Canadian Fusion Fuels
Technology Project

ITER - TORUS VACUUM PUMPING SYSTEM REMOTE HANDLING ISSUES

CFFTP G-9053
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J. Stringer
Wardrop Engineering Inc.

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J. Stringer
Wardrop Engineering Inc.

Program Manager, CFFTP
2700 Lakeshore Road, West
Mississauga, Ontario
L5J 1K3

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EXECUTIVE SUMMARY

This report describes further critical design issues concerning remote maintenance of the ITER Torus Vacuum Pumping System. Key issues under investigation in this report are: bearings for inert gas operation, transporter integration options, cryopump access, gate valve maintenance frequency, tritium affects on materials, turbo molecular pump design and remote maintenance.

Alternative bearing materials are explored for inert gas operation. Encapsulated motors and rotary feedthroughs offer an alternative option where space requirements are restrictive. A number of transporter options are studied. The preferred scheme depends on the shielded reconfigured ducts to prevent streaming and activation of RH equipment. A radiation mapping of the cell is therefore required to evaluate this concept.

Valve seal and bellow life are a critical issues and need to be evaluated as they have a direct bearing on the provision of adequate RH equipment to meet scheduled and unscheduled maintenance outages.

The limited space on the inboard side of the cryopumps for RH equipment access requires a reconfigured duct and manifold. In this regard, a modified shielded duct arrangement is proposed. The advantages are: more access space; reduced activation of components; and the potential for improved valve seal life.

A brief literature search indicates that data researched by Mound Laboratories shows the adverse effects of tritium on some bearing lubricants. Based on Mound's work, silicone based lubricants should be avoided.

1.0 INTRODUCTION

The Canadian Fusion Fuels Technology Project (CFFTP) retained Wardrop Engineering Inc. on September 1990 to carry out further remote handling (RH) studies of critical design issues which have a major impact of the ITER Torus Vacuum Pumping System (TVPS). This work is a contribution to the ITER program within the framework of the European Community (EC).

The issues identified for further studies are:

- inert gas operation
- transporter integration
- cryopump handling
- turbomolecular pump handling
- materials/lubricants - effects of tritium and inert gas operation

Some overlap into other areas is necessary as many aspects of TVPS handling are inter-related. This work augments a previous study[1] on TVPS design issues.

2.0 SERVOMOTORS - INERT GAS OPERATION

2.1 Background

An inert gas atmosphere of either helium or nitrogen has been proposed for the TVPS cells. RH equipment must operate in this environment during maintenance missions and their drive motors must be compatible with this environment. Industrial suppliers of servomotors in North America express concern regarding operation of their motors in a helium atmosphere (and radiation). This section addresses these concerns and explores alternative drive options.

2.2 Discussion

Because of concerns regarding servomotor operation in inert gas, eg, helium, investigations were made to determine how motors could be modified to avoid these problems. Based on the experience of industrial suppliers of motors, two major areas of concern are:

(a) helium strips bearing lubricants;

(b) combination of low dielectric strength of helium and radiation damage of motor windings has the potential to reduce motor life[2].

Discussions with motor suppliers in the United States (US) indicate that servomotors are not generally designed to withstand radiation or inert gas operation in helium. For example, Moog's servomotors are not rad hardened and they will not guarantee their performance in a helium atmosphere. Other suppliers of motors in the US have a range of rad hardened servomotors designed for a radiation environment up to 10^6 rads and these are currently being subject to hot cell life tests.

Another concern is bearing life. Industrial experiments[2] indicate that helium strips lubricants from motor bearings necessitating bearing replacement when operating in a helium environment. One method of overcoming this problem is to exchange the motor bearings with dry film or ceramic type bearings. The feasibility of using materials in this manner are explored in more detail in this section (Option 1 below).

Another approach is to hermetically seal the motor so that the cell atmosphere will not enter the windings, or the motor bearings. A scheme is developed to explore the feasibility of this approach (Option 2 below). Although there are obvious advantages, there are also complications.

2.3 Options

Option 1 - Materials Upgrade

(a) bearings

Motor suppliers recommend bearing replacement if servomotors are required to run in a helium atmosphere. The following bearing materials/lubricants replacement options suggested by motor suppliers are: Baycote (PFE), dry lube (M_0S_2), tungsten disulphide (WS_2), ceramic, and Ion Implantation.

However, not all these materials are acceptable for the torus vacuum pumping system requirements. Baycote is a 'PFE' material, vacuum rated, with minimum outgassing to 10^{-12} Torr at 20°C. M_0S_2 is a dry film lubricant also used for UHV applications. WS_2 has certain performance advantages over M_0S_2. Ceramics are used as a bearing material and are available in discreet sizes (supplied by outside vendors). Ceramic bearings have good life and are very hard, but they are not available in all sizes. This could affect the motor sizing--the next motor frame size may have to be selected to permit bearing replacement. Some concerns exist regarding the use of PFE (tritium affects fluorines leading to the formation of corrosive acids), M_0S_2 and WS_2 (contain sulphur).

Ion deposition is a coating method which uses simultaneous deposition by evaporation and ion bombardment of the substrate. A range of pure metal and compound coatings can be provided.

The 'preferred' bearing materials are ceramic (Fig. 1.0) and BN or ZrO_2 by Ion Deposition methods (Fig. 2.0).

(b) Rad-Hardened Motors

Motor manufacturers in North America can supply rad-hardened servomotors by upgrading motor winding materials to withstand high radiation doses. Currently rad hardened stepper and servomotors are subject to hot cell life tests. These particular motors are designed for a total dose of 10^8 rads. Some motors have been given short duration tests at 10^5 rads/hr.

Motor manufacturers confirm that rad-hardened motor frame sizes are unaffected due to the upgrade in motor materials. Specific motor materials designed to withstand radiation are: magnet glues, laminates, cell liners, windings and cabling.

The main concern is that where motors are used in a helium atmosphere, reduced operating life will result if low dielectric strength helium is in contact with radiation weakened winding insulation. Rad hardened motors should improve the motor operating life substantially. Bearing conversion to ones more compatible with a helium gas atmosphere should also give improved operating life. Manufacturers confirm that motors operating in an inert gas of nitrogen are preferred to operation in helium. It would appear that no special modifications are required to motors for use in nitrogen applications.

Option 2 - Hermetically Sealed Motors

Another approach to protecting servomotors against the effects of helium is by hermetically sealing the motor. This is achieved by sealing the motor/bearings against ingress of the helium gas using an external cover and special rotary feedthrough for the output shaft. A concept of this scheme is shown in Figure 3.

The motor assembly consists of the following components: servomotor, rotary feedthrough, cover (rigid or flexible) and a cooling system.

Briefly, the feedthrough prevents gas from entering the motor at the output shaft end. The cover provides a chamber to which a motor cooling system is attached. If cooling by the surrounding medium is adequate, then no forced cooling is required. The outboard bearing of the motor must be sealed so that gas cannot enter the motor windings at this end.

Rotary feedthroughs are drive components commonly used in high vacuum technology. An example of a feedthrough is shown in Figure 4.0 although this particular component is quite small (the shaft is approximately 10mm), it shows the general principle of operation. The main components consist of: output shaft/bearings, bellows, input shaft/bellows, unit housing.

In rotary feedthroughs, the motor side (input) is sealed from the output shaft end. However, the output shaft bearings, which are subject to the operating environment, must be compatible with ultra high vacuum (UHV) requirements.

2.4 Operating Experience

A specific example of a rotary feedthrough[3] is given as follows:

A hermetically sealed drive, capable of precision insertion of a radio frequency tuner into the buncher cavity of the continuous wave proton linear/accelerator, was required by AECL-CRL. Figure 5 shows a scheme to meet these requirements.

The concept is a hermetically sealed, high torque transmission device suitable for operation in vacuum (or pressure), high temperature or liquid service. The scheme shows a metal bellows, combined with a special shallow tooth gear, to provide a sealed system of transferring rotary motion through a pressure boundary. Two conventional components, ie, a metal bellows and a pair of modified gears are used. The bellows are designed for any life expectancy, using the appropriate ratio of mean convolutions diameter to both the length of convolutions and the amount of lateral deflection.

A model drive unit has operated at nearly 1 x 10^6 cycles while subject to an external pressure of 4mPa. This particular bellows is roll-formed. This example is given to show the special requirements and complexity of rotary feedthroughs.

2.5 Summary/Conclusions

From the standpoint of the design and selection of drives for RH equipment to operate in a helium atmosphere the following concerns have been identified:

a) Helium strips lubricants from motor bearings;
b) Low dialetric strength of helium could affect motor life.

To avoid these problems: In a) motor bearings can be replaced bearings with treated races or with ceramic type bearings. In b) rad hardened motors can be used to improve life. Alternatively, rotary feedthroughs can be used to encapsulate motors to protect them against the adverse effects of helium. However, rotary feedthroughs require a lot of space axially and are quite complex mechanically.

3.0 TRANSPORTER INTEGRATION

3.1 Background

There is a need to determine remote handling equipment requirements based on machine duty cycle, to integrate the equipment within the building, to prevent activation of the equipment, and to provide an adequate storage area for servicing and decontamination of the equipment. Alternative methods of integrating the overhead transporter RH equipment within the pump cells are evaluated in this section. Information used in this evaluation has been obtained from a NET memo of January, 1991 (Ref. N2/L/3710/13)[4] and recent ITER Building layouts[5].

In ref. N2/L/3710/13, the ITER reference cycle is two weeks on followed by five weeks down time.

Plant availability is therefore 29% and down time is 71%. Assuming that plant operating time per year is 8000 hours, then the available outage time will be approximately 5680 hours for scheduled maintenance outages.

Unscheduled maintenance operations could be performed during the next available 5 week outage (840 hours).

3.2 Equipment Needs

The total remote handling equipment needs (N) can be defined in terms of the time to complete a specific maintenance task (t), the number of tasks (n) and the given outage time (T_0). These variables are expressed in the following manner:

$$N = \frac{n.t}{T_0}$$

The product of "n" and "t" gives the total machine hours while "T_0" is the available time for the maintenance task(s). A plant outage time of 5680 hours/year is used (T_0) for determining equipment needs. Based on a maintenance mission of 150 hours per seal exchange operation, and a total of 24 seals to be replaced, a total of 3,600 hours is required to complete the exchange.

RH equipment needs can be estimated for "scheduled" outage times. In this case, for an outage time of 5680 hours only one piece of equipment is required, although two are preferred. This relationship of "N" and "T_0" can be illustrated as shown in Figure 6. It can be seen from this graph that two pieces of RH equipment are adequate for "scheduled" plant outage times of between 2000 hours and 5680 hours.

For "unscheduled" outages due to plant malfunction and to maximize plant availability, outage times will presumably be of much shorter duration. Low outage times may require additional RH equipment if operational goals of the facility are to be achieved. Adequate remote handling equipment must, therefore, be available to meet these brief maintenance scenarios, and they may well be the criteria on which the equipment is "sized."

"Unscheduled" RH requirements are estimated in the same manner. For example, if two maintenance operations are required in two cells, then the total machine time to complete these tasks is: 600 hours (150 x 2 x 2). The equipment requirements are illustrated in Fig. 7. The remote handling equipment is described as Overhead Transporters (OTs).

The equipment needs (N) are shown as a function of unscheduled outage time (T_0) in the graph. It can be seen that one OTs is adequate for an outage time of 840 hours (35 days @ 3 shifts/day).

These two examples, based on the ITER reference cycle, are used to illustrate the effect of outage time on equipment requirements. Other factors affect the equation such as the "life" of components (mean time between failure).

Clearly, the equipment needs depend on the "scheduled maintenance" as well as the "unscheduled maintenance" requirements. The available or allowable outage times can have a significant impact on equipment requirements. For ITER, because the downtime is large, unscheduled operations can be carried out in the next available 5 week outage period.

An overestimate of RH needs tends to system complexity and high equipment costs, while an underestimate of equipment needs could, indirectly, affect plant availability. Also, failure frequency for pump components (valve stems, seals, bellows, etc) is the other important element in estimating machine down-time. The mean time between failure (MTBF) should therefore be estimated for all pumping equipment components.

Before a final quantitative assessment of RH equipment requirements can be made, the life of various pump components (MTBF) need to be determined. As an example, components requiring periodic replacement on the gate valve are the following:

- main seals
- pneumatic valve actuators or electric motors
- feedthrough bellows

- valve drive mechanism/bearings (B-10 life)
- electrical or pneumatic disconnects
- instrumentation

The main seal is subject to radiation and tritiated dust burdened atmospheres. Currently various seal materials to determine their operating life are being studied. The valve actuator organic seals, although external to the valve, are also irradiated. Feedthrough bellows are subject to cyclic stress (one per two hours) during cryopump (CCP) regeneration. Based on a life of 5000 cycles, maintenance may be approximately 2.5 years and may even be less for dust burdened atmospheres. Operational experience on large tokamaks, such as JET, indicates that bellows malfunction is the main item causing machine stoppage[6]. Clearly a planned maintenance program is required based on MTBF values for all working components.

Comments by valve manufacturers suggests that as valves get larger, so do the drive mechanism operating forces, which result in increased maintenance and servicing. The internal toggles, where these forces are generated, operate in vacuum, are typically dry film lubricated. The B-10 life of ball and roller bearings therefore needs to be estimated and a replacement frequency determined.

However, while component life is being quantified, schemes for integrating transporter equipment within the building can be explored. These schemes will be used to compare the relative advantages/disadvantages of each concept, from which a preferred arrangement can be selected.

3.3 Concepts

A number of concepts are examined for integrating overhead transporter (OT) RH equipment within the current building layout. Some general design needs which impact the arrangement of these concepts, are:

- prevent activation of RH equipment;
- maintenance operations to be carried out in cells containing inert gas atmosphere;
- RH equipment to be accessible for tool exchange, maintenance, and servicing;
- decontamination/cleaning of RH equipment;
- back-out features in the event of malfunction of RH equipment.

A major concern is the need for RH equipment to avoid "NB" ducts which pass through some pump cells, and the circumferential access corridor. RH Concepts, which use two or four overhead transporters are examined to determine their feasibility and impact on the building.

Another major concern is the impact a shielded or unshielded pumping duct has on RH equipment. An unshielded duct implies that RH equipment is located outside the cells, i.e., docked radially in the transfer corridor. A shielded duct, on the other hand, implies that the RH equipment can be stored/docked over the cryostat access corridor - much closer to the cells. Basically the need to prevent the activation of RH equipment is a major design driver. The following concepts are based on either an unshielded duct (Concepts I-IV) or a shielded duct arrangement (Concept V).

Concept 1

This scheme (Figure 8a) is based on two OTs servicing eight pump cells (one transporter serves four cells). A separate container or flask is used for inter-cell transfer. Each pump cell has an access port by which the RH equipment gains entrance to the cells for maintenance. The container is mounted on its own overhead track system. In this scheme, two OTs can access as many as four pump cells. The need for shielding of the containers would have to be determined based on expected contamination levels. The container/OT arrangement (Figure 8b) consists of the following components: container/closure door, internal rail support system, overhead transporter, and support trollies.

The access port consists of a shielded sliding door. Each pump cell is independent of the others. Maintenance operations can be carried out in a cell without shutting down pump equipment in adjacent cells.

Advantages:	Minimum equipment can serve as many as four cells or more using an external container flask and rail system.
Disadvantages:	Potential interference with NB ducts. This can be circumvented by relocating the access ports at cells T10 and T17. Eight access shielded/doors and seals are required (one/cell).

Concept II

In this concept (Figure 9a), the mobile container is replaced by fixed shielded storage areas - one storage area for every two cells. Similarly, one piece of RH equipment maintains two cells. The storage area is such that the RH equipment can transfer between adjacent cells via shielded access doors. All pump cells are independent of each other. Although there is a common RH transfer/storage area, maintenance in one cell permits pump operation in adjacent cells. The concept requirements are:

- four storage areas (one per two/cells)
- dual shielding doors per storage area
- four overhead transporters (one per two/cells)

A cross-section of the arrangements showing in-cell and ex-cell sections is conceptualized in Figure 9b. The approximate width of the pump cell is 13.5m. The width of the transfer area, external to the cell, is approximately 11.0 m. The span of the OT must not exceed approximately 10m to keep within the width of the transfer area. In this scheme, an access room is provided for tool exchange/maintenance.

Comments: Because the four RH equipment transfer areas are located on the cell separating wall line, there will be no interference with the "NB" ducts. RH equipment is "fixed" or limited to four. Access to RH equipment is somewhat restricted.

<u>Concept III</u>

This scheme (Figure 10) is similar to Concept II in that four overhead transporters are used to service eight pump cells. However, in this arrangement two cells must be combined into one. There are concerns with this concept regarding contamination spread into a larger cell volume and pump operation. These concerns must be discussed with ITER-EC people.

The OTs enter directly over the cryostat access corridor. However, the access to the cryostat is below and independent of the cells. In this scheme, an OT is located directly adjacent to two cells (T15/16, T13/14, T11/12, and T9/10). A shielding door isolates each storage area. However, during maintenance missions, two cells are affected. The orientation of the cells is such that little or no interference with the 'NB' ducts is anticipated. The advantages and disadvantages of this scheme are:

Advantages:	Minimum equipment servicing the cells and minimum shielding door size.
Disadvantages:	Maintenance operations will affect two cells.

Concept IV

This scheme (Figure 11a) uses two OTs to service eight pump cells. One OT services three cells while, adjacent to the NB, one OT services only one cell. The space (between cells) over the cryostat access corridor is used for a temporary decontamination area. RH equipment is serviced in the exterior corridor. The RH equipment is transferred to this corridor via a shielded door. No external RH container is used.

A guided rail system is required to move the RH equipment between the three cells and a radial track system is used to remove the RH equipment from the cells to the service corridor.

In this scheme, the zone between cells can be used as a decontamination area. Once RH equipment is cleaned, it is removed, via a shielding door, to the exterior service area for tool exchange and maintenance.

Figure 11b shows an end view of the cells and cryostat access port. Preferably, the RH equipment should be removed from the cells during normal operation of the pump system. Zone A is therefore only a temporary storage area. No activation of equipment is foreseen in this scheme. Subsequently, RH equipment will be removed to the *external service area.*

Advantages:	Minimum RH equipment requirements. No RH container is required.
Disadvantages:	Potential interference with "NB" ducts. Increased equipment costs.

Concept V

This concept (Figure 12) uses 4 OTs to service 8 pump cells. Each OT is docked in a location as shown between adjacent cells above the access corridor to the cryostat. Interference with the NB ducts is avoided. This scheme uses 2 overhead transporters, more than is required for the ITER reference cycle.

The following assumptions are made in this scheme based on a shielded duct arrangement:

- no shielding of the OTs is required
- manned access to Zone 'A' is feasible after shutdown
- Zone 'A' can be decontaminated and purged with air

Advantages:	No linear radial track system is required. No external access corridor polar tract system is required.

Disadvantages: Requires 4 OTs based on the pump cell arrangements. RH maintenance and tool exchange must be carried out in Zone 'A' above the level of the access corridor.

Note: A radiation mapping of the cell is required to confirm the feasibility of this scheme. If radiation levels are high then this scheme would require large shielding doors to protect RH equipment located in the docking area.

3.4 Concept Evaluation

The schemes are classified in terms of complexity, as follows:

Concept	Summary	Level of Complexity
I	• Radial track system • 1 (or 2) Flask/container (shielded) • External corridor polar track system • Accessibility problem • 8 Cell access ports required	1
II	• 4 Shared shielded docking areas • Difficult access for maintenance • Radial track system required for OTs • Accessibility problem	3
III	• 4 Separate, independent docking areas • 4 OTs required (min.) • Accessibility problem	4

IV	- 4 Access ports required - Radial tract system - Polar corridor tract system - No shielded flask required - Reduced no. of OTs - Improved accessibility	2
V	- No corridor polar track system required - No radial track system required - Simpler isolation doors required for Zone 'A'	5

Based on a scale rating of one to five, where one is maximum complexity and five is minimum complexity, concept five is preferred.

3.5 Summary/Conclusions

In current ITER pump cell duct scheme, beyond the cryostat, where they enter the pump cells, the ducts are unshielded. As such heavy shielding doors would be required to prevent direct streaming and activation of docked RH equipment, located in the zone over the cryostat access. To avoid this problem schemes were studied where 'RH' equipment is transferred radially external to the corridor. Four such options (Option 1-IV) have been investigated for comparison purposes. The fifth option (Option V is essentially the original scheme, but now based on the modified duct arrangement (shielded), which assumes that no heavy shielding doors are required.

Of the five options, Concept V appears to be mechanically the simplest solution. However, the scheme is based on either having adequate duct shielding to minimize activation of RH equipment. Before a complete assessment of this scheme can be made, a radiation mapping of the cell during operation and during shutdown is required.

4.0 CRYOPUMP ACCESS

4.1 Background

The current torus vacuum pumping system layout is studied from the standpoint of overhead access by RH equipment to pumps, valves and valve box flange connections and to make recommendations for relocation of system components where required.

The current pump cell layout information[5] is used to investigate access requirements to the CCP/valve flange connections (Figures 13 and 14):-

Access to the inboard side of the cryopumps for RH equipment is severely restricted by the downcomer ducts to the manifold. The ring main location also restricts access. In addition, access to the combined regeneration - isolation valves is obstructed by the location of the cryogenic valve boxes (CVBs).

