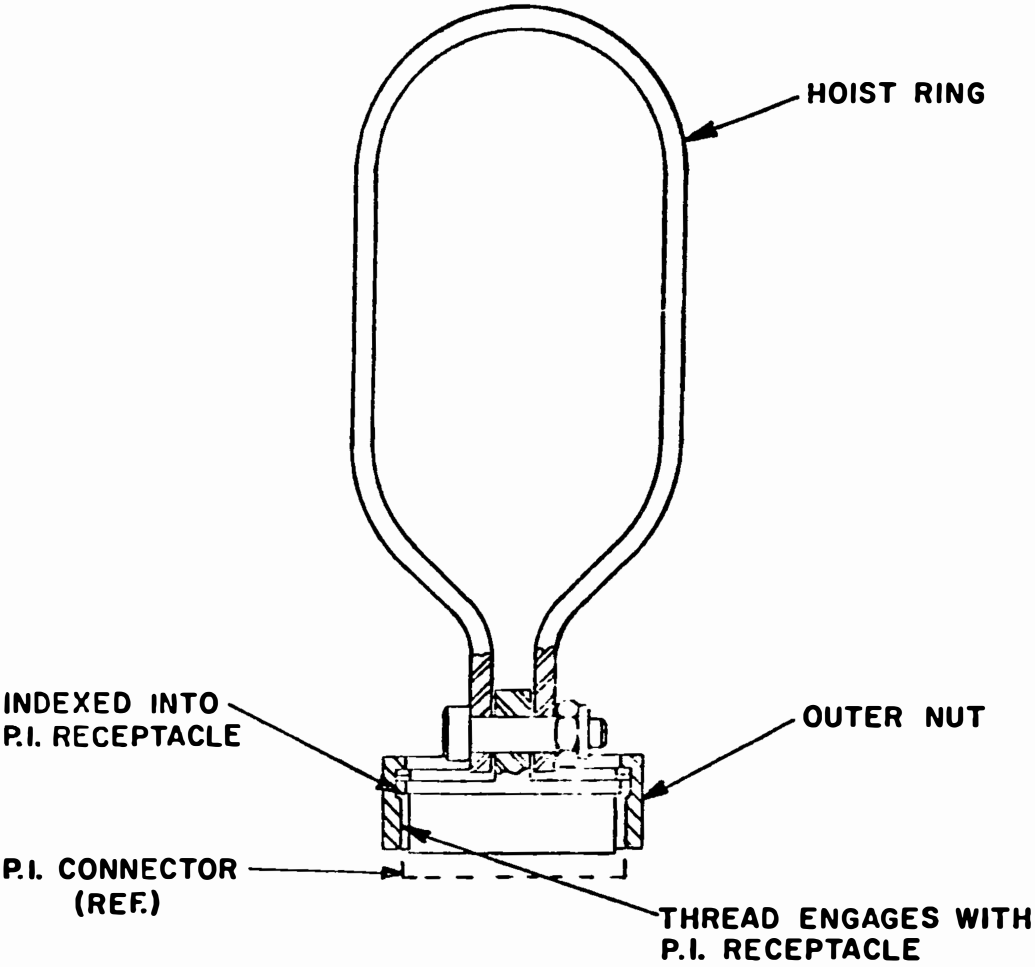
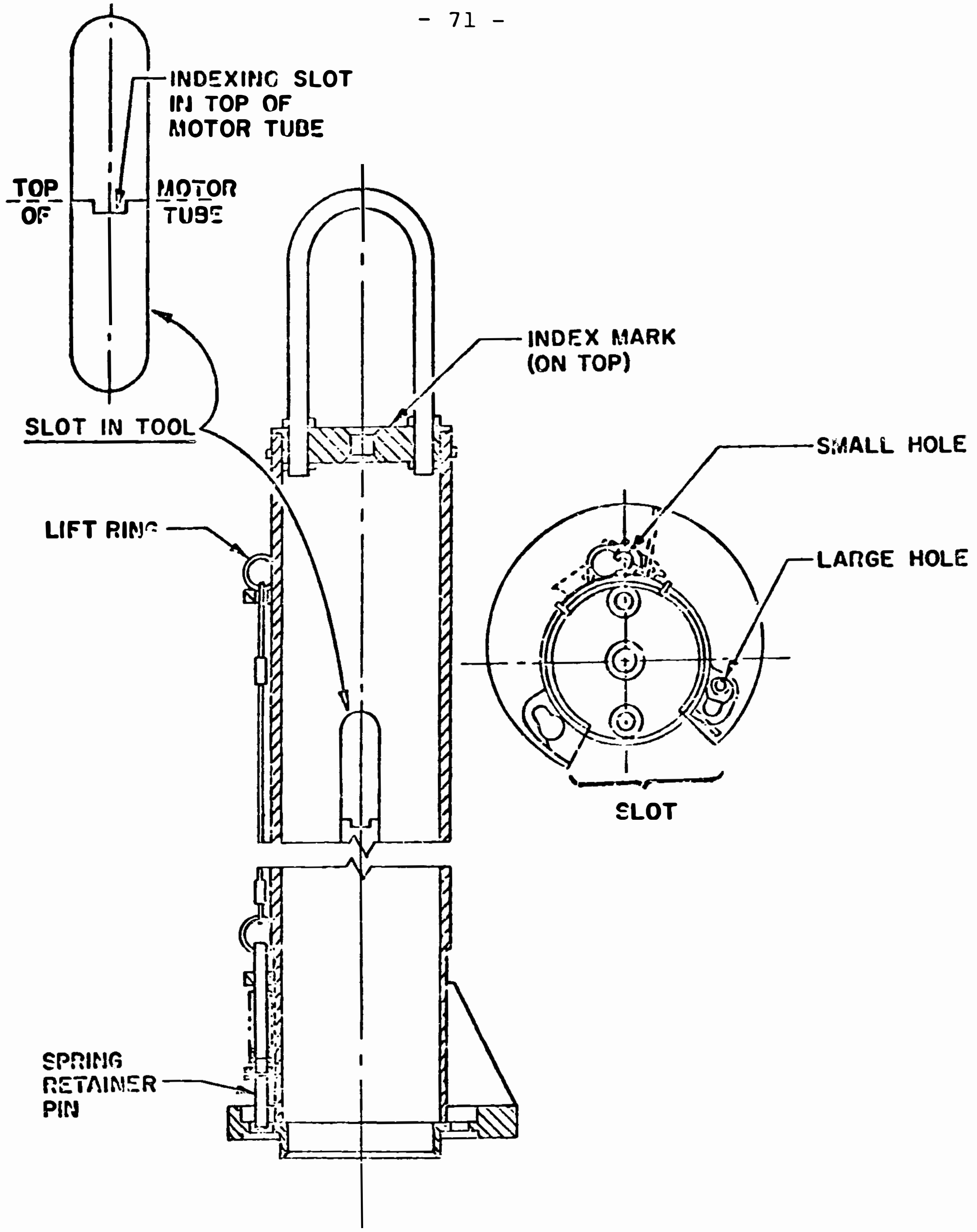


FIGURE I-2 P.I. LIFTING TOOL, 703724-1143



APPROX. TOTAL LENGTH 190"

FIGURE I-3 STATOR INSTALLATION/REMOVAL TOOL, 706544-1052

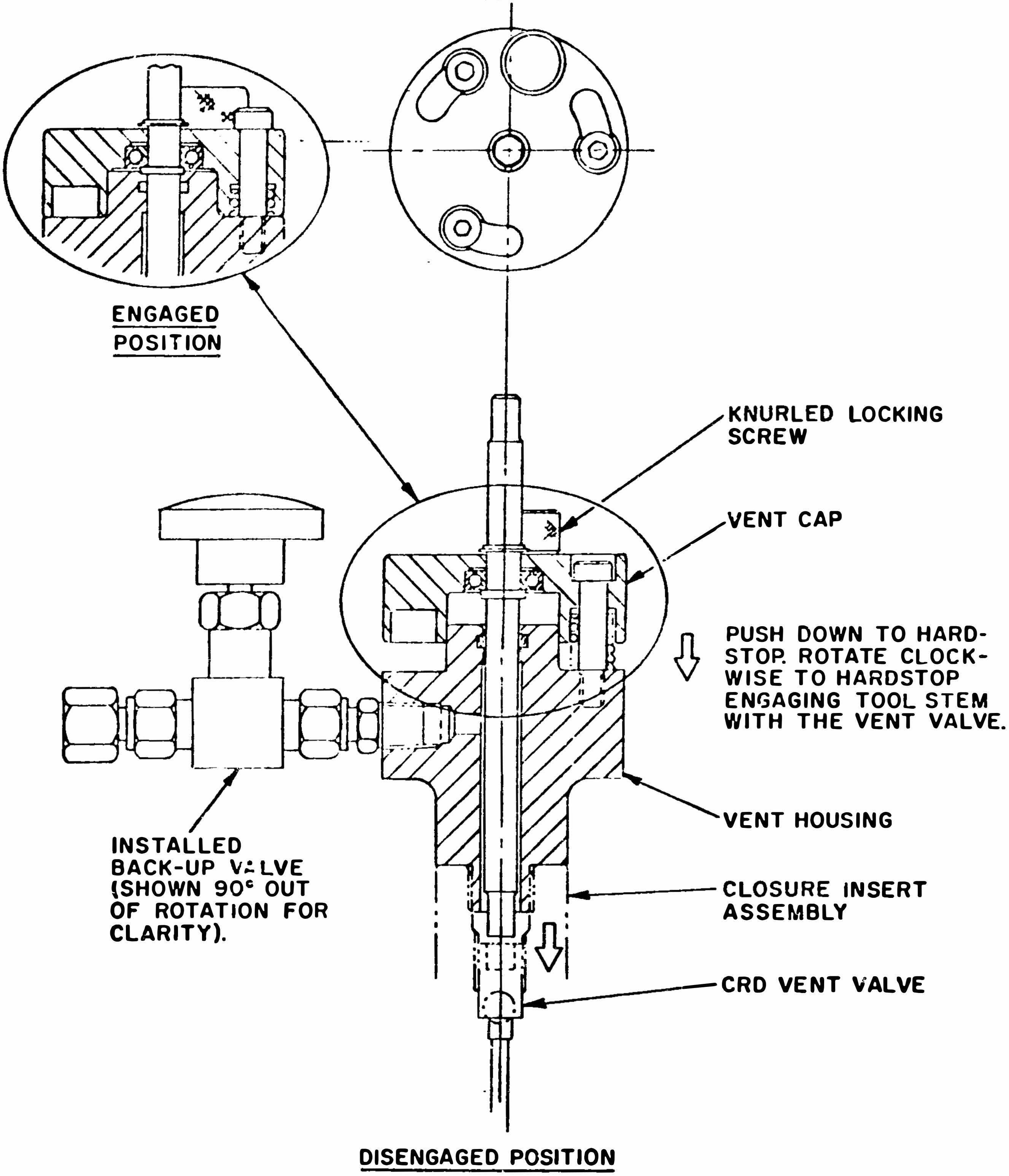


FIGURE I-4 VENTING TOOL, 707541-1046