The obstructions caused by the current location of TVPS equipment will require some relocation of some or all of the following components: large diameter manifolds; cryogenic valve boxes; cryogenic piping and ring mains. Some discussion is required with ITER designers to confirm the feasibility of relocation of these components.

Comments outlined in this report concern access and handling of TVPS components such as cryopumps, large gate valves and cryogenic valve boxes. Other comments concern access requirements for RH equipment such as the overhead transporter bridge and master-share manipulator equipment.

4.2 Cryopumps

Access to the pumps required by the overhead transporter telescopic mast is shown in Fig. 15. Access space is required approximately 2 metres either side of the pumps to reach the pump/valve flange connection. The proposed modifications are: (a) the ring main relocated further inboard; and (b) the downcomer manifold angle increased. A reduction in the length of inlet pipe to the pump will help to reduce the overall height of the pump/valve system from the floor.

4.3 Large Gate Valves

In the current RH scheme, access to the gate valves is necessary for removal of seal components. Therefore, space above and at the side of the valves must be kept clear for RH equipment.

The preferred orientation of the valves is radial with respect to the centre of the machine for overhead handling. The current orientation will require compound motions when assembling/disassembling RH equipment if overhead means are used. Access space in the cell when removing gate valve seals must be adequate for these operations. This depends on the method of handling and the type of equipment (flask) used in the operations. Once the seal replacement method has been conceptualized, then minimum space requirements in the cell can be identified.

4.4 Cryogenic Valve Boxes (CVBs)

Cryogenic valve box bayonet connections can be relocated to facilitate independent replacement of the valve boxes (Fig. 16). The relocation and orientation of bayonet connections facilitates the independent removal of cryogenic valve boxes. Bayonet connections make for simpler disconnections/connections of pipe runs. Where single line flange connections to the CCPs are used, then flange orientation should be as shown to facilitate the direction of component replacement (vertical).

The above bayonet configuration, permits removal of the CCPs and the valve boxes independently of each other. Bayonet connections to facilitate handling requires further discussion with ITER TVPS configuration design people. A preferred location for the CVBs, to permit more access (by manipulator equipment) to the valve outboard flange, is inboard behind the CCPs.

4.5 End Effector Tooling

The reach of electric master-slave manipulator (EMSM) equipment must be adequate to access all locations of the CCP/valve flange bolts. The reach of this tooling in the extended mode and the minimum envelope when it is stored, must be determined. From this data and the preferred size of equipment selected, the spatial requirements can be identified.

4.6 Bridge

The span of the bridge should not be greater than approximately 9.5 m. Any increase in span above this will increase the difficulties of radial docking of this equipment in the transfer corridor. A suggested location of the cell wall is about 8.0/9.0 m from the centre line of the CCPs. For tangential docking of RH equipment (Concept 5) in the pump cells a larger span can be used (approximately 10.5m).

4.7 Summary/Conclusions

The foregoing comments show that the current baseline duct configuration needs to be modified to provide more access by overhead means. The following modifications are proposed: the downcomer duct angle increased, the ring mains moved inboard, and CCP/CVB flange connections to be oriented to permit vertical, independent removal of these components.

Further duct modifications are outlined in paragraph 5.0 to permit handling by floor mounted means.

5.0 CRYOPUMP REMOTE HANDLING OPTION

5.1 Background

The feasibility of pumping component replacement by floor-mounted RH equipment is examined based on a proposed modified duct arrangement.

Relocation of the main duct manifold from the current position interconnected beneath the CCPs to an inboard position against the cell inner wall not only provides greater access to the inboard side of the pumps by overhead means but also permits access to the CCPs by floor supported equipment (not possible in the current duct scheme). These advantages permit floor-mounted RH replacement of components as well as by overhead methods. These options are: valve internal components (floor mounted); pump and valve (floor mounted); and, pump only (overhead). This report outlines further modifications required to the current duct schedule to develop the scheme and examines the implications on RH options.

5.2 Proposed Duct Modifications

Relocation of the main manifold supplying the CCPs provides enhanced access to pump components. Five modifications are proposed:

(a) relocate the main manifold inboard against the cell wall;

(b) vertical orientation of the 2 downcomer pumping ducts rather than inclined;

(c) three horizontal, radial deployed ducts connecting each pump/valve unit to the main manifold;

(d) flanged connections introduced in the three radial ducts for ease of assembly/disassembly of pump/valve assemblies;

(e) relocation of the cryogenic valve boxes inboard against the wall.

Figure 17 shows the current 'baseline' duct arrangement. Figure 18 shows the suggested arrangement without shielding, with pumps located 6.75 metres from the cryostat wall. Figure 19 shows the modified duct arrangement, with shielding, with the pumps located 7.0 metres from the cryostat wall.

5.3 Concept

Re-orientation of the duct configuration inboard against the cryostat wall will provide clear access to the CCPs from the inboard side as well as from underneath (in the current scheme access to the CCP is only possible by overhead means). A modified manifold opens up a number of possibilities for handling the CCPs, valves and components from a floor-mounted position not feasible in the current manifold arrangement.

The following handling options are possible:

(a) Valve internals handling. (Fig. 20)
(b) CCP and valve combined handling. (Fig. 21)
(c) CCP, valve and manifold combined handling. (Fig. 22)

A modified duct make it possible to assemble and remove each CCP/valve assembly as a unit by floor (or overhead) RH equipment. The double door, or flanged connection in the horizontal duct permit separation of the unit in a radial direction. The complete unit (CCP/Valve/duct) can therefore be removed to the air lock with the minimum of contamination spread in the cell.

In this concept CCP/valve/duct assembly can be replaced as units, as well as individually without having to replace the complete unit. (For example, valve internals can be removed without having to remove the valve body.)

CCPs - Relocation of the manifold inboard provides more space under the CCP for removal using floor-mounted means. (The manifold is not directly under the pumps to obstruct access of RH equipment.)

Isolation/Regeneration Valve - With the cryogenic valve box relocated inboard, access to the outboard end of the valve is unobstructed and can be accessed from floor mounted equipment, as well as by overhead telescopic arm. (The present valve box location restricts access for seal replacement operations.)

Cryogenic Valve Boxes - If relocated inboard, these can be accessed by overhead or floor mounted equipment. If the vertical height is restricted, then this permits access for tools to be deployed to remove the valve stems from floor mounted support equipment.

Contamination Spread - The double door arrangement of the horizontal duct and the isolation/regeneration valve flask prevents contamination spread during remote maintenance operations. Handling the CCPs as part of the valve and duct would prevent contamination spread. Handling of individual CCPs will result in some contamination spread from the bottom of the pump unless a simple form of isolation door or flexible boot is introduced at the inlet port of the valve. Alternatively, combining the CCP and gate valve (no flange connection) will provide the necessary shut-off feature for contamination control.

Airlocks - The height of the airlock is affected by the various handling options. If the CCP/valve/duct units are removed and installed as units, then the airlock door opening must be approximately 6 meters high to clear the top of the CCP (Fig. 22). If the CCPs are removed/assembled independently of the valve and duct, then the airlock door height can be reduced to approximately 4.0 meters.

5.4 Comments

Relocation of the manifold has the potential to permit enhanced remote handling of TVPS components. Some advantages and disadvantages associated with this option are outlined below:

Advantages:

(a) Pumps/valve/ducts can be replaced as units thus reducing outage time.

(b) Pump system components (CCPs, valve seals, stems, valve boxes) can also be replaced individually.

(c) More efficient use of inboard space means some components can be handled from a floor-mounted position as well as from an overhead position.

(d) Ease of access to the CCP and flanged connections on the inboard side by overhead means.

(e) Floor mounted as opposed to overhead mounted RH equipment, avoids the complications of cut-outs in the cell roofs for the NB ducts.

(f) RH equipment, deployable from the airlock at floor level, is a less complex method of deploying RH equipment.

(g) Simplified overhead equipment.

(h) No special transfer containers are required for each size of component (the scheme permits bagging).

(i) The same RH equipment used for replacing components via the airlock can be used for handling components in the transfer corridor to the hot cell air lock.

(j) RH equipment deployed from the airlock is more readily decontaminated and serviced at floor level than in an overhead decontamination room or chamber.

(k) The floor-mounted RH option will provide simpler seal replacement demonstrations (no overhead crane is required for the seal exchange process).

Disadvantages:

(a) Larger airlock (assuming CCPs replaced as a unit)

(b) Potential for contamination spread unless some form of simple isolation door is introduced on the bottom entry inlet to the CCP (The feasibility of this should be explored with the pump designers.

(c) Potential increase in the duct conductance losses (a 30% increase in duct conductance losses can be offset by a 10% increase in the duct diameter).

(d) Pumps must be moved approximately 0.50/0.75 metres outboard from the current position for the unshielded and shielded arrangements, respectively.

5.5 Shielded Manifold

Activation of pump components can be reduced by incorporating a concrete shield around the duct and manifold (Figure 19). In this scheme the shielding is integral with the cryostat wall. The effect of this will be to reduce neutron streaming. Reduced streaming will minimize activation of pump equipment and increase the life of the seals. In addition, shielded ducts could permit the use of nitrogen as an inert gas, much preferred to helium from a RH standpoint. Reduced streaming will limit C_{14} levels--perhaps to levels acceptable from a safety standpoint.

5.6 Summary/Conclusions

Conductance losses and streaming effects of the baseline duct scheme are currently being evaluated by NET. If a reconfigured duct appears to be mechanically feasible, then both the conductance and streaming should be reassessed for the 'proposed' configuration and the effect of improved seal life evaluated.

The handling of heavy pump components should be explored using floor-mounted RH equipment. A hybrid scheme (light duty overhead/heavy duty floor-mounted) has the potential to provide the optimum handling arrangement.

Alternate airlock concepts (flexible, rigid) are being explored in a separate report.

6.0 TURBOMOLECULAR PUMP HANDLING

6.1 General

In this section TMP handling preliminary pump requirements are outlined from a remote handling standpoint and recommendations made to minimise maintenance down time for these system components. A TMP configuration by Pfeiffer/KfK is used as a basis for discussion purposes (Figure 23).

6.2 Discussion

The basic assumption is that TMPs will be replaced in the event of malfunction, ie, no in-situ replacement of internal components is envisaged. Pump rotor shafts, bearings, motors, etc, are all removed from the pump in a hot shop, remote from the cell. The following comments are made in order to provide preliminary input to the pump design; to minimize the complexities of handling during maintenance; and to contribute to a more reliable, maintenance-free system.

6.3 Overhead Handling

(a) Shielding

The following general overhead handling requirements are made regarding shielding design:

- Shielding design must be studied in parallel with the pump configuration design.

- Shielding must be integrated with the pump configuration.
- The shielding must be split in three (at least) sections: one above the pump centre line; the second below the centre line; and the top section removed vertically (the two lower sections removed horizontally).
- Support method for the shield must be identified.
- Adequate clearance for mechanical/electrical connections for ease of removal must be identified.
- Shielding weights must not exceed the polar crane capacity and a removal procedure defined.
- Shielding removal procedures need to be defined.

(b) Pump Handling

The pump cell RH scheme (Fig. 24) shows overhead transporters for handling all cell components. The overhead handling of TMPs, dictates, to some extent, the orientation of the following mechanical/electrical connections:

- Relocation of the shut-off valve
- Access for manipulator tooling to inlet/outlet/flanged connections
- The use of double shut-off gate valves for contamination control purposes
- TMP shielding orientation for access and removal.

Assuming overhead handling, the following modifications to the TMP are recommended (Fig. 25):

- Relocate the outlet flanged connection below the pump
- Relocate the two inlet connections below the pump

- Pump supports located below the pump
- Electrical connectors located below the pump
- Spreader beam attachment points at two locations above the pump.

6.4 Concerns

The following comments are made to give improved life of pump components and reduce down time on TMP maintenance due to component malfunction:

Emergency Bearings

Concerns are expressed regarding the use of unlubricated emergency bearings in TMPs. In UHV applications bearing components could potentially cold-weld due to the lack of lubricant. The failure of the lubricant to provide an elasto-hydrodynamic film separating the bearing surfaces results in a failure mechanism which progresses through several stages from initial damage to the lubricant to metal/metal welding, and finally wear particle generation. The application of the special surface treatments, described in Section 2.0, should be considered in the bearing design as this technology has application to UHV systems.

Dry Seals

Magnetic bearings require small clearances for efficient operation. Unless some form of 'dry seal' is used on the outboard side of the bearings, the potential to malfunction due to the presence of metallic dust is a distinct possibility.

Dry seals, in conjunction with magnetic bearings, have been developed for large gas compressors in Canada (Trans Canada Pipelines). The possibility of application of some form of dry seal to protect the bearings, using existing technology should be investigated. Dry seal and magnetic bearing technology is proven technology in large gas compressors in North America, and could be exploited in the design of TMPs bearings and seals for ITER. Dry seal technology should be investigated before the design of the pump is well advanced. Improved dry seal design will result in minimizing plant outages for TMP maintenance.

7.0 GATE VALVE BELLOWS LIFE

7.1 Discussion

Linear feedthroughs are required in UHV equipment, such as large gate valves, to move internal working parts. Bellows, an integral part of feedthroughs, where the actuators are attached to the valve bonnet housing, are necessary to isolate the vacuum from the external atmosphere.

Bellows are subject to static loads due to pressure and alternating loads due to cycling (deflection). The life of bellows depends on maximum stresses developed due to pressure and deflection which, in turn, depend on the bellows size (thickness and span).

Bellows life and replacement frequency is required in order to estimate RH equipment needs. Experience gained at JET shows that bellows malfunction is a major contributing factor in plant shut-down[6]. A typical bellows design, suitable for large gate valves, such as that proposed for the ITER TVPs, has been analyzed to determine the approximate operating life and replacement frequency. The results of this study are discussed in this report.

7.2 Concept

A simple bellows design (Fig. 26) is analyzed to determine the approximate cycle life and replacement frequency. Bellow stresses are dictated by bellow span, thickness, stroke and number of convolutions. In addition, some of these parameters, such as span and thickness, can be optimised to limit operating stress levels.

The bellows sample used has the following proportions:

Outside diameter (D)	= 100mm
Inside diameter (d)	= 75mm
Bellows span (w)	= 12.5mm
Bellows stroke (s)	= 150mm
Number of active convolutions (n)	= 150
Bellows thickness (t)	= 0.2mm

Based on the above data, the bellows stress due to pressure is 30 N/mm^2, and the deflection stress is 49 N/mm^2, to give a total stress of 79 N/mm^2. Based on this value, the maximum operating bellows life is 4870 cycles[7]. Gate valve designs, proposed for the ITER TVPs, will be cycled 1200 times per year. Therefore, the bellows life, based on this cycle time, will be approximately 4 years.

Bellows stresses are very sensitive to span (w) and thickness (t). In the above example, if the span is increased to 19mm from 12.5mm, the pressure stress becomes 72 N/mm^2, the deflection stress becomes 21 N/mm^2, to give a total stress of approximately 93 N/mm^2. This stress level will reduce the cycle life to 2800 cycles, to give a bellow life of 2.3 years, a reduction of 42%.

Bellows stresses can be optimised to minimise stresses and maximise bellows life. In the above example, if the span is increased to 14mm from 12.5mm, the operating life is increased to approximately 5 years.

7.3 Summary/Conclusions

Life and replacement frequency for all valve working parts are required in order to estimate RH equipment requirements. Bellows used in valve feedthrough devices, have been shown to be prone to malfunction, based on operating experience at JET.

A simple bellows design is analyzed in order to obtain an indication of bellows life and replacement frequency. For example, based on a valve cycle time of 1200/year of plant operation, bellows life will be approximately 4 years. Bellows life is very sensitive to span/thickness ratio and small changes in the span will increase or decrease stresses significantly, followed by a corresponding change in life. For this particular design, by optimising the span/thickness ratio the life of the bellows can be increased to 5 years.

As bellows are an integral part of valve design and subject to malfunction, valve designers must ensure that stress levels are minimised and that the optimum bellows configuration is obtained. Ideally, to minimise plant outage, similar bellows and seal life should be aimed for, with simultaneous replacement of both components.

8.0 MATERIALS - EFFECTS OF TRITIUM

8.1 Introduction

The life and replacement frequency of vacuum pumping equipment components such as valve seals is dependent on the environment in which they are required to operate. For example, the life of seals used in the large gate valves in the current ITER reference scheme are subject to the combined effects of neutron streaming, radiation due to activation, dust from the first wall, and the interaction of tritium. Some of these effects can be mitigated by reconfiguration of the pumping duct manifold.

Dust ingress into the valve working parts is minimised by having a bottom entry cryopump/valve arrangement (reference design). The proposed shielded duct modification is designed to minimise direct neutron streaming of valve seals while avoiding activation of valve components. These modifications will reduce damage to valve seals and extend their working life. However, the effects of tritium on soft seat materials needs to be evaluated independently. Tests are proposed for the long term ITER R and D program and seal materials will be subject to reactor relevant conditions. It is important, therefore, to select valve seat materials which will maximise their life and minimise the number and complexity of RH equipment required to service these components.

The interaction of tritium on a number of polymeric materials such as natural rubber, buna-S, neoprene, hyperlon, teflon and silicone, have been investigated by the General Electric Co., Schenecteday, New York. Exchange rates of tritium and the extent of hardening as a result of exposure to tritium have been examined in these tests. Some of this data is referred to in this report.

The choice of seal material is an important one, not only from a valve design standpoint, but also from the standpoint of selection of RH equipment. Preliminary estimates of RH equipment needs, based on seal life data, is examined in this section.

8.2 General Information[8]

Because of its chemical reactivity, radicactivity and high permeability, T_2 gas interacts with most materials in some way, ie:

(a) Ceramics - these materials show slow deterioration of mechanical properties.

(b) Organics - T_2 mixes permeates through plastics and 0 rings at high flux rates. The mechanical properties of polymeric materials can degrade quickly, depending on the dissolved tritium concentration.

(c) Tritium Effects in Polymers

- Polymers are easily penetrated by tritium and so are modified at the surface and within the bulk of the material. Once organic radicals are formed in the bulk, they can migrate and react with each other.
- Material degradation is observed macroscopically by a progressive softening, increased gumminess, increased elongation and decreased tensile strength.
- Information on the stability of polymers to tritium β irradiation is very limited. Polymers stable under γ irradiation are expected to exhibit similar behaviour under T_2 β irradiation (general lack of data).

- Figures 27 through 29 illustrate the relative radiation resistance of resins and elastomers. This data can be used to compare the expected lifetimes of polymers in T_2 service.

8.3 Tritium Experience with Polymers by Mound[9]

Some additional experience of polymers with tritium, obtained by Mound, is summarized below:

(a) Teflon or Kel-F exposure in T_2 produces tritium fluoride (TF). Because of acid production, the combination of T_2, moisture, and teflon in a stainless steel system at high pressure caused stress corrosion cracking. The substitution of D_2 for T_2 or removing teflon or moisture caused no failure.

The relative increase in hardness of several elastomers after 87 days' exposure in 100 Torr T_2 was investigated.

(i) hardening increased in the following order: natural ~butadiene/styrene~chlorosulfonates <butadiene/acrylonitrile~chloroprene <silicone.

(ii) this series follows quite well the relative stabilities as determined under γ-radiation.

(b) Surface versus bulk effects have been noted in polymer/T_2 studies.

(i) hardening of neoprene (above) occurred throughout the bulk while that of natural rubber primarily occurred at the surface (crack propagation).

(c) Polyimides (good in γ service) appear good in T_2 service.

(d) After 130 days' exposure in T_2 at ~1.5 atm, increase in polymer hardness fell in the series:

Vespel (polyimide) ~ Kalrez (perfluoro) < Viton (perfluoro)

(e) Tritium effects in Neoprene and National Rubber[10].

The interaction of tritium on a number of polymeric materials have been investigated by General Electric Co., Schenectady, New York, to determine exchange rates and hardening mechanisms.

The results of the elongation measurements carried out on samples of neoprene and natural rubber are shown in Figures 30 and 31. Both rubbers show a marked decrease in elongation with increasing exposure time. The two rubbers exhibit a basically different hardening process which affects the elongation. The neoprene shows a regular decrease with no discontinuities in the curve. Natural rubber shows first a regular decrease and then an increase in elongation with several sharp discontinuation in the latter part of the curve.

The hardening and embrittlement in the case of neoprene seem to occur throughout the body of the sample. In the case of natural rubber, the hardening is predominantly a surface effect which produces a decrease in elongation until cleavage occurs in the hardened surface. Following surface rupture, unhardened inner layers are exposed and elongation increases, followed by surface cleavage, eventually leading to complete rupture of the sample.

8.4 Summary/Conclusions

Data provided by Mound Laboratories, showing relative radiation resistance of thermosetting resins, thermoplastic resins, and elastomers, is useful in comparing materials and estimating their useful life. Valve seal material, such as natural rubber, loses its elasticity between 10^7 and 10^8 rads integrated dose. Other seal materials, such as neoprene, viton and silicone, all show lower radiation resistance than natural rubber. Based on radiation levels of 3×10^6 rads/hr, the life of seal material will be in the order of 3 - 30 hours. If shutdown dose rates are 10^4 rads/hr then seal life will be approximately 1.5 to 15 months.

Life estimates, using Mound data, can be obtained for seal materials subject to tritium. Valve seat materials have been estimated to be approximately 4 months and 2 months for viton and silicone materials respectively. These estimates do not include the effect of cycling. The proposed seal life tests for ITER will include the combined effects of cycling and radiation. Other valve seal materials, such as some grades of polimides, which show higher radiation resistance, will give increased life. These materials, however, are much harder, and the higher sealing forces required can affect the design of valves.

Seal materials are known to have a considerable impact on valve design. For example, more resilient seal materials have been proposed for ITER valve studies in order to minimise the valve weight and to be more compatible with the dust burdened environment. Harder seal materials, such as some grades of polyimides, less resilient than soft seal materials, may result in heavy valve designs. Seal life will, however, be greater for hard seat materials than for soft seat materials.

There is concern therefore that where resilient materials are used, such as viton, seal life may be short, as the radiation resistance of these materials is much lower. The impact of low life and high replacement frequency on RH requirements could be substantial.

Tritium tests on neoprene and natural rubber by GE show marked deterioration of these materials. In the case of natural rubber, hardening appears to be a surface effect, while neoprene shows a uniform hardening process throughout the material.

The impact of seal life on RH equipment requirements can be shown to be based on the total hours to service the seals and the available outage time. For example, if 4 transporters are used to service 8 pump cells, then based on 150 hours/seal exchange operation, 24 valves to be serviced and a total outage time of 5680 hours per year, seal life must not be less than 2 months, otherwise there will be insufficient RH equipment to service the seals in the given outage time. As allowance must be made to service other pump components, the minimum seal life must be in excess of 4 months, based on the use off 4 overhead transporters. Harder seat materials which give longer life will result in reduced RH equipment requirements, but could result in heavier valve designs. If seal life proves to be low then rapid seal exchange methods will have to be developed.

9.0 LUBRICANT EVALUATION - EFFECTS OF TRITIUM

9.1 General

Anti-friction bearings will be used in many locations in RH equipment. Tritiated atmospheres, if present in pump cells, could potentially affect the operating performance of bearing lubricants resulting in increased maintenance and down time. The effects of tritium on lubricants should therefore be evaluated at an early stage in the development of RH concepts. This section describes the results of a preliminary literature search (from one source) on lubrication tests involving tritium[11].

9.2 Discussion

Drives used in the design of RH equipment can be enclosed or hermitically sealed to prevent the ingress of contamination. However, rotary feedthroughs and gear boxes will require bearing supported shafts potentially exposed to the cell atmosphere at the output end of these drives. Bearing lubricants for RH equipment must therefore be selected to resist not only inert gas atmospheres and radiation, but also the effects of low tritiated atmospheres, if present.

A preliminary literature search within thee available time reveals that laboratory tests have been conducted by various sources (Mound Laboratories) to determine the effects of tritium on different types of industrial lubricants. The following information (Paragraph 9.3) is extracted from literature describing these tests, and their results. It would be helpful to discuss the results of these tests with Mound in order to better assess their application to TVPS/RH requirements.

9.3 Lubricants Resistant to Tritium[11]

Test Evaluation

A primary requirement for a pump lubricant for use with tritium is a low degree of hydrogen exchange. The replacement of hydrocarbon hydrogen atoms by tritium adds undesirable protium to the process stream when the lubricant is changed. In addition, it is possible that the decay of a tritium atom attached to a carbon atom can cause structural changes in the molecule and cross-linking between molecules. This cross-linking is a probable cause of the solids and semi-solids which formed when Welch Duo-Seal hydrocarbon oil and Dow-Corning 560 silicone fluid were exposed to tritium in a bronze-vane pump.

For a quantitative study of the general effects of tritium on various oils, such as hydrogen isotope exchange, viscosity changes and solids formation, several small tanks were designed to permit a known amount of tritium to remain in contact with a known amount of oil for an extended period of time. The tanks, each having an approximate volume of 630cc were fitted with 1/2-in. Cajon plugs for adding and removing oil, and Hoke FY-440 valves for adding and removing tritium. In each tank were enclosed bronze and hardened steel rods, the two materials used in vane pumps.

To three of the above described tanks were added 100cc of CVC Convalex 10 (polyphenyl ether), 100cc of Welch Due-Seal hydrocarbon oil, and 100cc of Dow-Corning 560 silicone fluid. The three oils were outgassed to less than 20 μ Hg, then pressurized to 2000 torr with hydrogen gas having the following isotopic mixture (by mass spectrometry):

Isotope	%
H	0.51
D	69.20
T	30.20*

*or 0.11 g T_2 per tank (by PVT calculation)

The lead lined tanks were tumbled continuously at approximately 8 rpm for 900 hours to provide intimate contact of the liquid and gas. Then the overpressure was measured, and the gas was analyzed by mass spectrometry. After the gas had been pumped from the oils to less than 200 μ Hg, the oils were calorimetered in their respective tanks. The tanks were then passed into an argon-atmosphere drybox and opened. The viscosities of the exposed oils were measured and compared to the original viscosities at the same temperatures. Also noted were any solids formation and any apparent effects on the bronze and the hardened steel. The results are given in Table 1.

As the table indicates, Convalex 10 polyphenyl ether showed the least amount of hydrogen exchange and Dow-Corning 560 silicone fluid the most (nearly 100%). The amount of tritium found by calorimetry in the Convalex

10 oil must be due to absorption of the hydrogen isotopes in nearly equal amounts, rather than to isotopic exchange. This theory is supported by the observed low over-gas pressure with the Convalex 10 oil.

The present work supports an earlier finding that polyphenyl ether lubricants, such as Convalex 10, are highly resistant to tritium, and therefore, suitable for vane pump lubrication. The findings also indicate that silicone oils should never be used where exposure to tritium is possible. This study is extended to include other lubricants and polyphenyl ethers of various molecular weights.

9.4 Lubricant Evaluation

Following the experimental method outlined above, three additional lubricants were tested for resistance to tritium: Du Pont's PR143AD perfluorinated aliphatic polyether, and Monsanto's XCS210 poly (4) phenylether and OS 124 poly (5) phenylether.

As the data in Table 2 indicates, all three oils show only slight tendency to exchange with tritium or increase in viscosity. Of special significance is the extremely low degree of exchange or absorption with Du Pont's PR143AD fluid. This fluid, available in a wide range of viscosities, should be used for the lubrication of all equipment involved with tritium. Monsanto's XCS210 and OS124 fluids are also suitable for this purpose, although they tend to absorb hydrogen isotopes (see calorimetry results and ending gas pressure), causing some loss of tritium when oils are changed.

9.5 Conclusions

From the data lubricating available on oil samples tested by Mound, the indicators are that viscosity can be marginally affected by tritium or severely affected. This seems to be dependent on the type of oil and the tritium exchange. It is interesting to observe that the viscosity of silicone with a very large exchange of tritium is drastically affected. Other lubricants with low tritium exchange are essentially unaffected. Silicone based oils should not be used where there is the potential for tritium to be present.

A discussion with Mound would be most useful in assessing the applicability of their experience to the TVPS/RH lubrication requirements. These discussions would lead to recommendations for the application of specific oil/gases to be used for remote handling equipment, for this particular system.

APPENDIX 1

REFERENCES

REFERENCES

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8. Tritium Safe Handling Course, CFFTP, Report No. I-9067, September 1990.

9. Tritium Handling in Vacuum Systems, Mound Laboratories, August 1982.

10. Interaction of Tritium with Polymeric Materials, GE Co., March 1960.

11. Evaluation of Lubricants that are resistant to Tritium, Mound Labs, 1966.

APPENDIX 2

TABLES

TABLE 1

EVALUATION OF LUBRICANTS AND PUMP MATERIALS IN MUTUAL CONTACT WITH TRITIUM

	Convalex 10 Lubricant	Welch Duo-Seal Lubricant	560 Silicone Lubricant
Beginning Gas Pressure (torr) at 25.6°C	2030	2030	2030
Ending Gas Pressure (torr) at 25.6°C	931	1242	1330
Ending Isotopic Mixture in Over-Gas %	H 2.64 D 65.40 T 31.97	H 16.02 D 57.84 T 26.14	H 96.85 D 2.94 T 0.22
Calorimetry Results (g T_2/100 cc oil)	0.0182	0.0055	0.09672
Viscosity Increase (%)	40	13.6	Oil solidified
Colour Before Test Colour After Test	Nearly colourless Light amber	Light amber Light amber	Colourless Light amber
Solids Formed	None	None	~100%
Effect on: Bronze rod Steel rod	None None	None None	None None

TABLE 2

EVALUATION OF LUBRICANTS FOR TRITIUM EQUIPMENT

	Du Pont PR143AD Perfluorinated Aliphatic Polyether	MCS-210 Poly (4) phenylether	OS124 Poly (5) phenylether
Beginning Gas Pressure at 25°C (torr)	2031	2031	2031
Beginning Isotopic Mixture in Over-Gas (mole %)	H 1.43 D 68.44 T 30.12	H 1.43 D 68.44 T 30.12	H 1.43 D 68.44 T 30.12
Ending Gas Pressure at 25°C (torr)	1076	953	888
Ending Isotopic Mixture in Over-Gas (mole %)	H 0.01 D 70.34 T 29.65	H 3.00 D 66.94 T 30.06	H 3.48 D 66.18 T 30.34
Calorimetry Results (g T_2 /100 cc oil)	0.0044	0.0156	0.0163
Viscosity Increase (%)	2.1	26.6	19.7
Colour Before Test	Colourless	Light amber	Light amber
Colour After Test	Colourless (slightly cloudy)	Light amber	Slightly darker Amber
Solids Formed	None	None	None
Effect at (25°C) on Bronze rod Steel rod	 None None	 None None	 None None

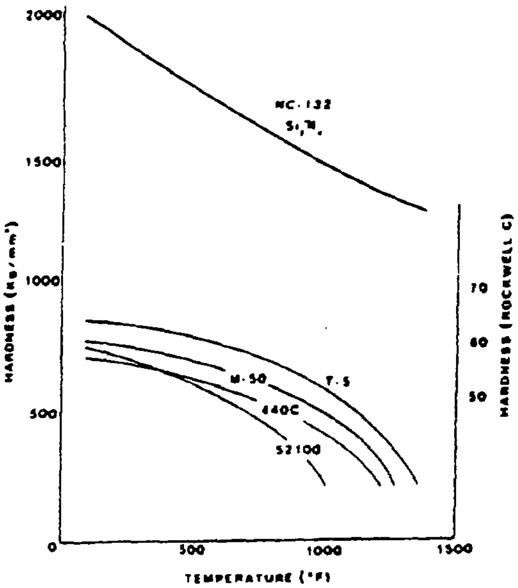
APPENDIX 3

FIGURES

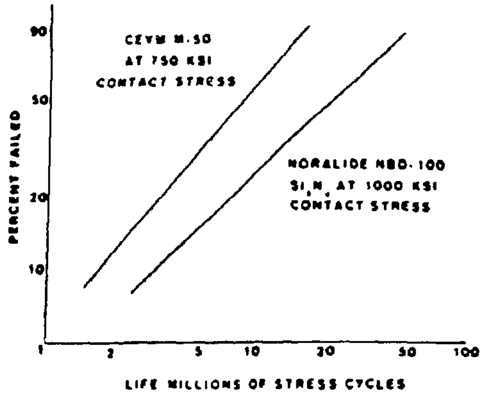
FIGURES

TYPICAL PROPERTIES OF NC-132 AND NBD-100 SILICON NITRIDE

Density	3.2 grams/cc
Hardness	KHN_{1000} 1600 (Approx. R_c 80)
Coefficient of Sliding Friction	0.12 lubricated 0.17 unlubricated
Fracture Toughness	4.9 × 10^{3} lb-$in^{3/2}$
Young's Modulus	45 × 10^{6} PSI
Thermal Expansion Coefficient	1.9 × 10^{6}/°F

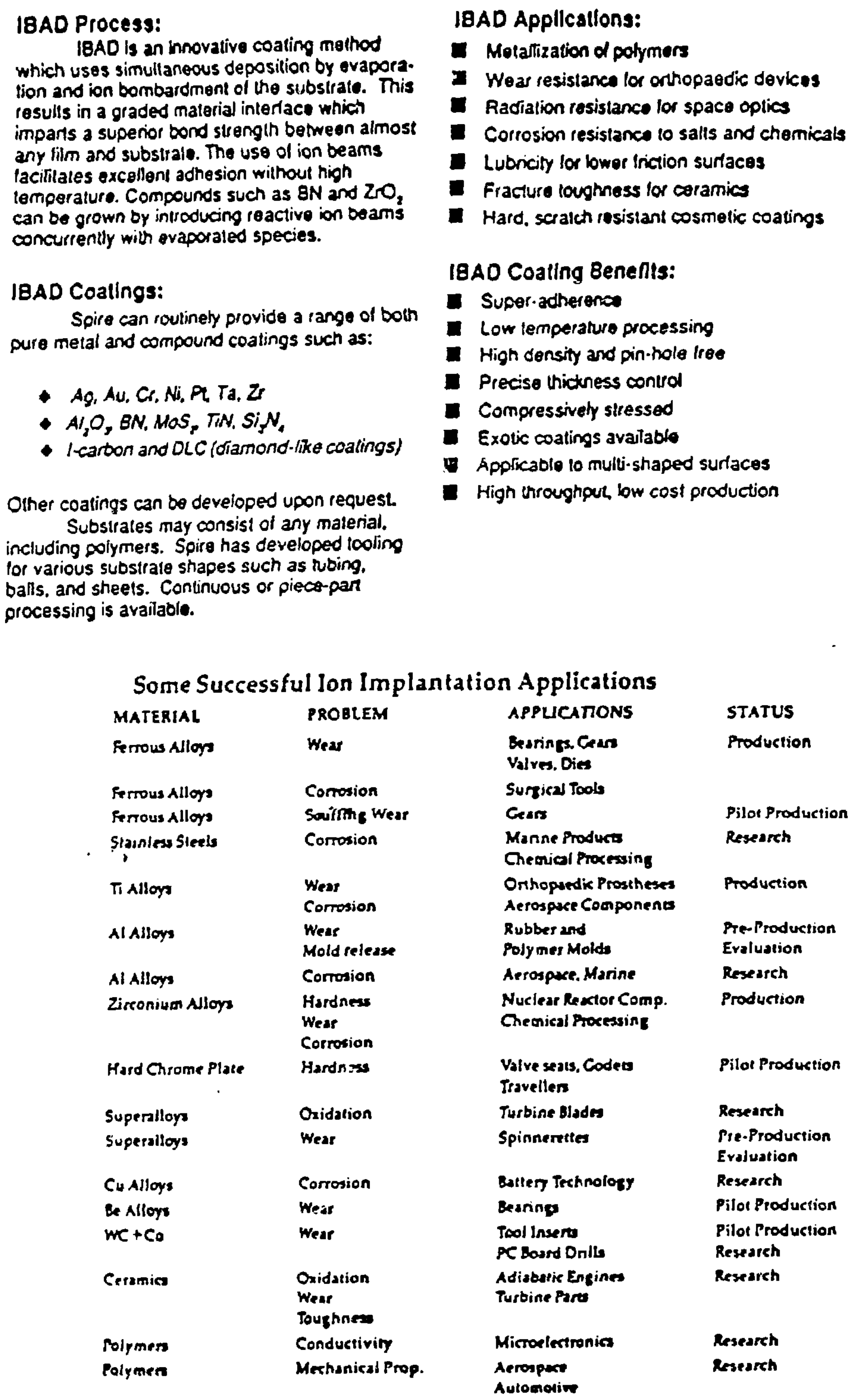


Hardness Comparison



Rolling Contact Fatigue Life

FIG.1 CERAMIC BEARINGS



IBAD Process:

IBAD is an innovative coating method which uses simultaneous deposition by evaporation and ion bombardment of the substrate. This results in a graded material interface which imparts a superior bond strength between almost any film and substrate. The use of ion beams facilitates excellent adhesion without high temperature. Compounds such as BN and ZrO_2 can be grown by introducing reactive ion beams concurrently with evaporated species.

IBAD Coatings:

Spire can routinely provide a range of both pure metal and compound coatings such as:

- *Ag, Au, Cr, Ni, Pt, Ta, Zr*
- *Al_2O_3, BN, MoS_2, TiN, Si_3N_4*
- *i-carbon and DLC (diamond-like coatings)*

Other coatings can be developed upon request.

Substrates may consist of any material, including polymers. Spire has developed tooling for various substrate shapes such as tubing, balls, and sheets. Continuous or piece-part processing is available.

IBAD Applications:

- Metallization of polymers
- Wear resistance for orthopaedic devices
- Radiation resistance for space optics
- Corrosion resistance to salts and chemicals
- Lubricity for lower friction surfaces
- Fracture toughness for ceramics
- Hard, scratch resistant cosmetic coatings

IBAD Coating Benefits:

- Super-adherence
- Low temperature processing
- High density and pin-hole free
- Precise thickness control
- Compressively stressed
- Exotic coatings available
- Applicable to multi-shaped surfaces
- High throughput, low cost production

Some Successful Ion Implantation Applications

MATERIAL	PROBLEM	APPLICATIONS	STATUS
Ferrous Alloys	Wear	Bearings, Gears Valves, Dies	Production
Ferrous Alloys	Corrosion	Surgical Tools	
Ferrous Alloys	Scuffing Wear	Gears	Pilot Production
Stainless Steels	Corrosion	Marine Products Chemical Processing	Research
Ti Alloys	Wear Corrosion	Orthopaedic Prostheses Aerospace Components	Production
Al Alloys	Wear Mold release	Rubber and Polymer Molds	Pre-Production Evaluation
Al Alloys	Corrosion	Aerospace, Marine	Research
Zirconium Alloys	Hardness Wear Corrosion	Nuclear Reactor Comp. Chemical Processing	Production
Hard Chrome Plate	Hardness	Valve seats, Codets Travellers	Pilot Production
Superalloys	Oxidation	Turbine Blades	Research
Superalloys	Wear	Spinnerettes	Pre-Production Evaluation
Cu Alloys	Corrosion	Battery Technology	Research
Be Alloys	Wear	Bearings	Pilot Production
WC+Co	Wear	Tool Inserts PC Board Drills	Pilot Production Research
Ceramics	Oxidation Wear Toughness	Adiabatic Engines Turbine Parts	Research
Polymers	Conductivity	Microelectronics	Research
Polymers	Mechanical Prop.	Aerospace Automotive	Research