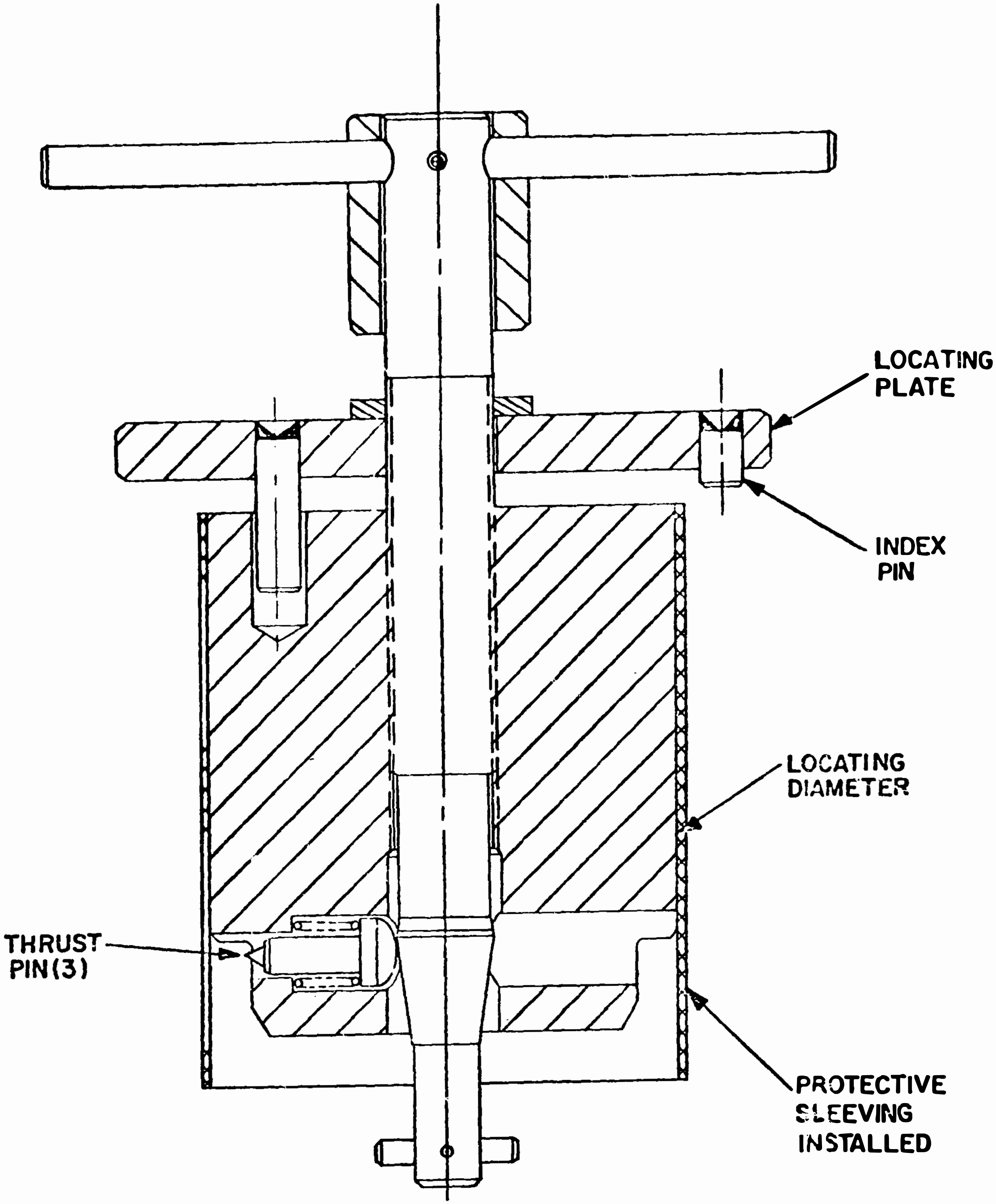
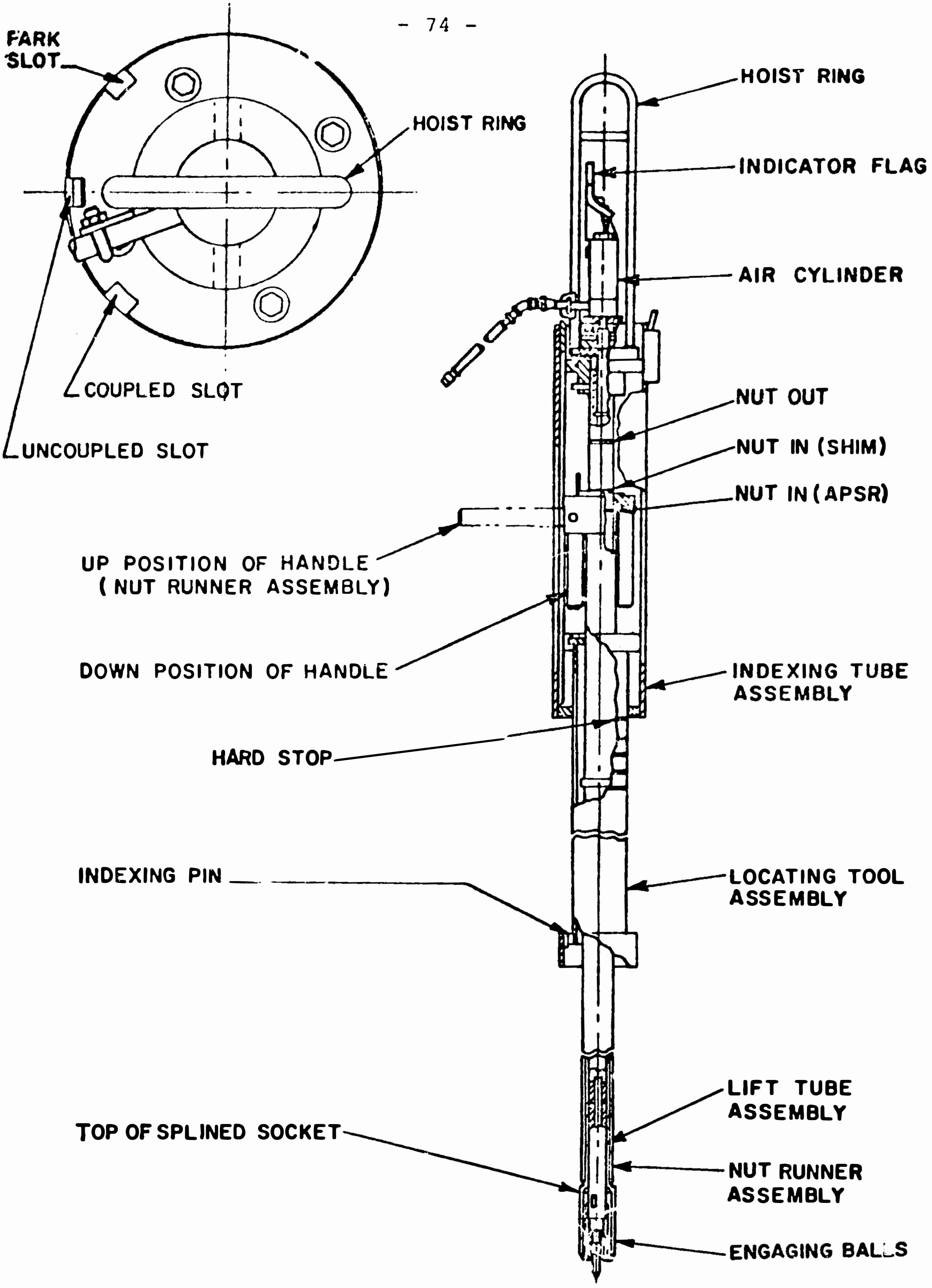


FIGURE I-5 O-RING REMOVAL TOOL, 709007-1049



APPROXIMATE TOTAL LENGTH 201 1/2"

FIGURE I-6 LEADSCREW INSTALLATION/REMOVAL TOOL,706564-1057

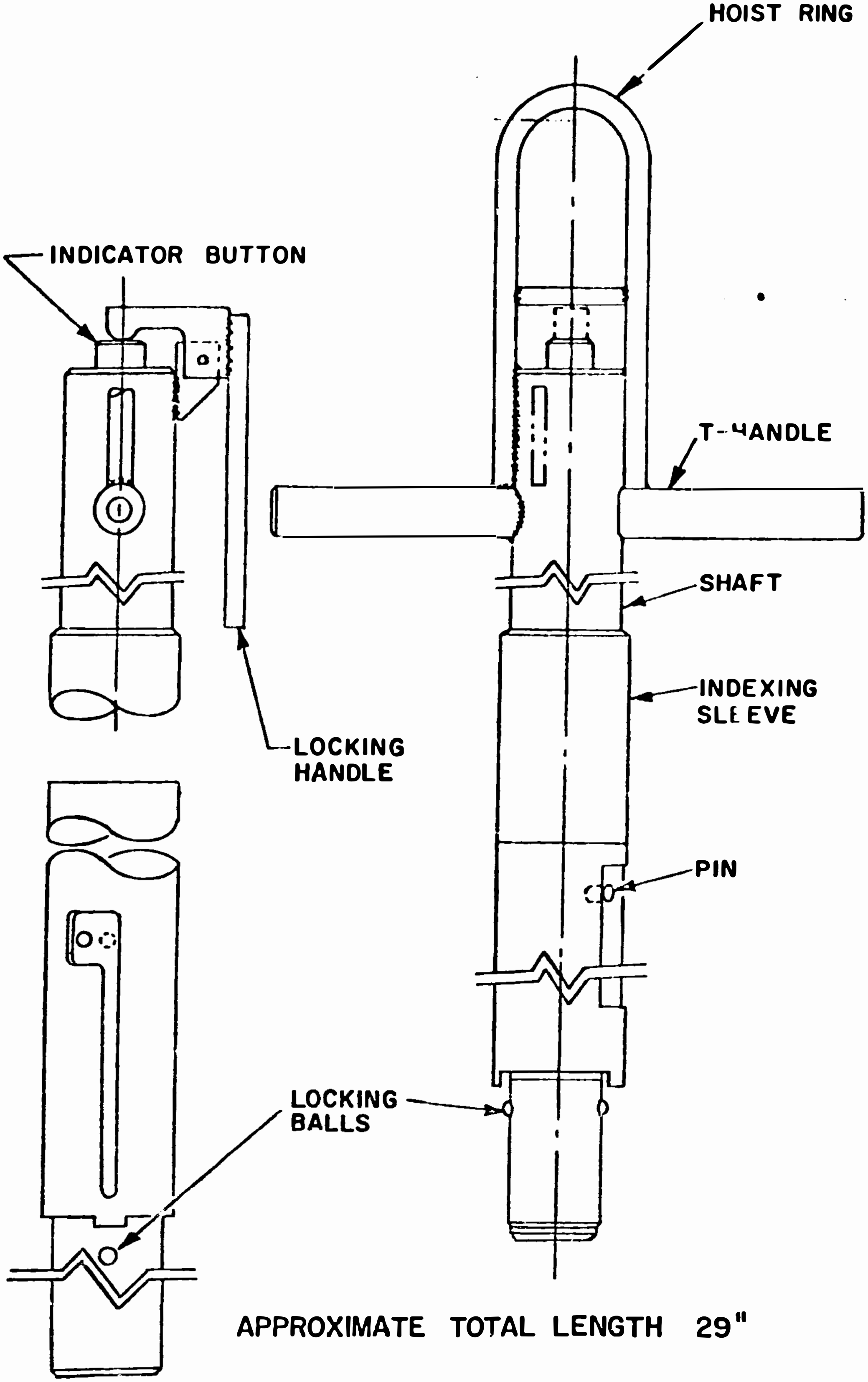