FIG.2 ION DEPOSITION

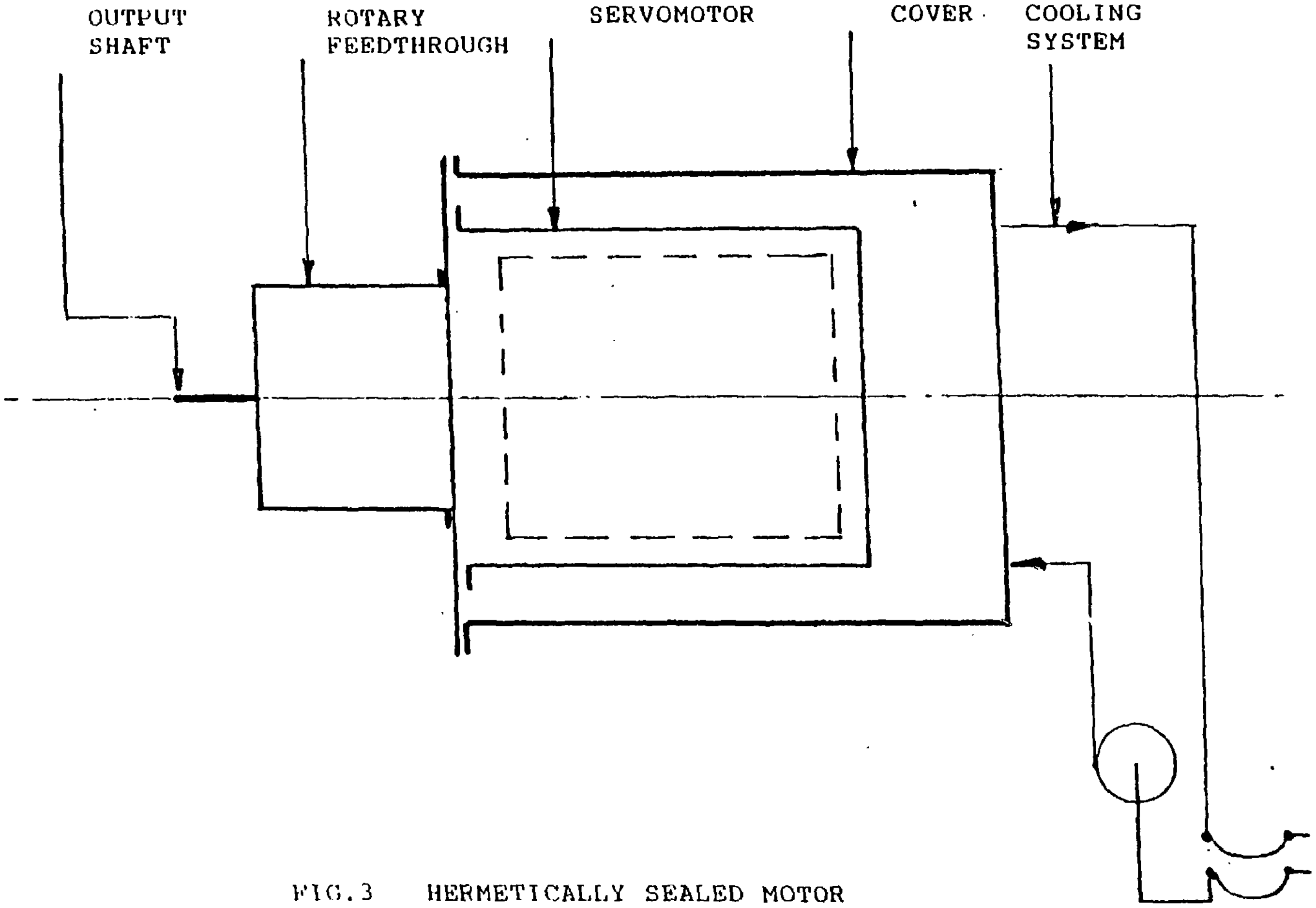


FIG.3 HERMETICALLY SEALED MOTOR

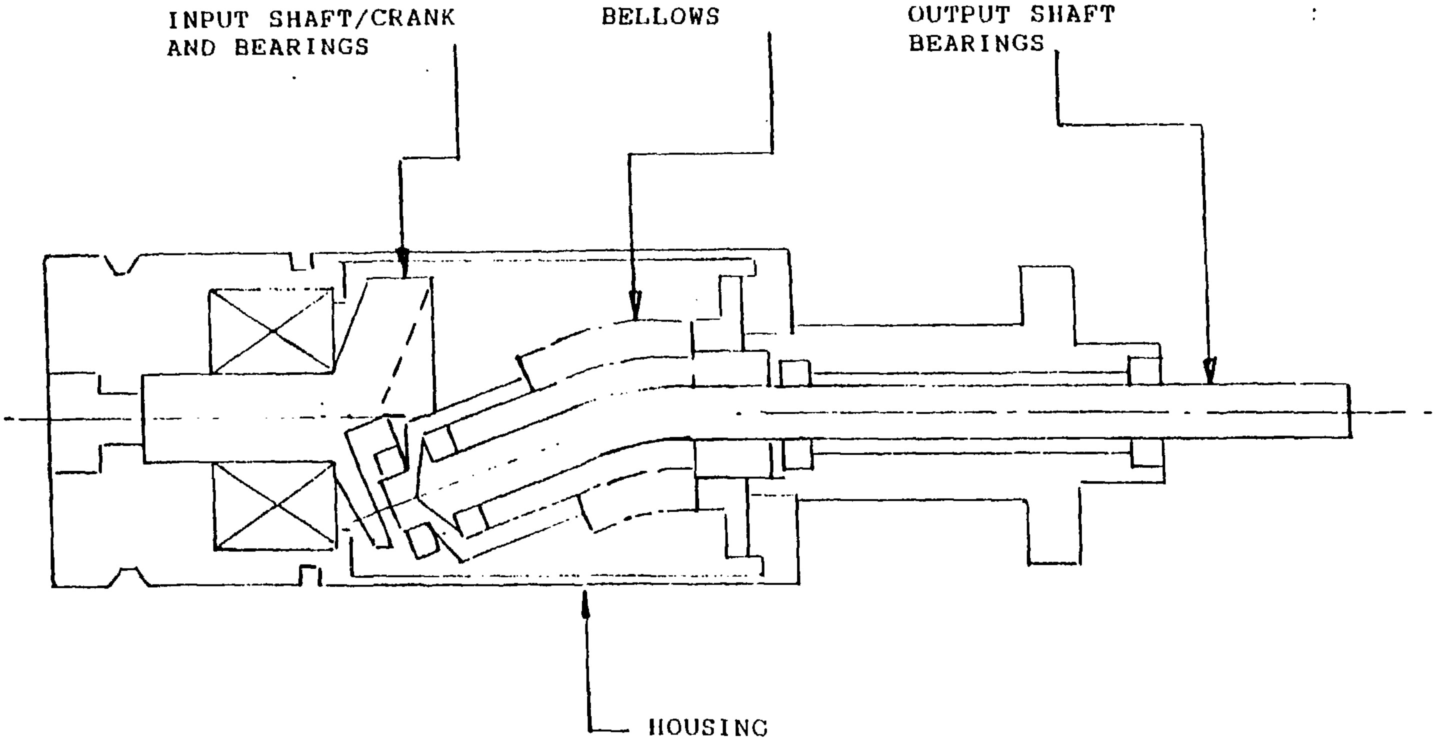


FIG.4 ROTARY FEEDTHROUGH

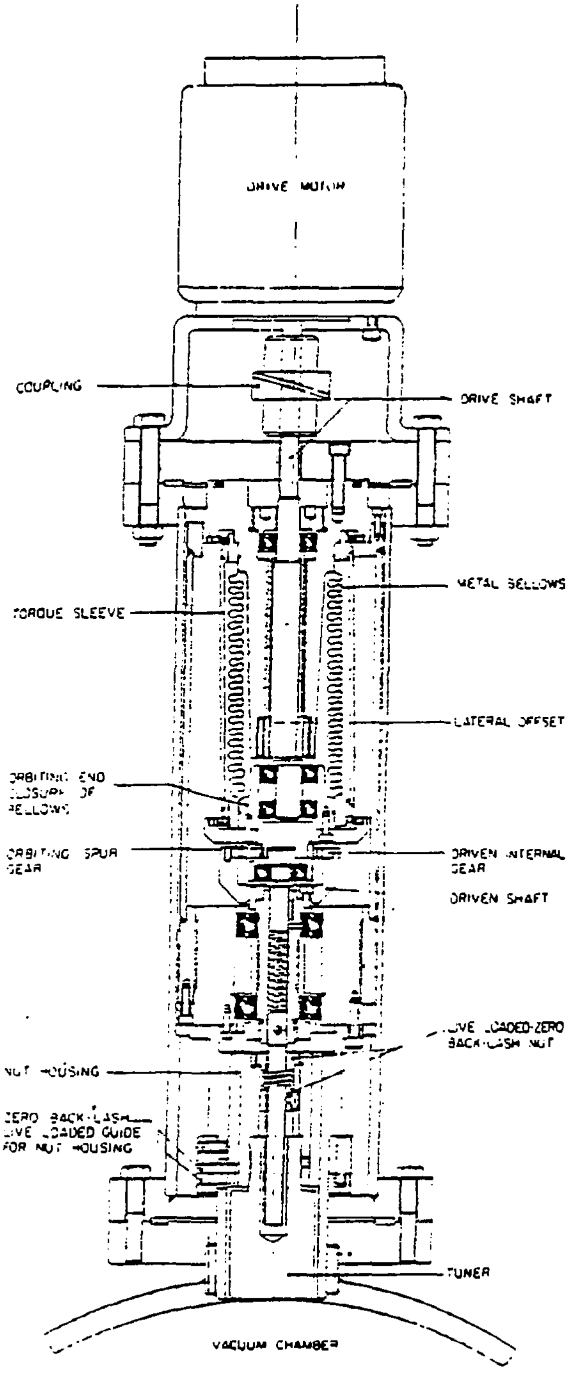


FIG.5 HERMETICALLY SEALED DRIVE FOR A VACUUM CHAMBER
(AECL - CRL)

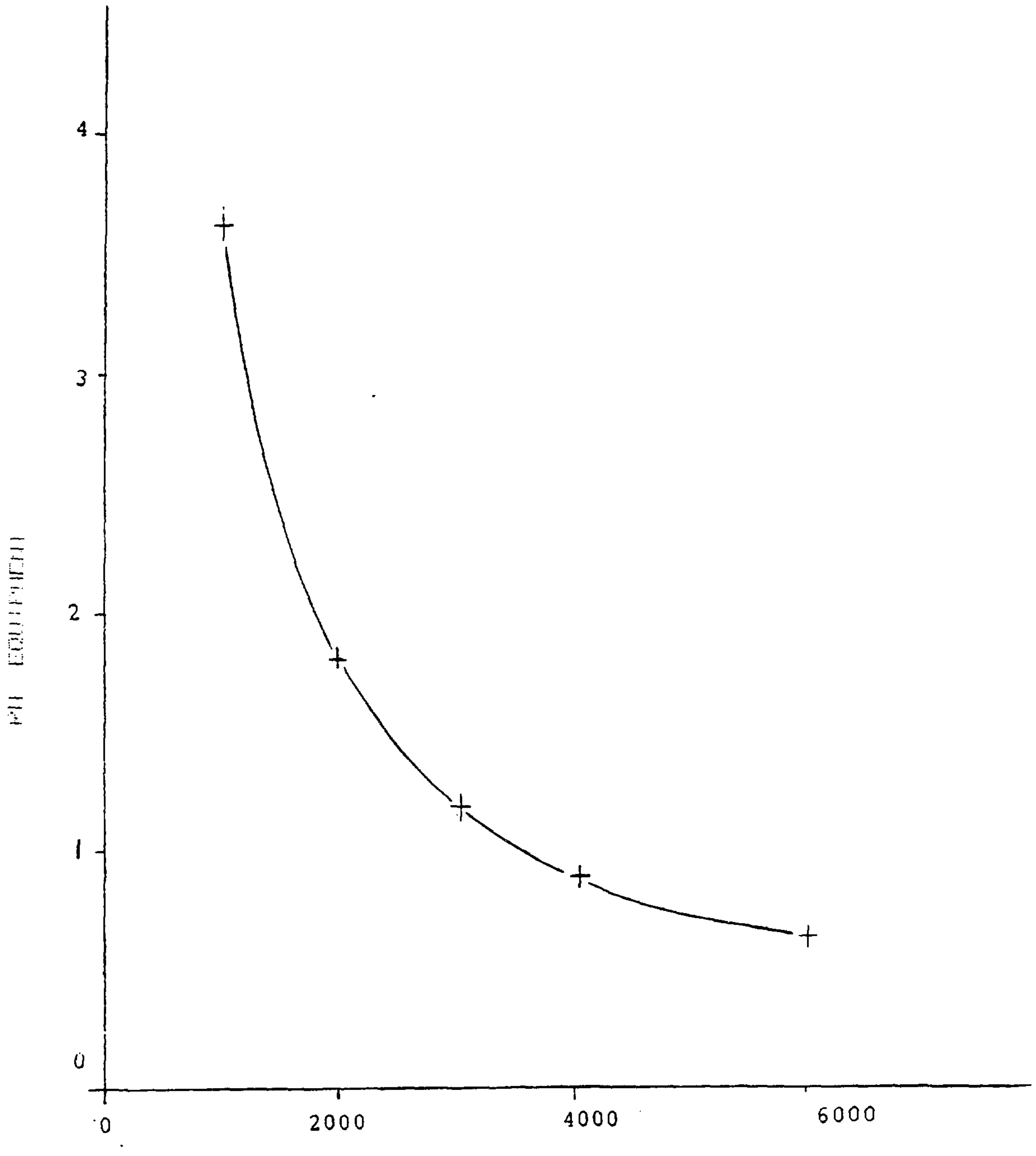


FIG.6 MACHINE HOURS (SCHEDULED)

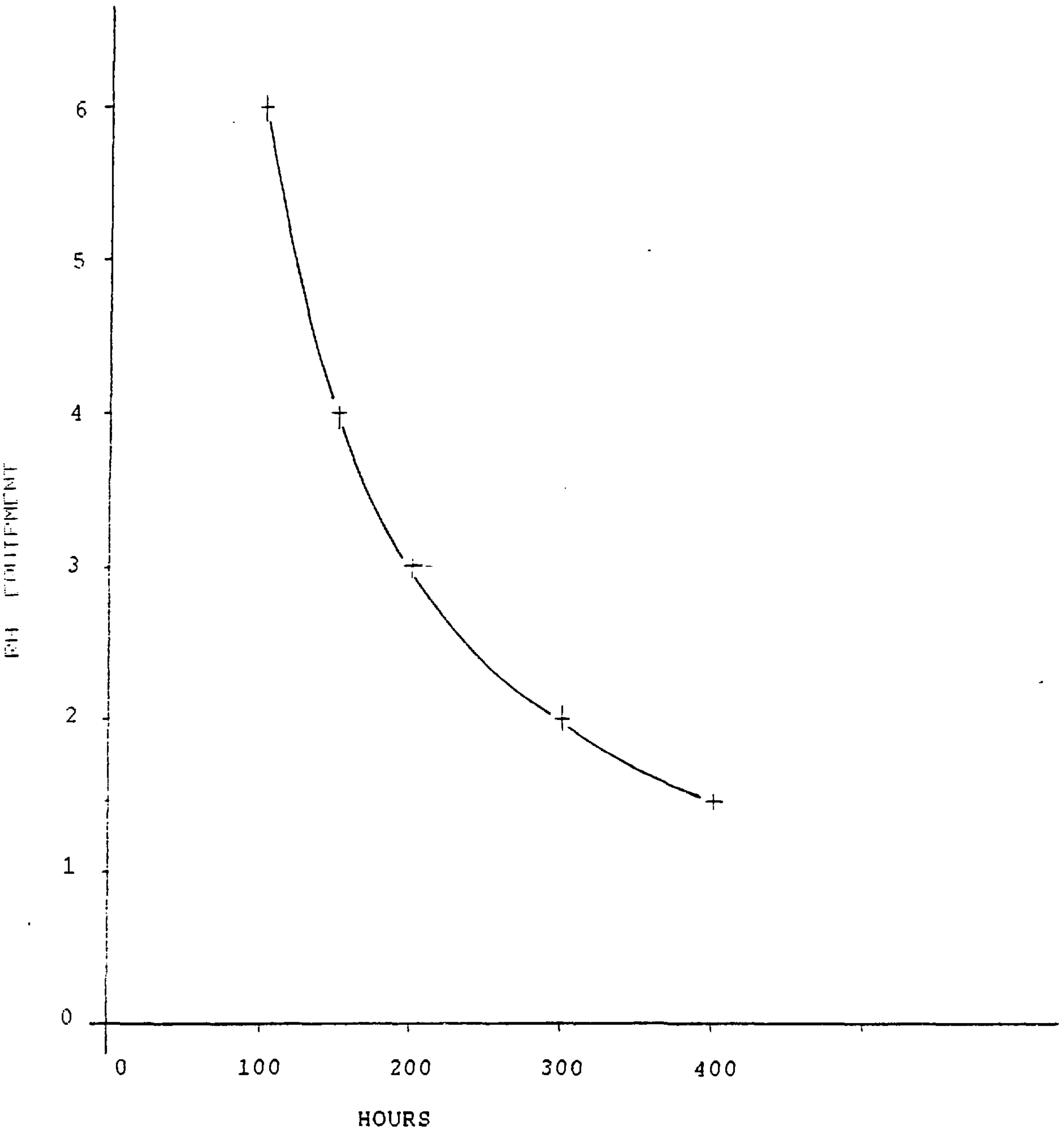


FIG.7 MACHINE HOURS (UNSCHEDULED)

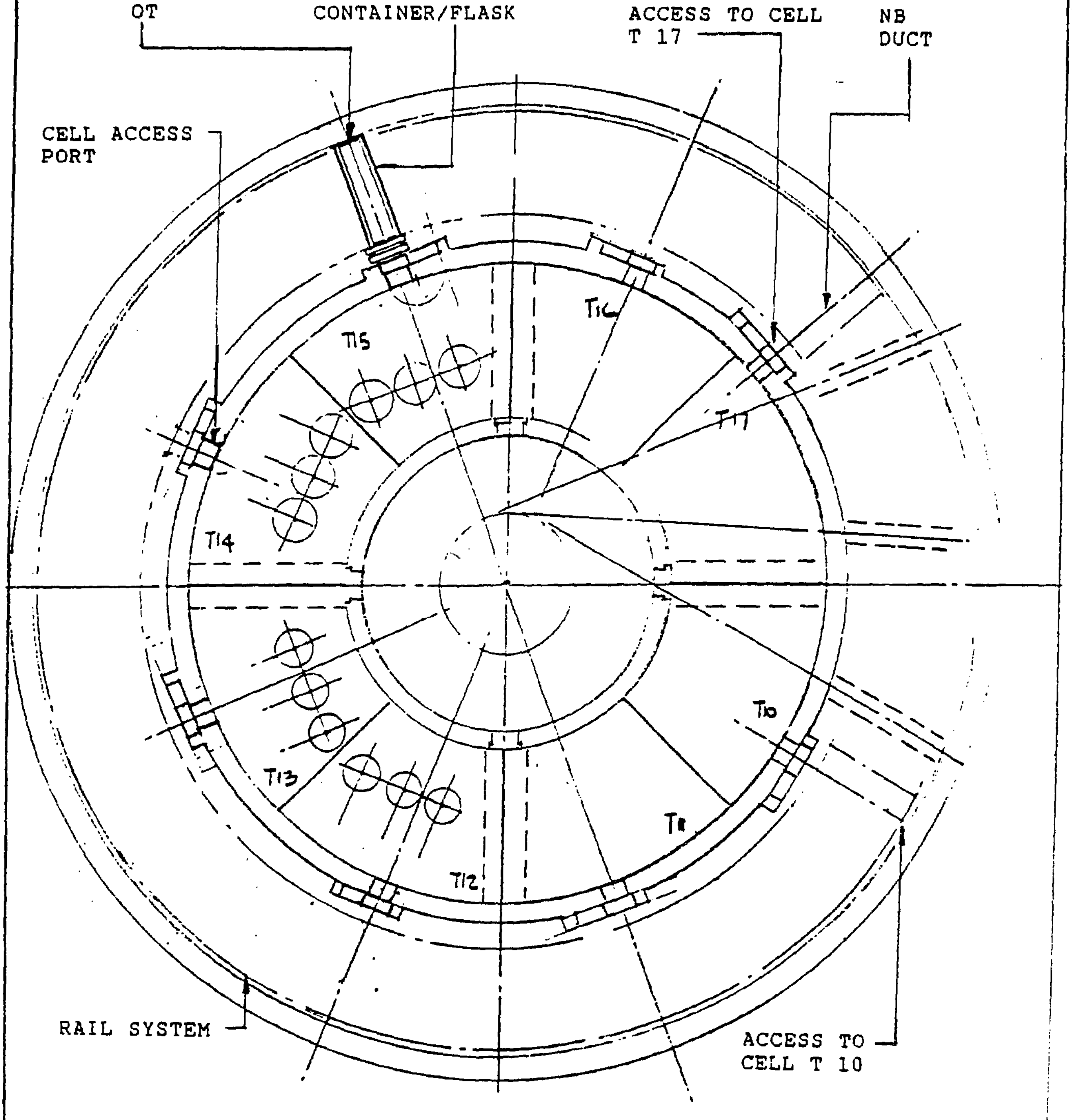


FIG.8a CONCEPT 1

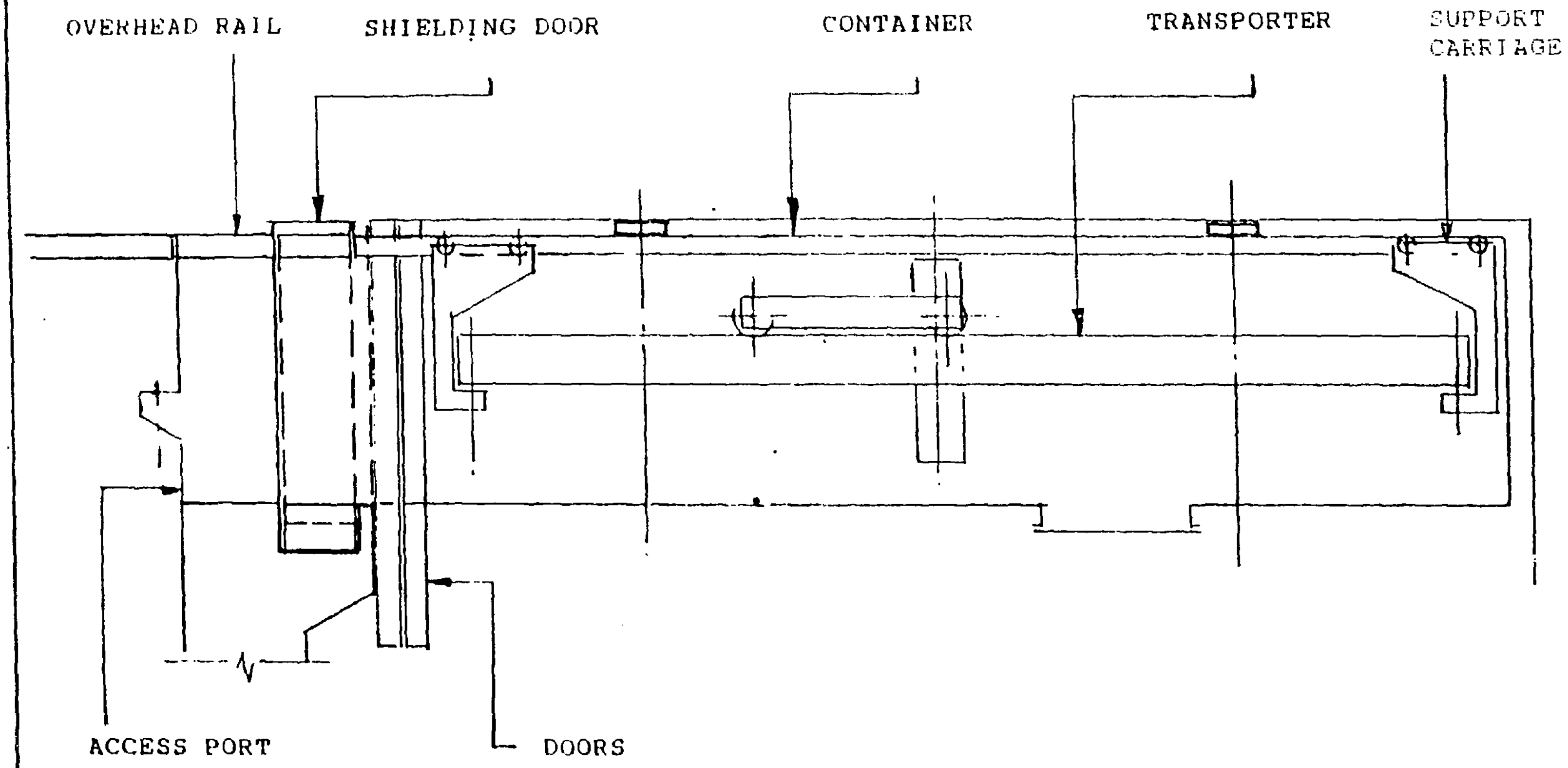


FIG.8b REMOTE HANDLING CONTAINER

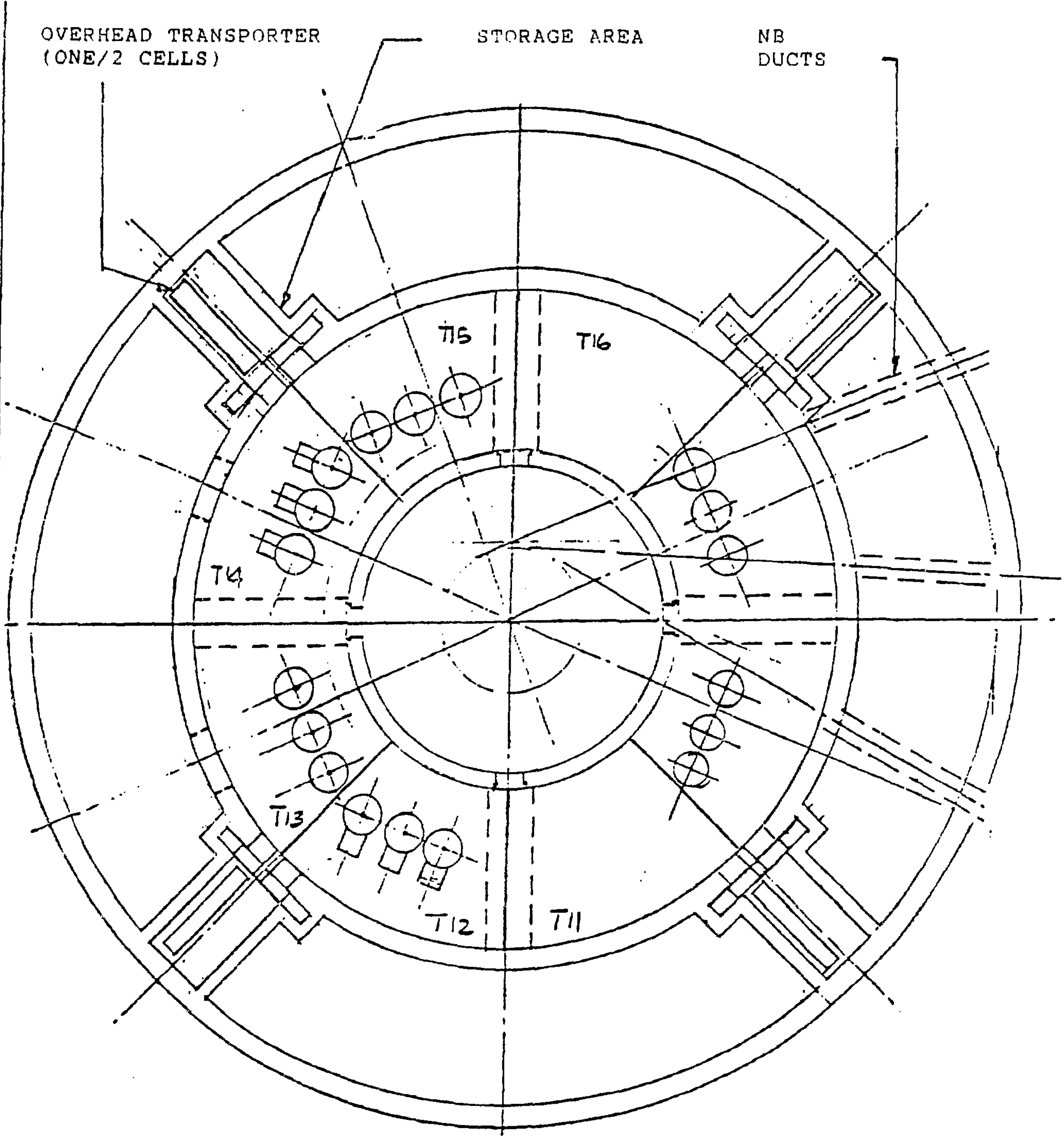


FIG.9a CONCEPT 2

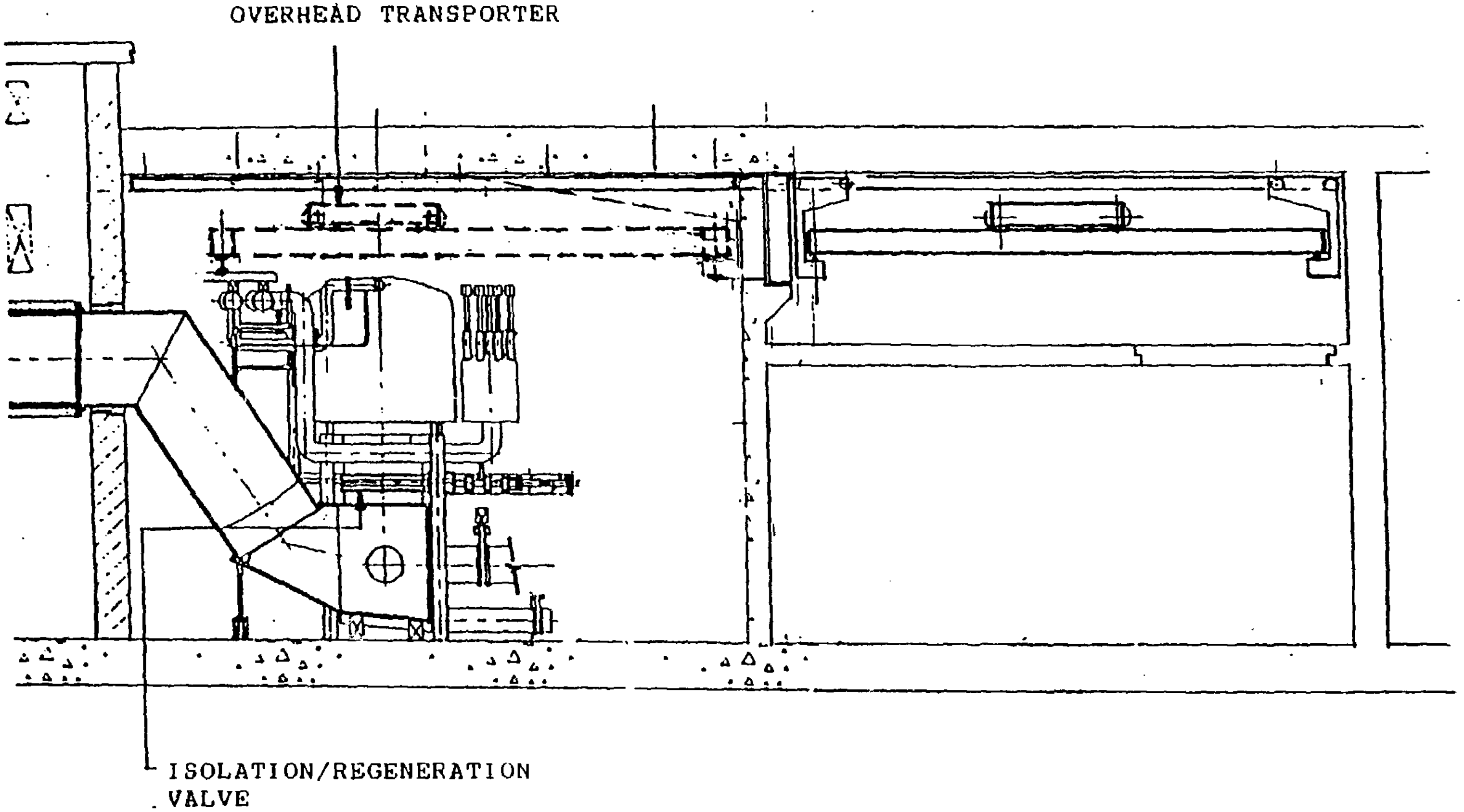


FIG.9b REMOTE HANDLING EQUIPMENT DOCKING AREA

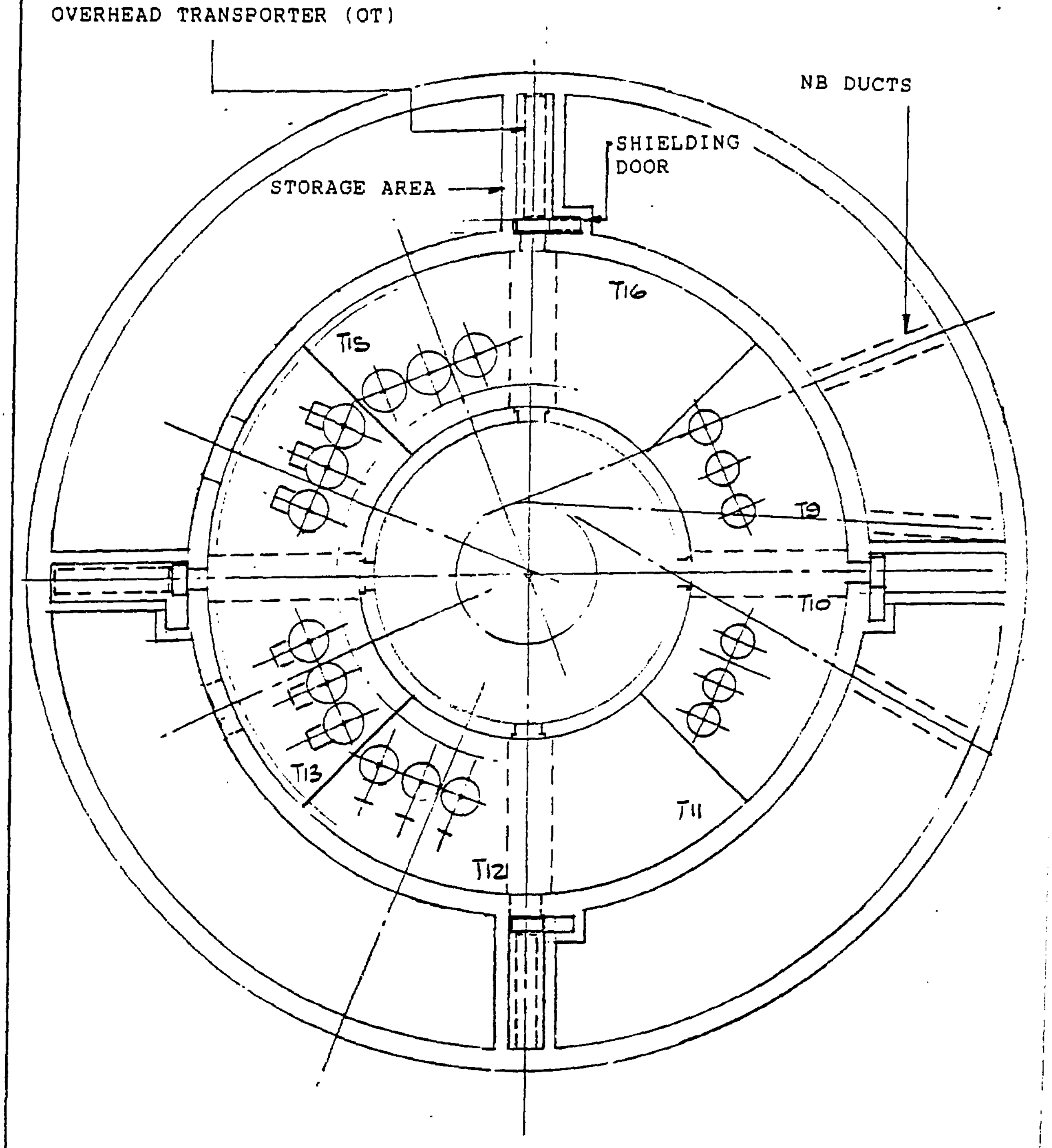


FIG.10 CONCEPT 3

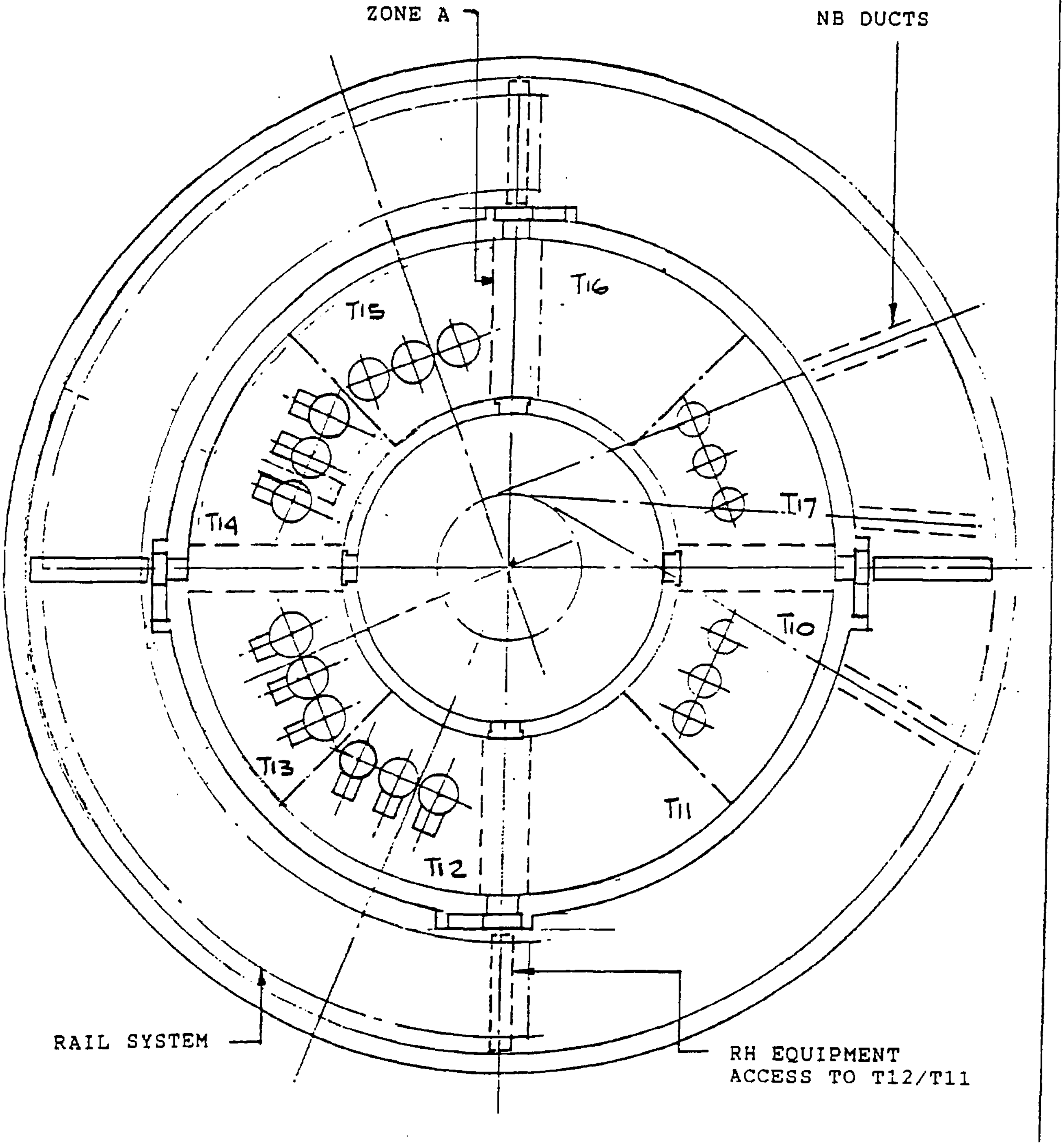


FIG.11a CONCEPT 4

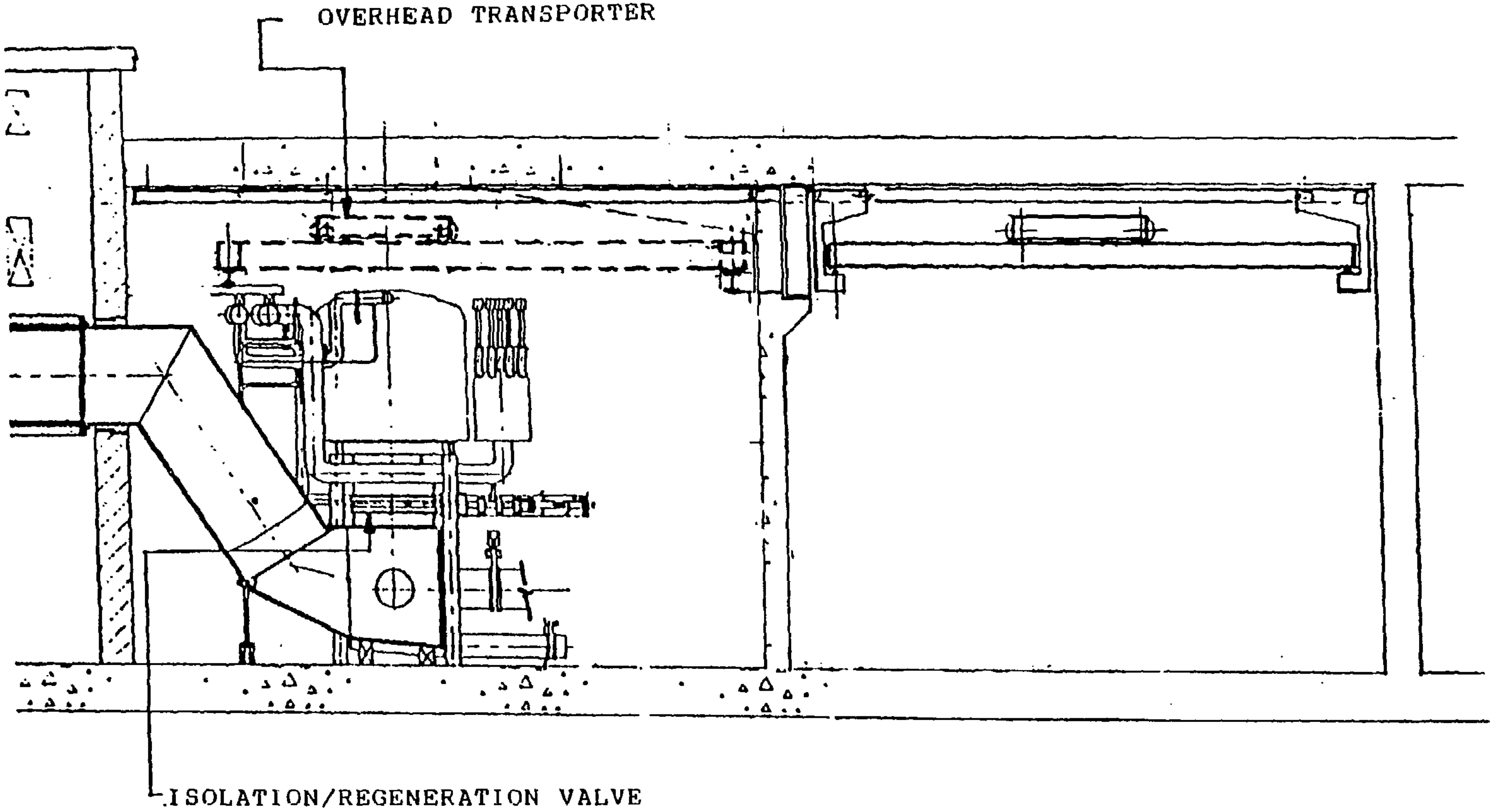