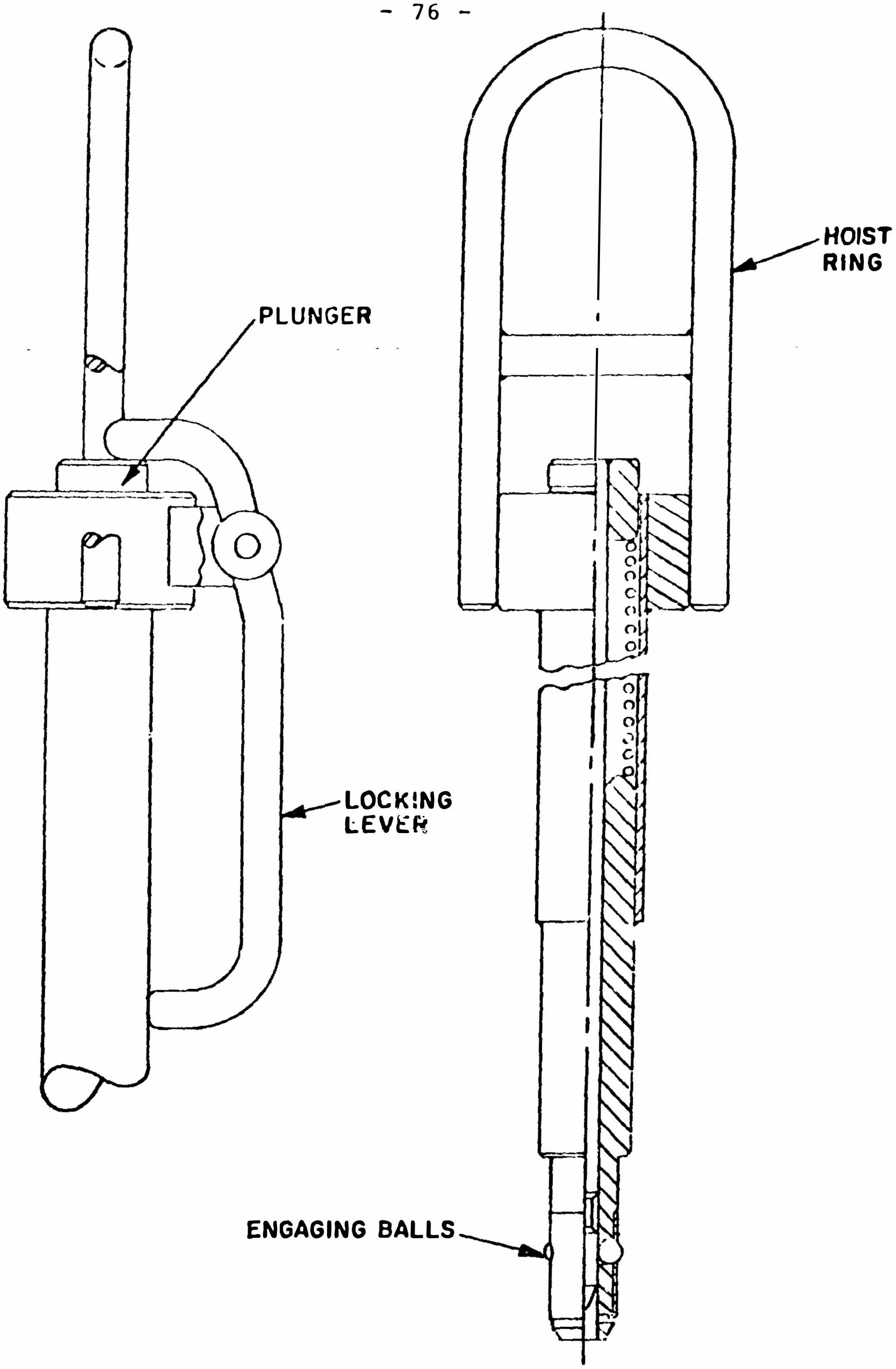
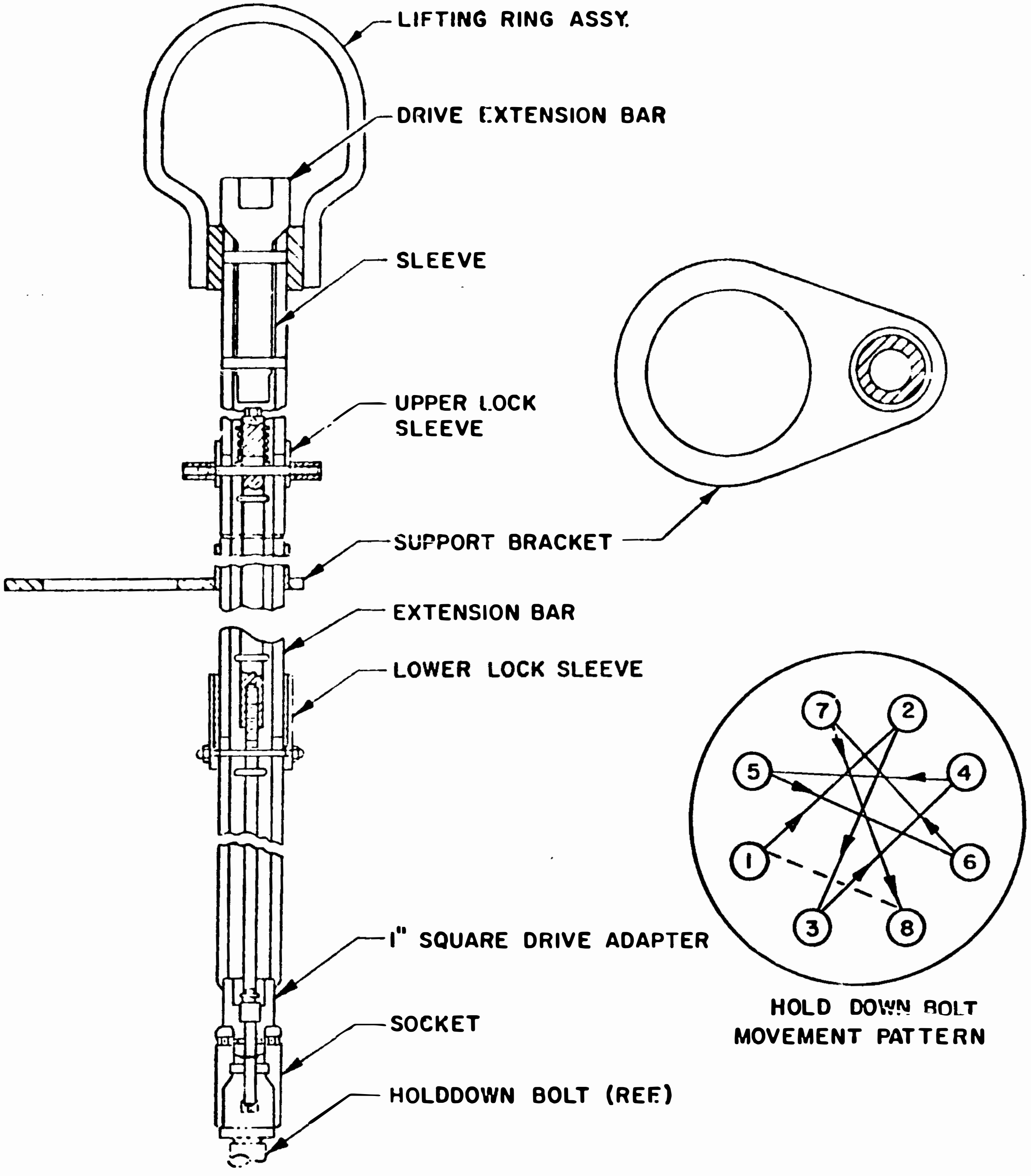