FIG.11b REMOTE HANDLING EQUIPMENT DOCKING AREA

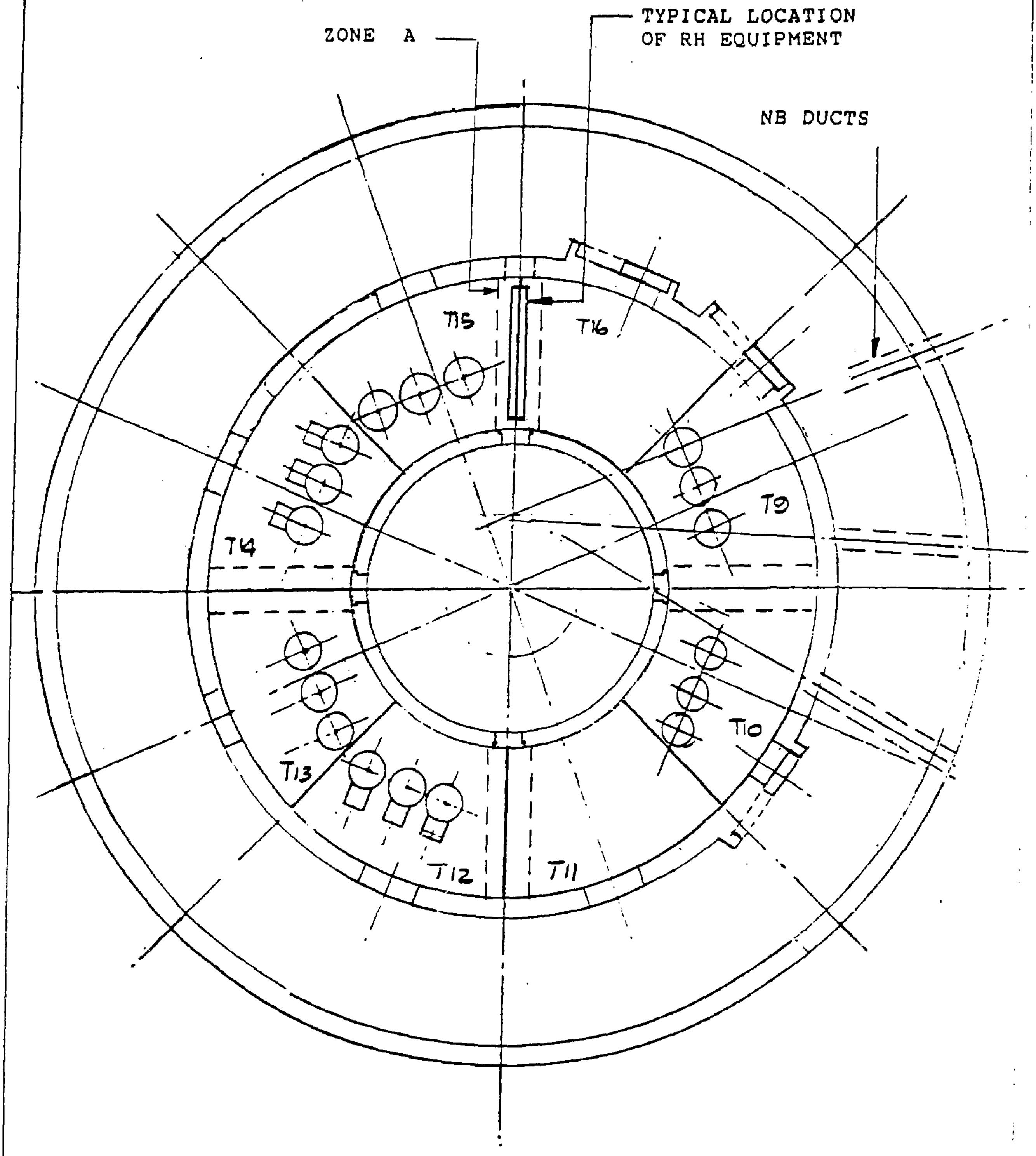


FIG.12 CONCEPT 5

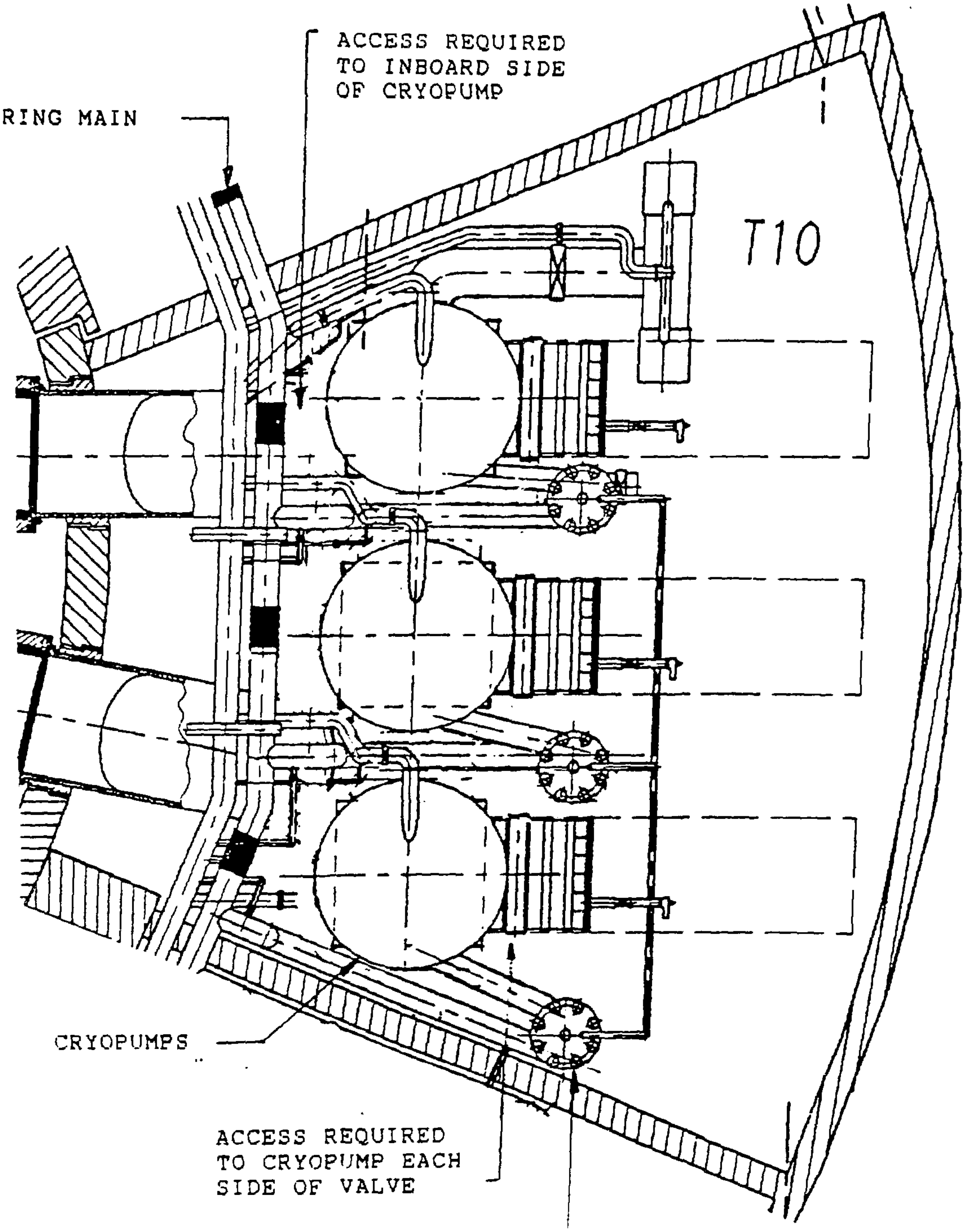


FIG.13 PUMP/CELL PLAN

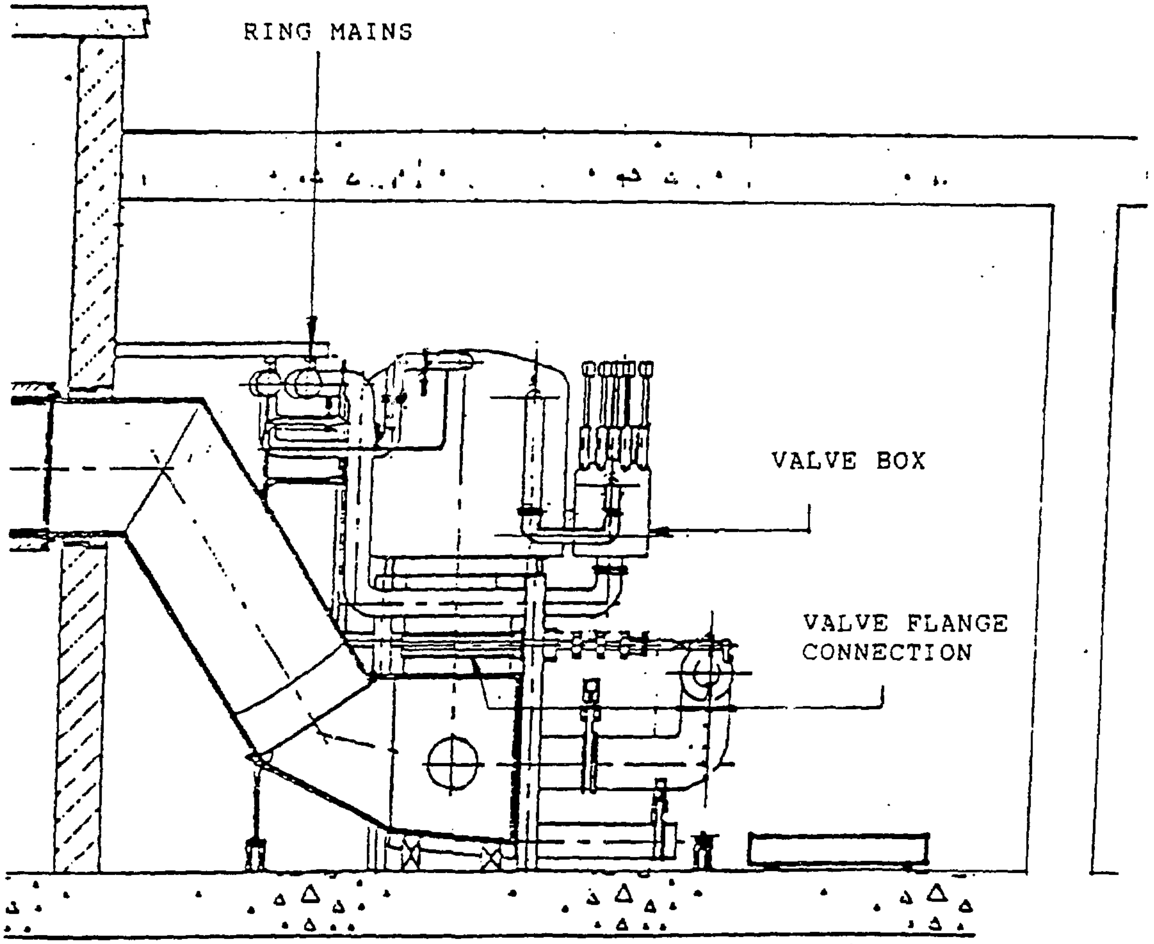


FIG.14 PUMP/CELL ELEVATION

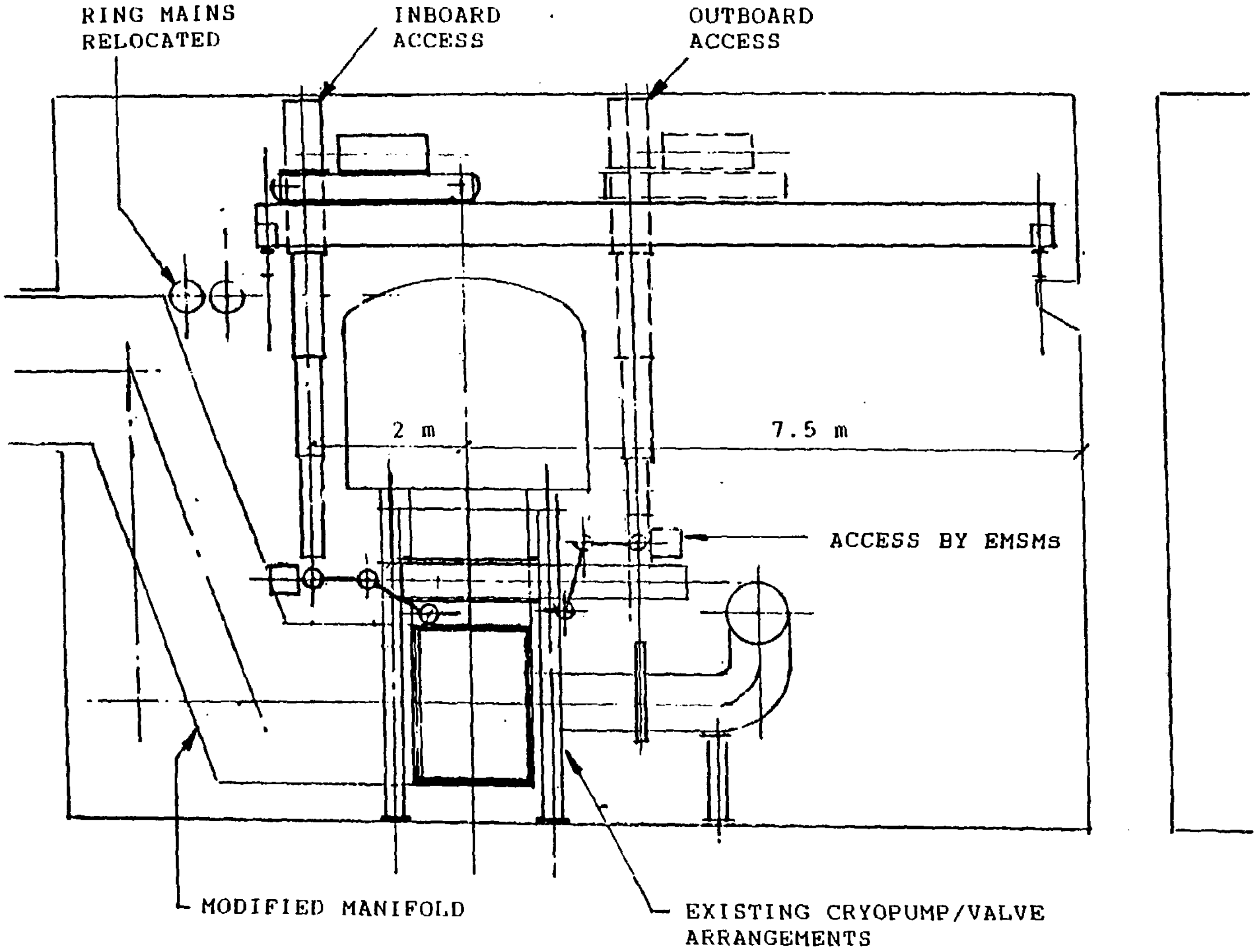


FIG.15 CRYOPUMP/VALVE ACCESS

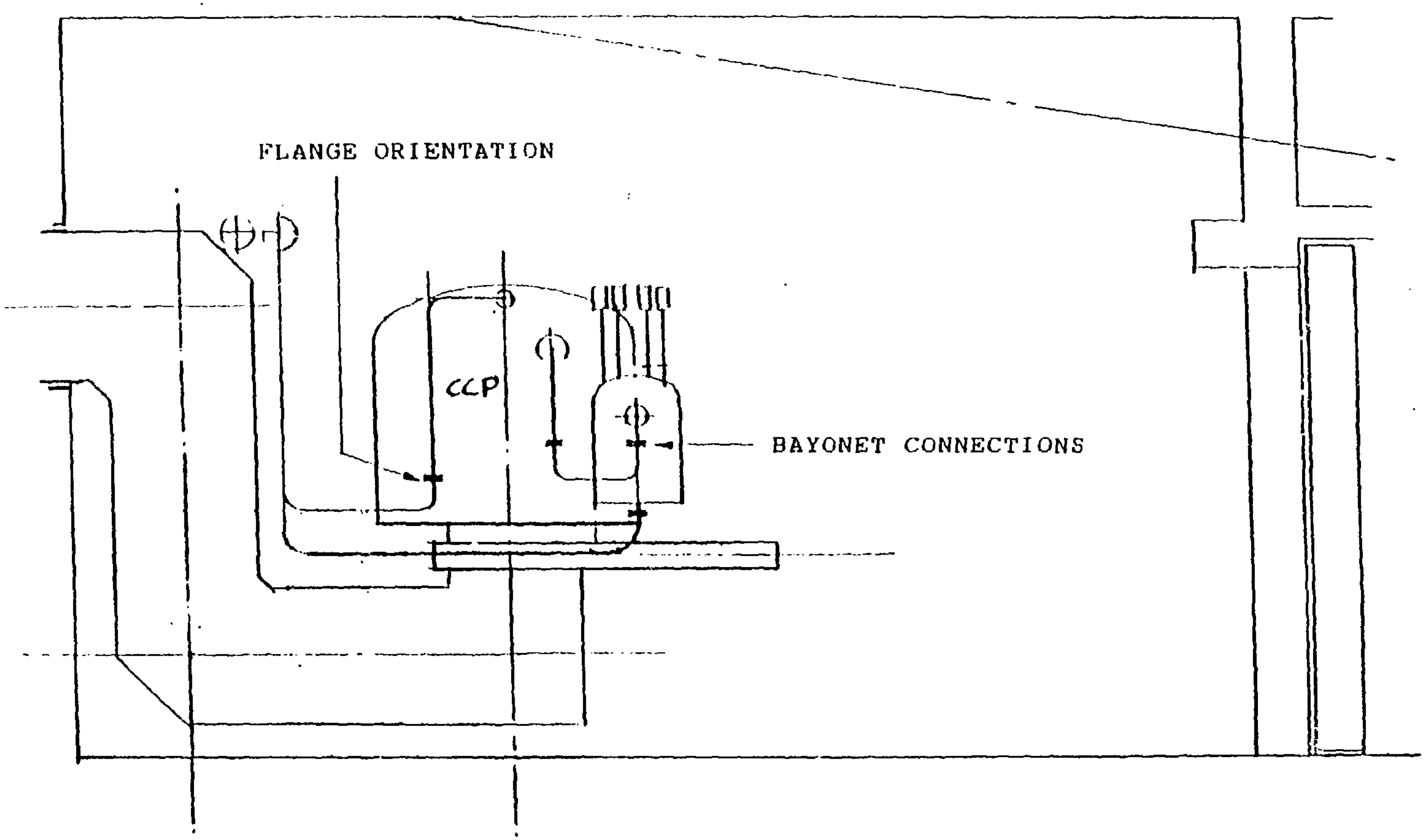


FIG.16 PROPOSED BAYONET CONNECTIONS

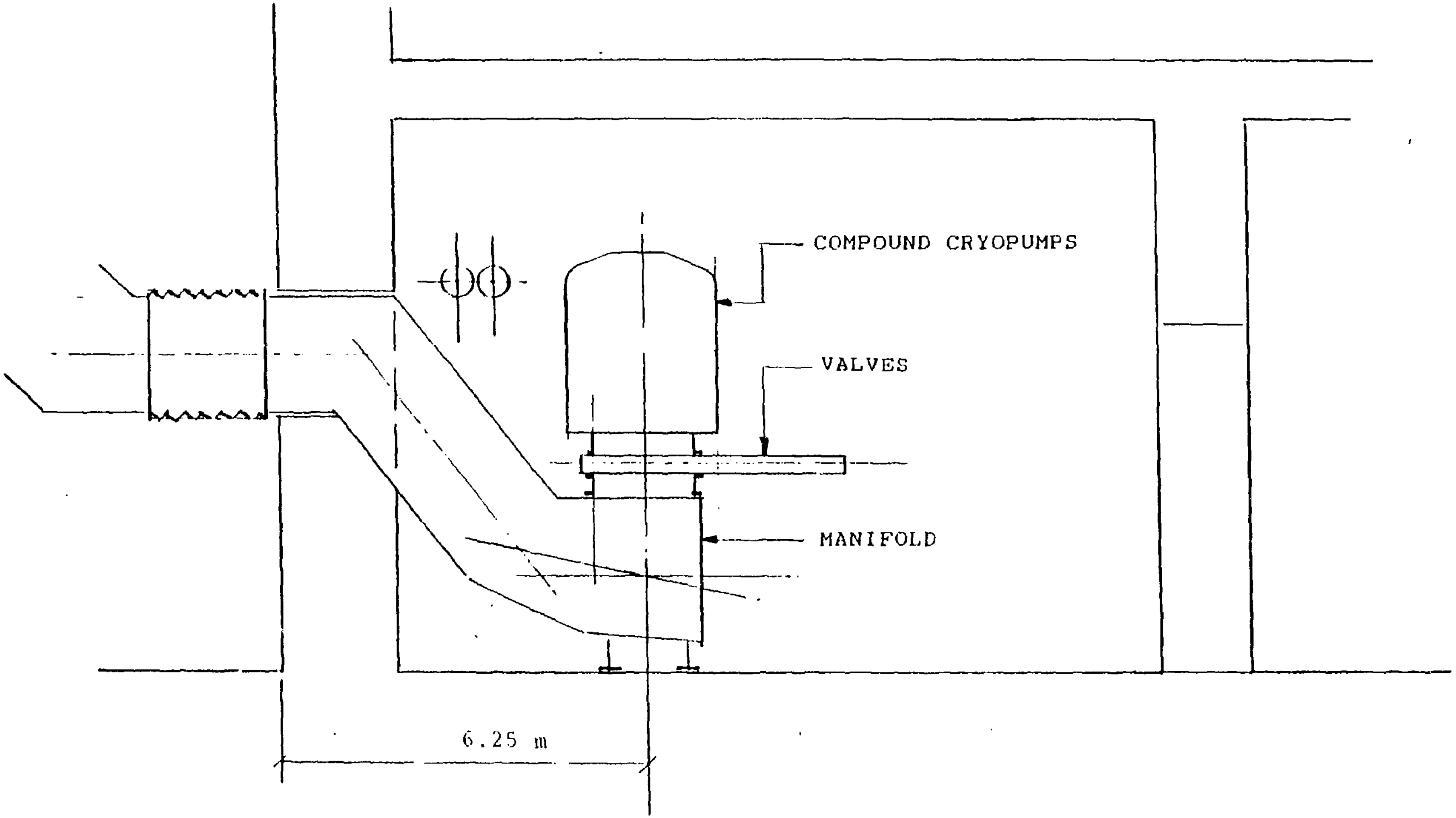


FIG.17 BASELINE DUCT SCHEME

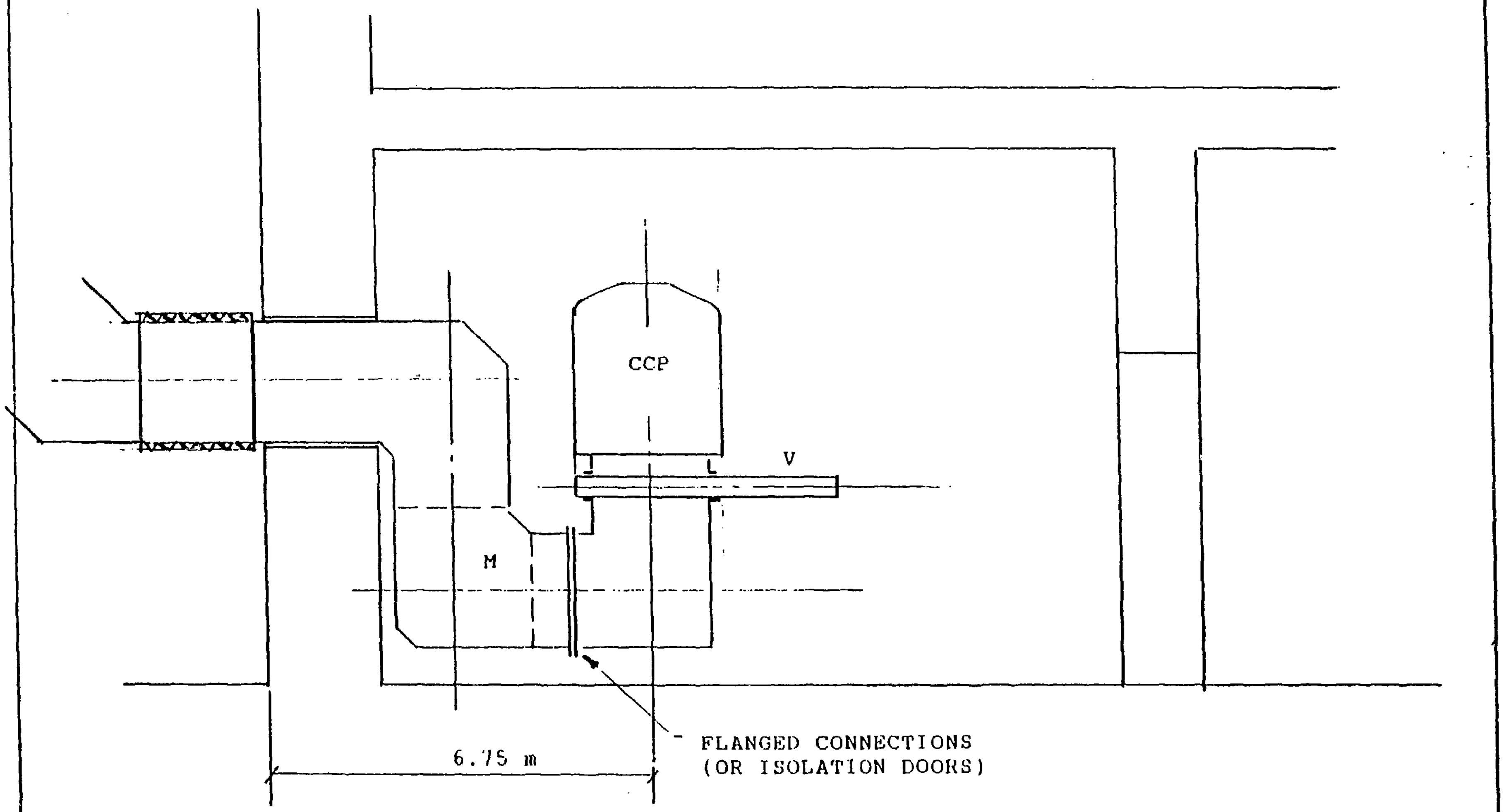


FIG.18 OPTION 1 (NO SHIELDING)

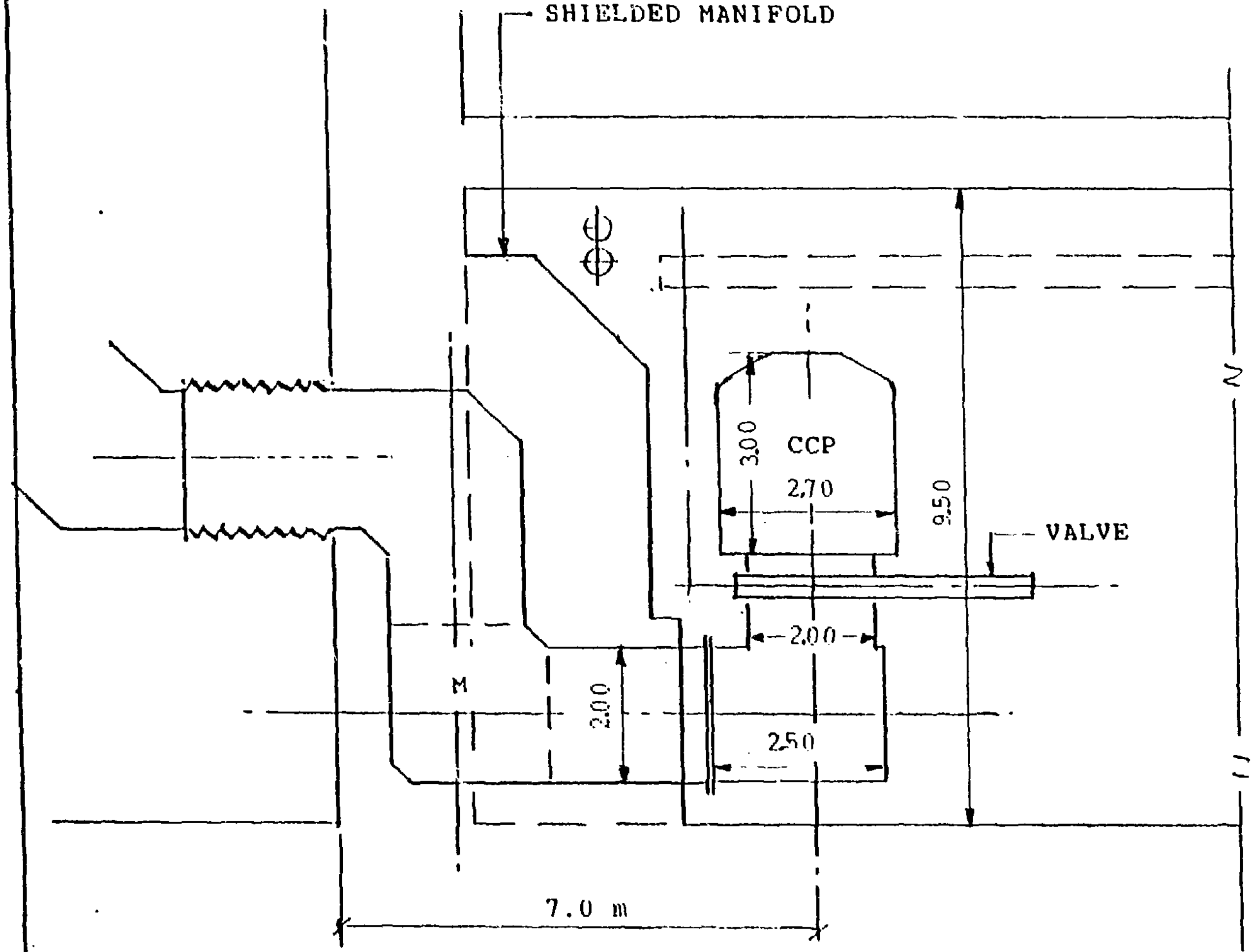


FIG.19 OPTION 2 (WITH SHIELDING)

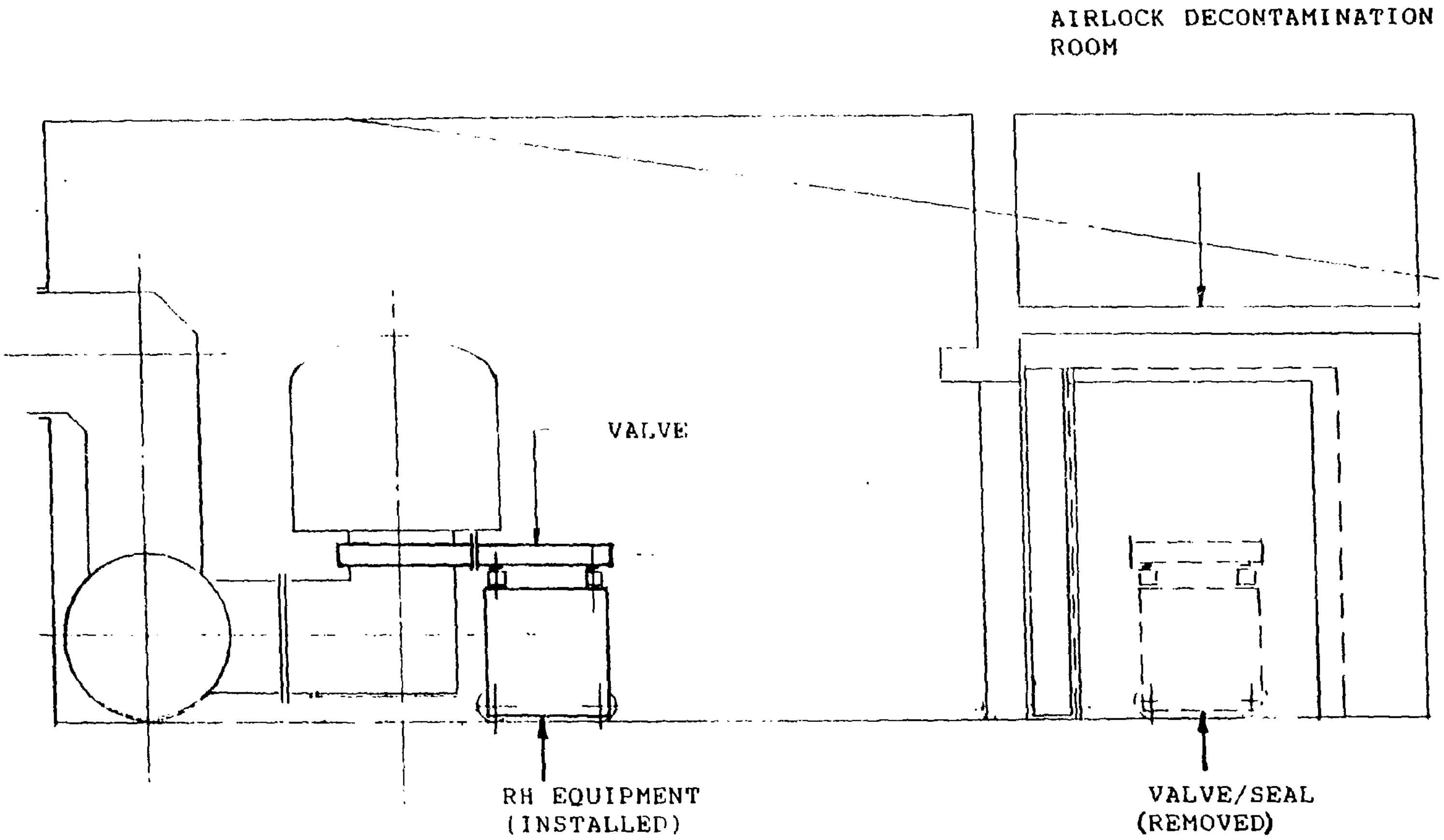


FIG.20 VALVE INTERNALS HANDLING

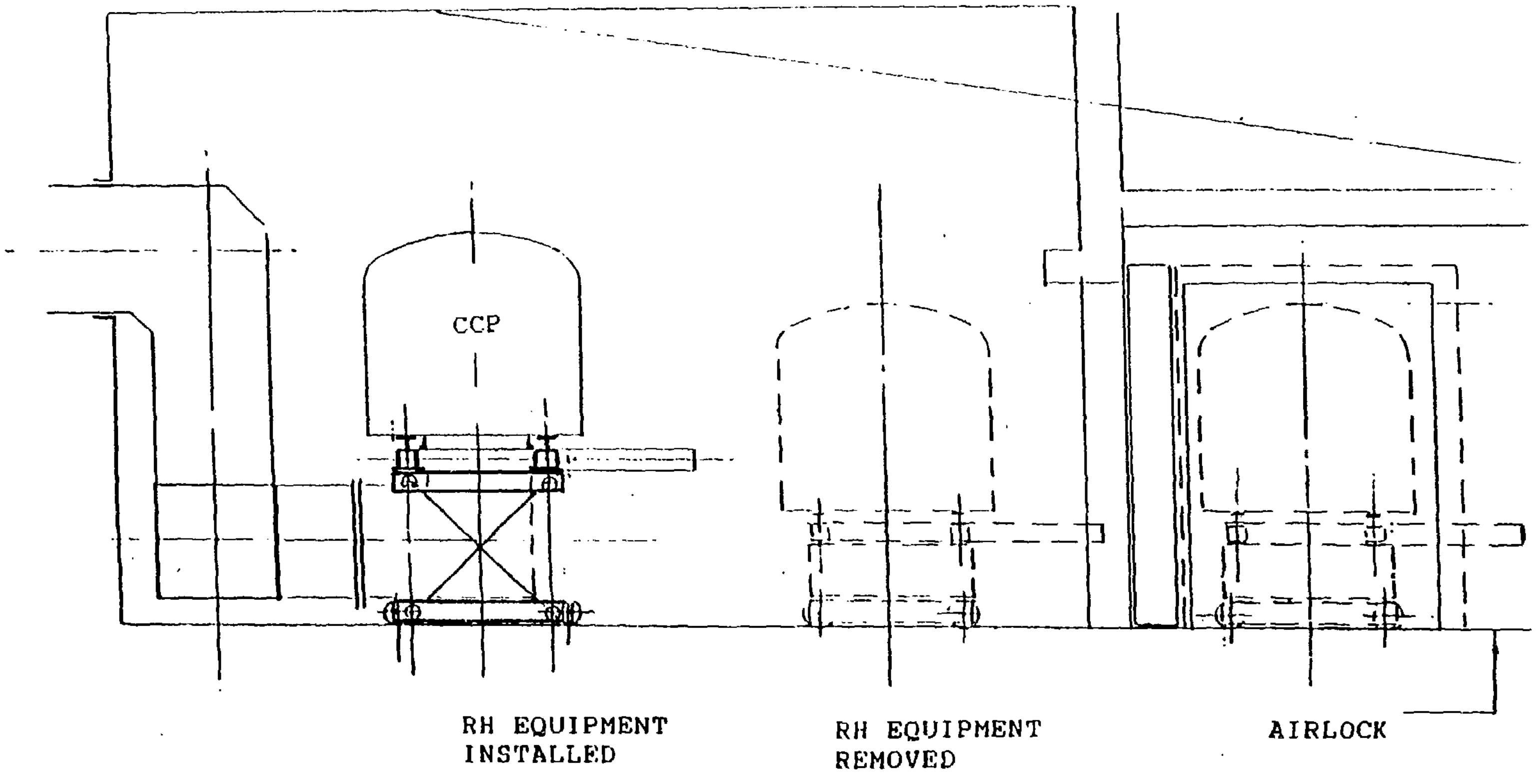


FIG.21 CCP/VALVE HANDLING

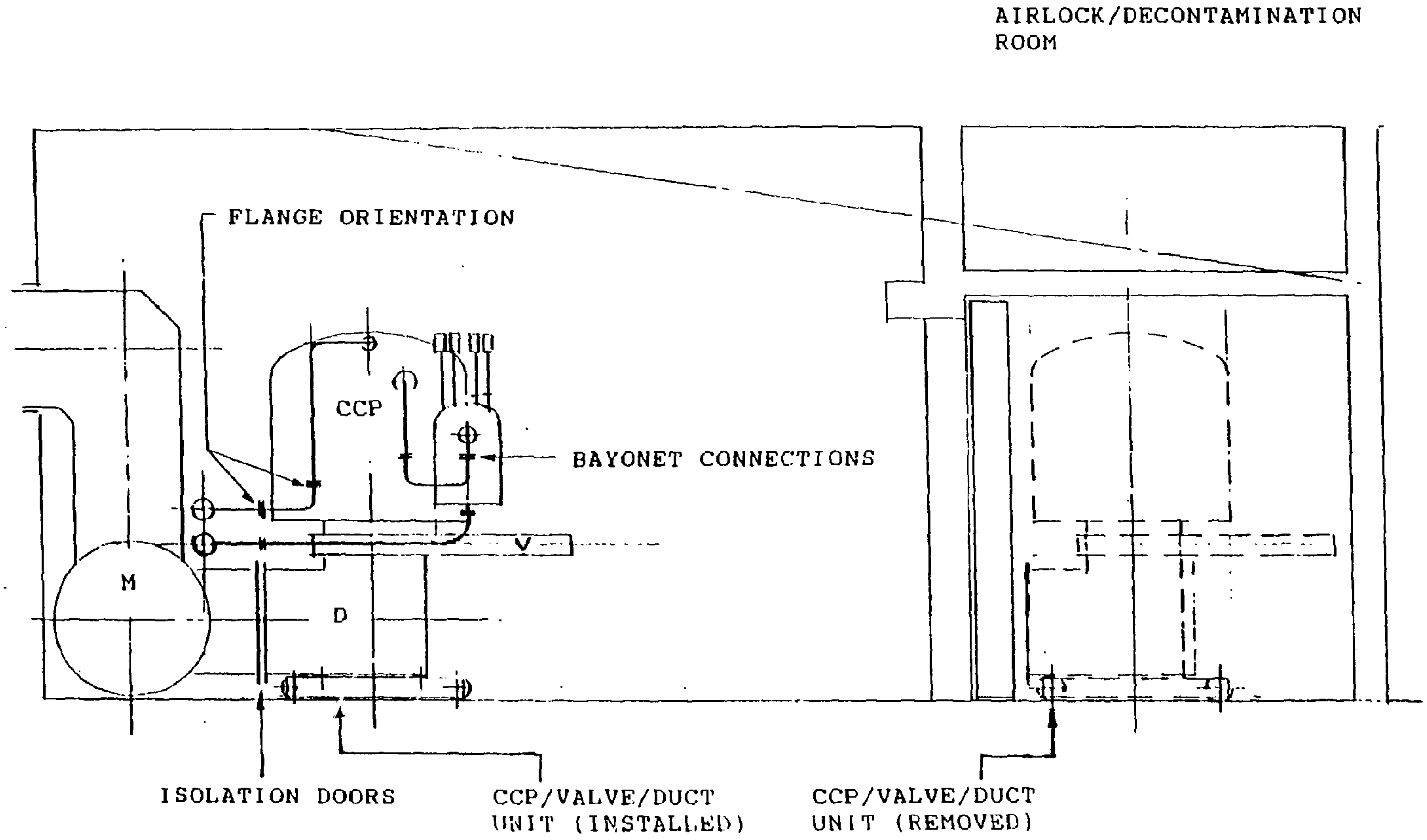
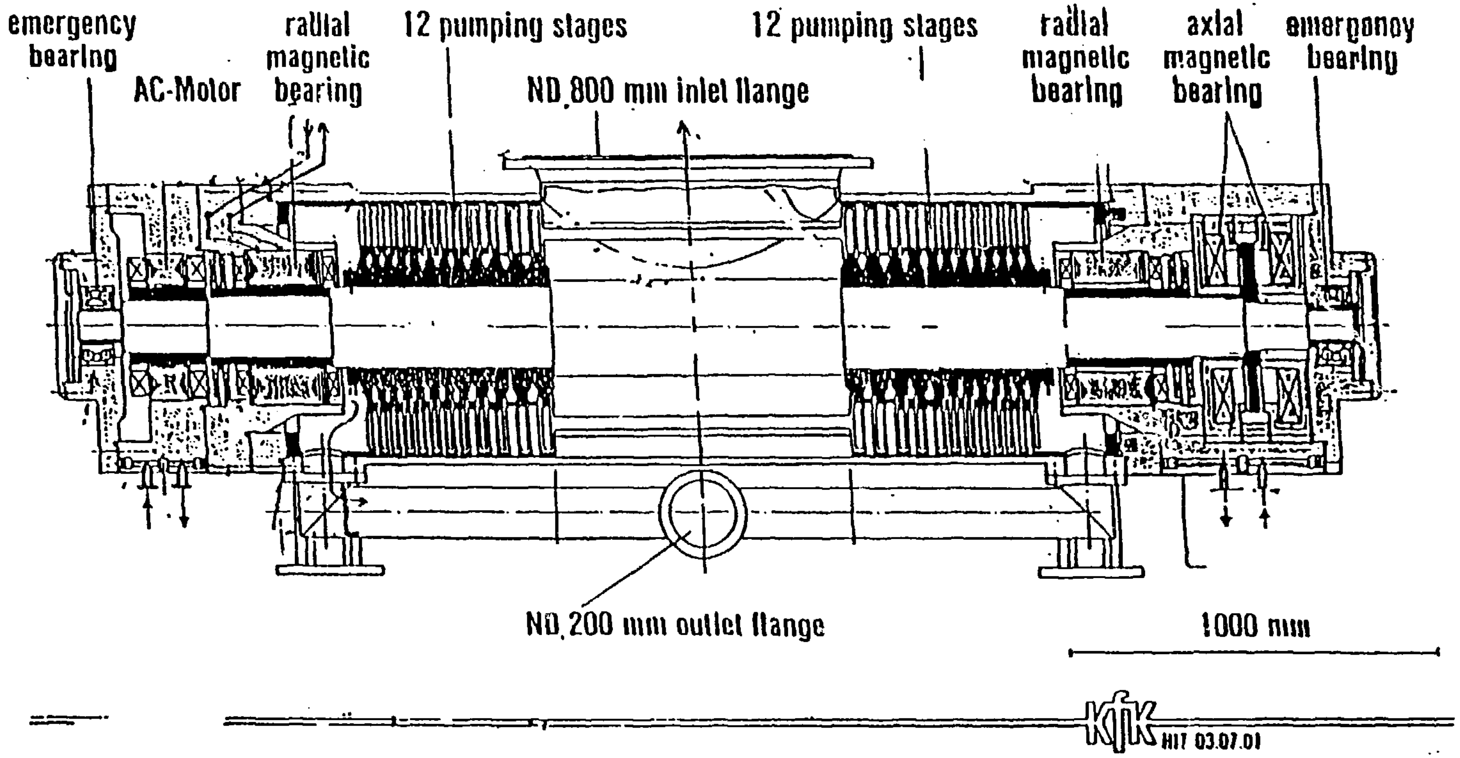