FIGURE I-7 ALTERNATE UNCOUPLING TOOL, 706788-1057



APPROXIMATE TOTAL LENGTH 20"

FIGURE I-8 LEADSCREW LIFTING TOOL, 706568-1053



HOLD DOWN BOLT MOVEMENT PATTERN

APPROX. TOTAL LENGTH 252"

FIGURE I-9 HOLDDOWN BOLT INSTALLATION/REMOVAL TOOL, 703707-1151

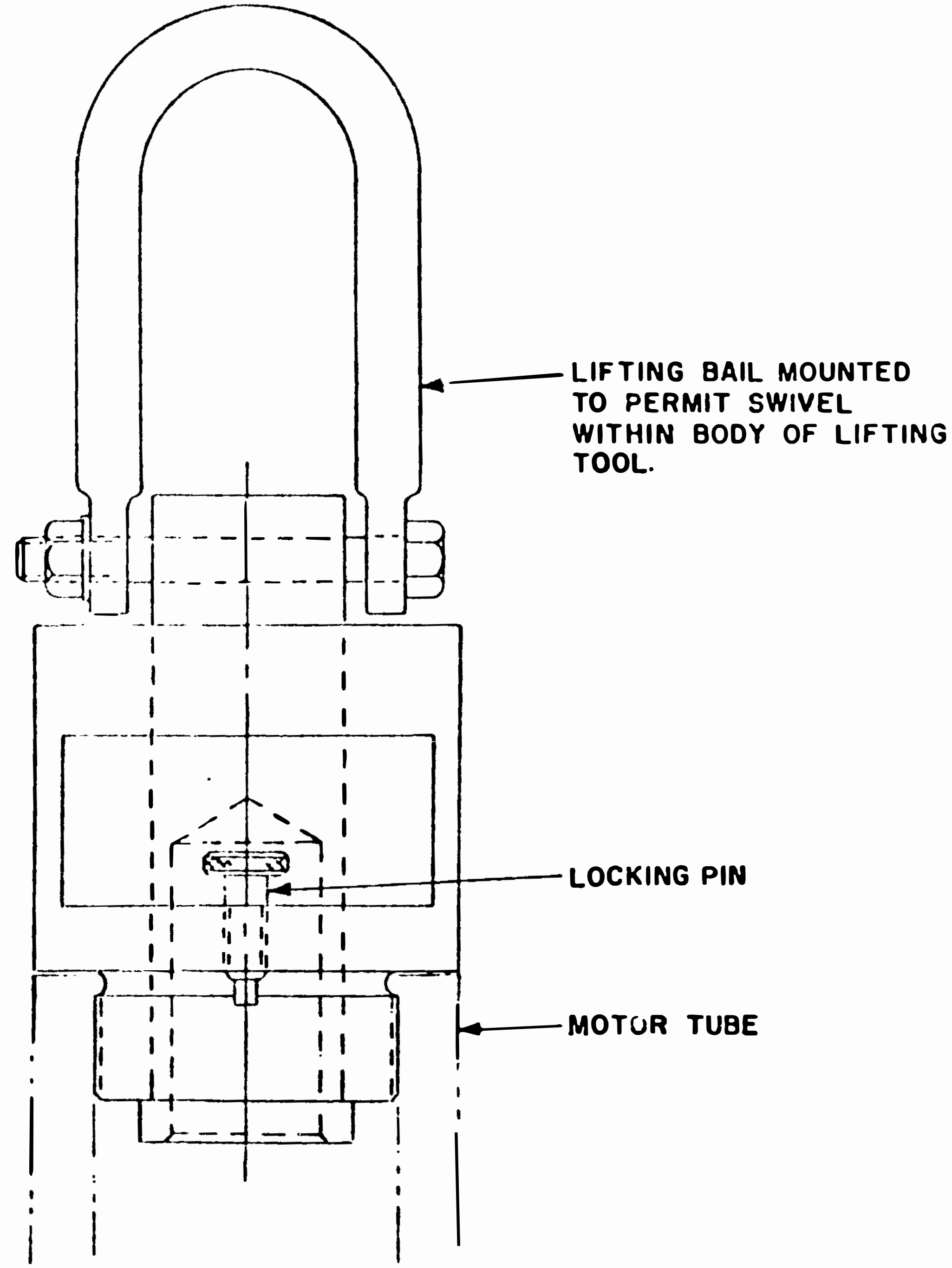


FIGURE I-10 CRDM LIFTING TOOL, 703708-1150