FIG.22 CCP/VALVE/MANIFOLD HANDLING



Sectional drawing of the PFEIFFER double flow TMP 15 000 l/S pump

FIG.23 TMP ARRANGEMENT (PFEIFFER/KfK)

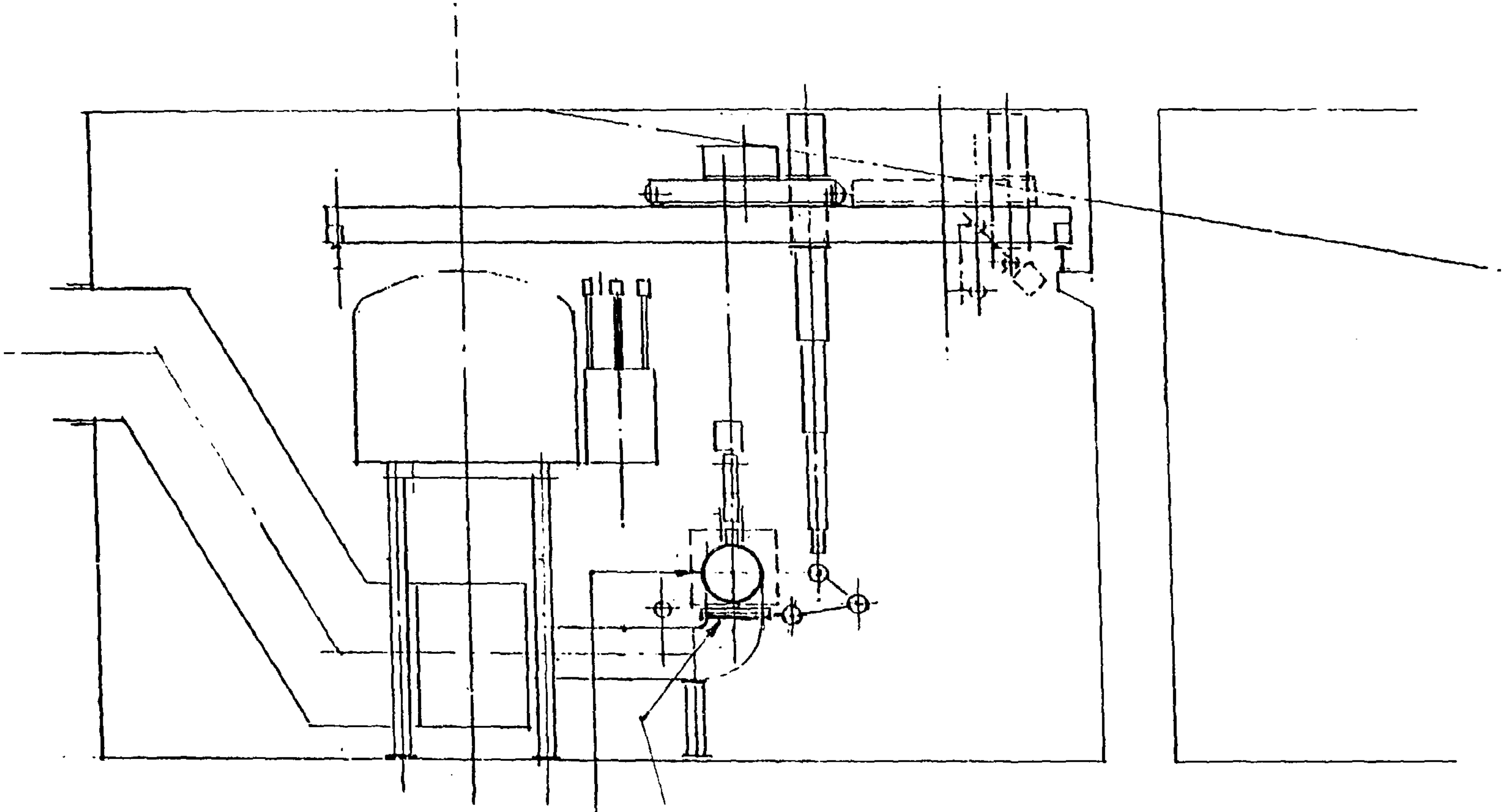


FIG.24   TRANSPORTER ACCESS TO TMPs

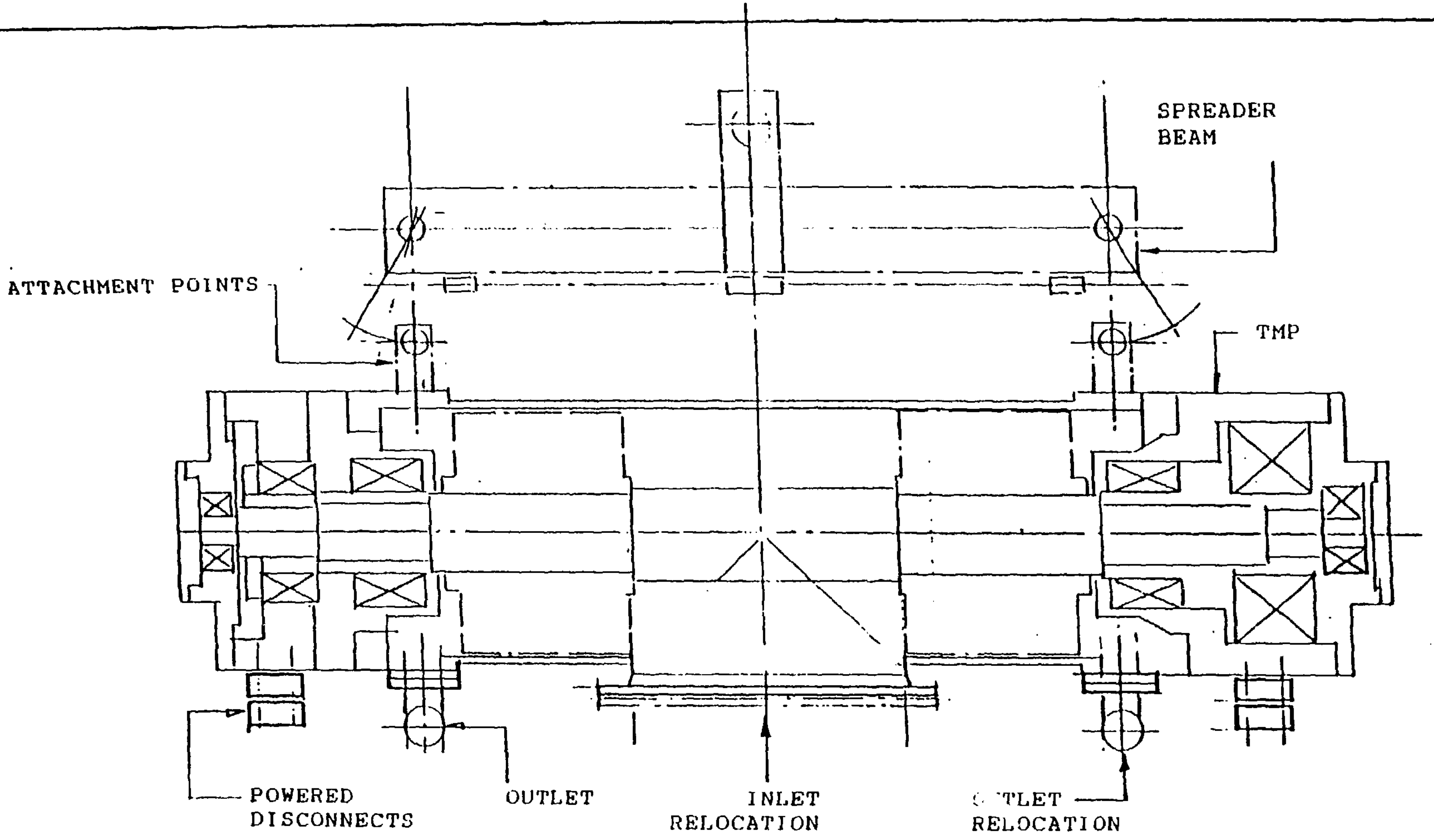


FIG.25 MODIFICATIONS TO TMP

D:OUTSIDE DIAMETER

d:INSIDE DIAMETER

W:SPAN

t:THICKNESS

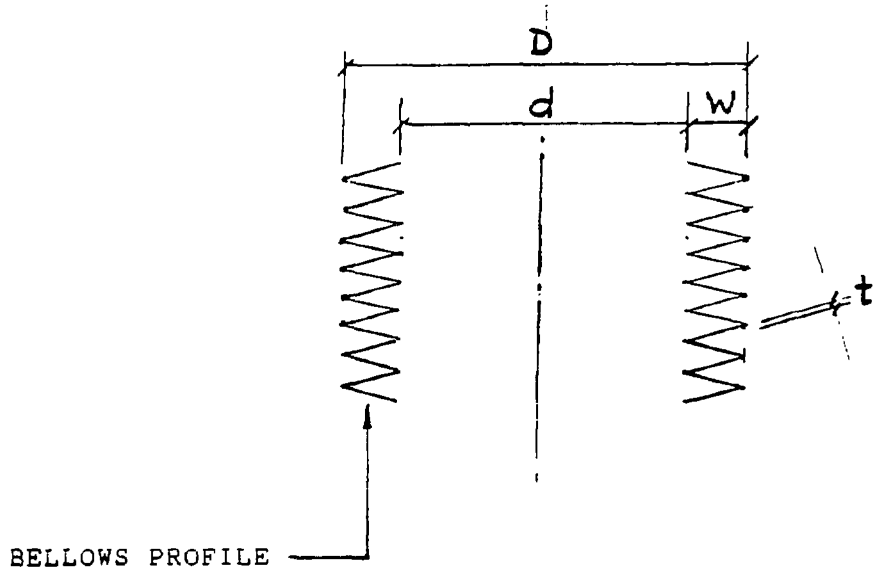


FIG.26 BELLOW PROPORTIONS

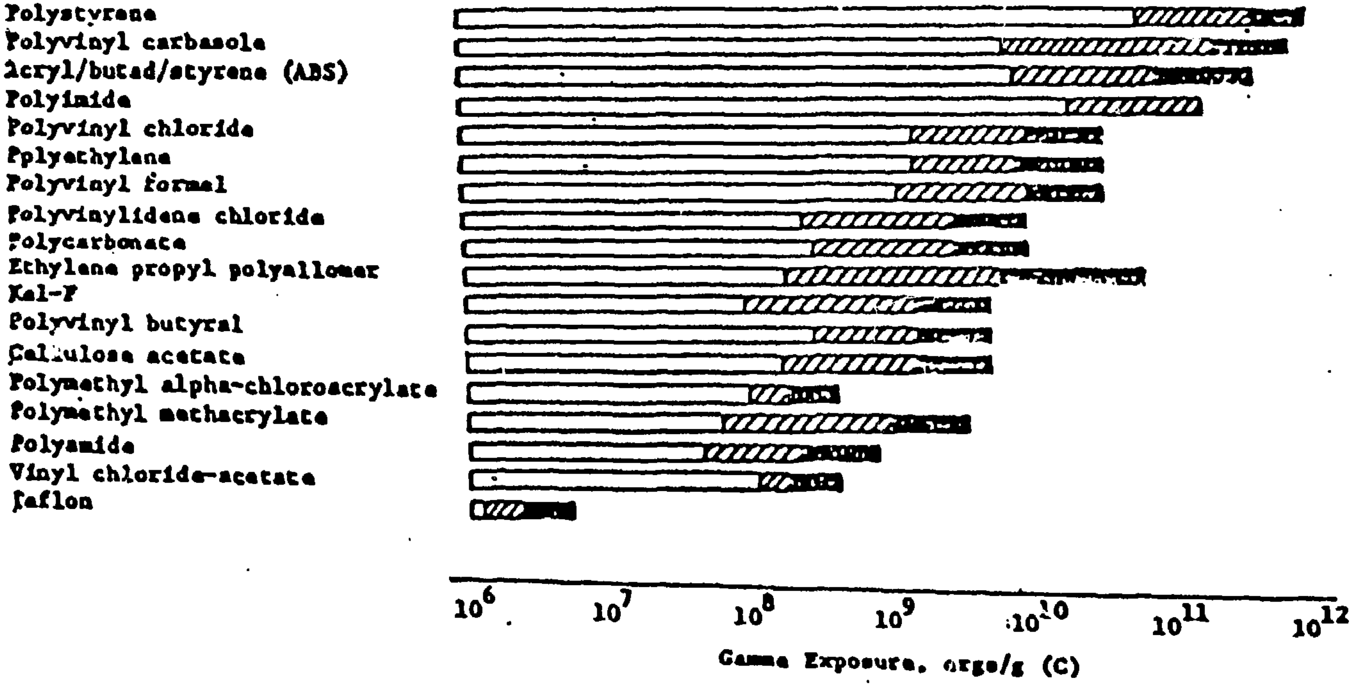


FIG.27 RELATIVE RADIATION RESISTANCE OF THERMOPLASTIC MATERIALS

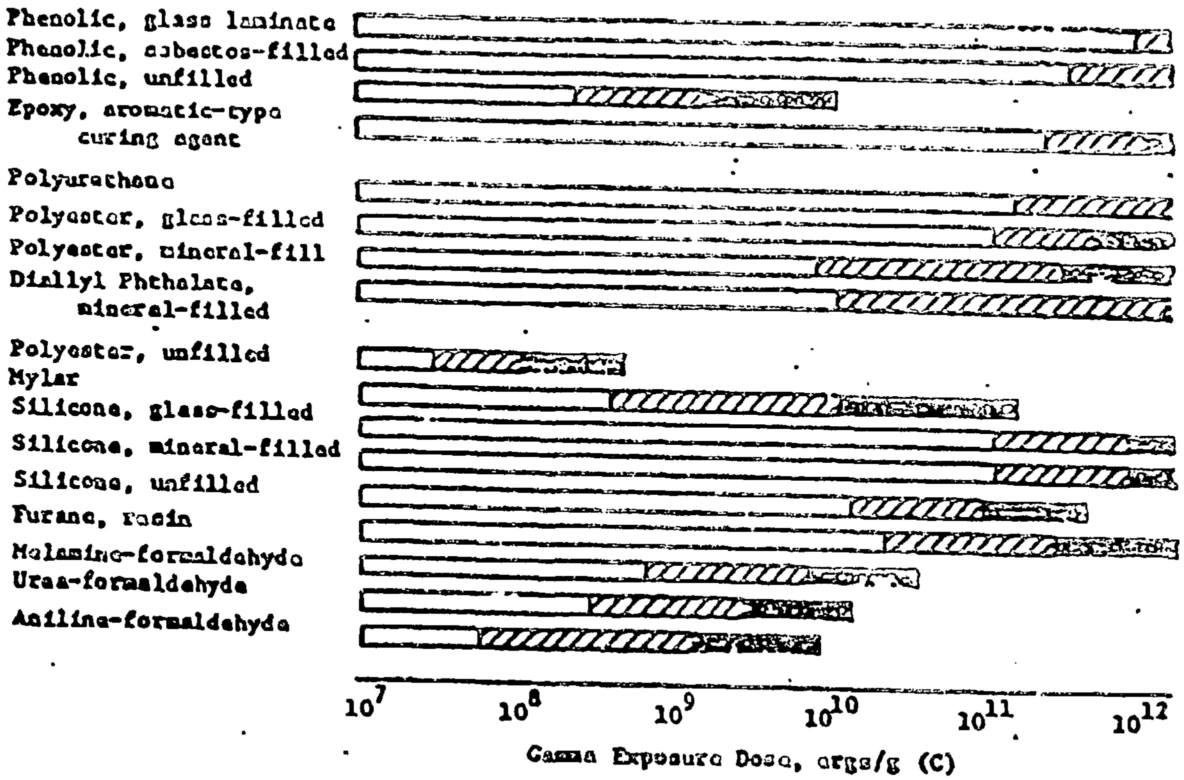


FIG. 28 RELATIVE RADIATION MOBILITY OF THERMOSETTING RESINS

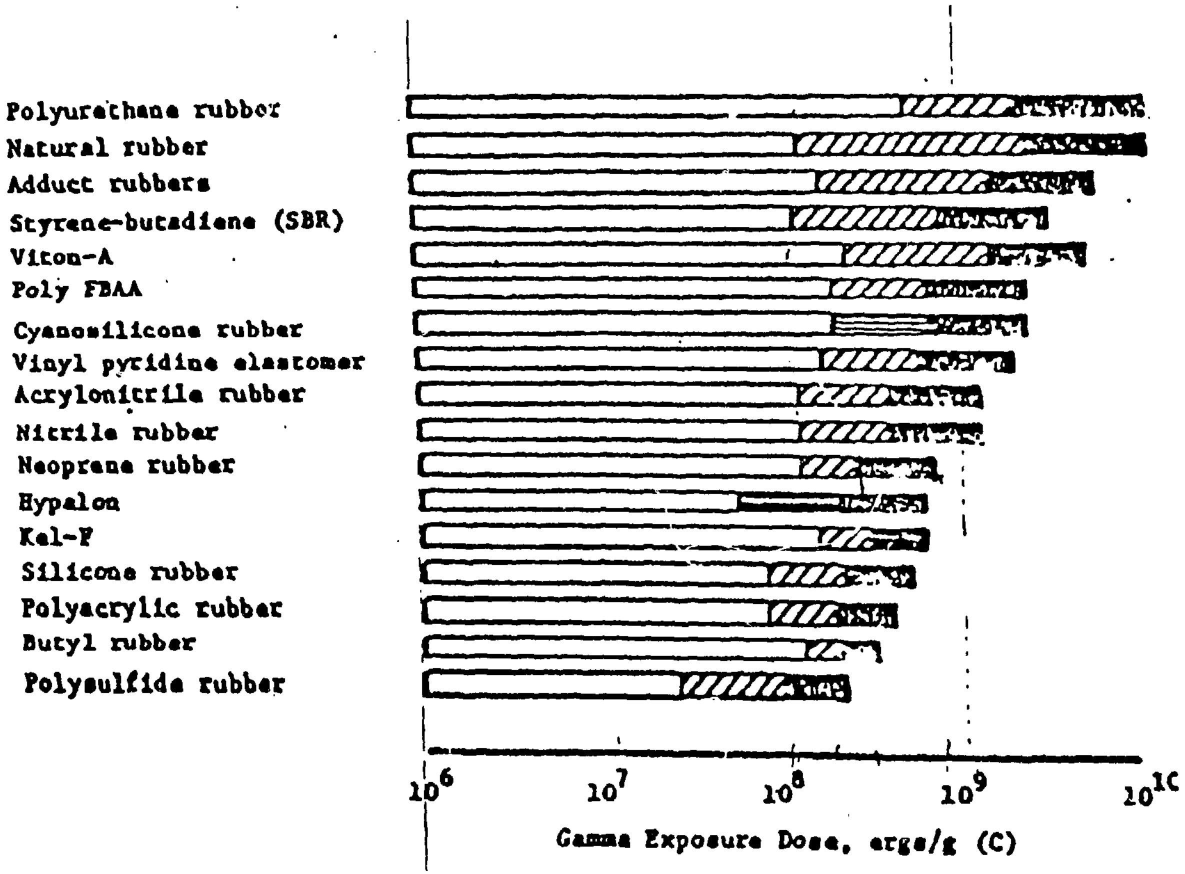


FIG.29 RELATIVE RADIATION STABILITY OF THERMOSETTING RESINS

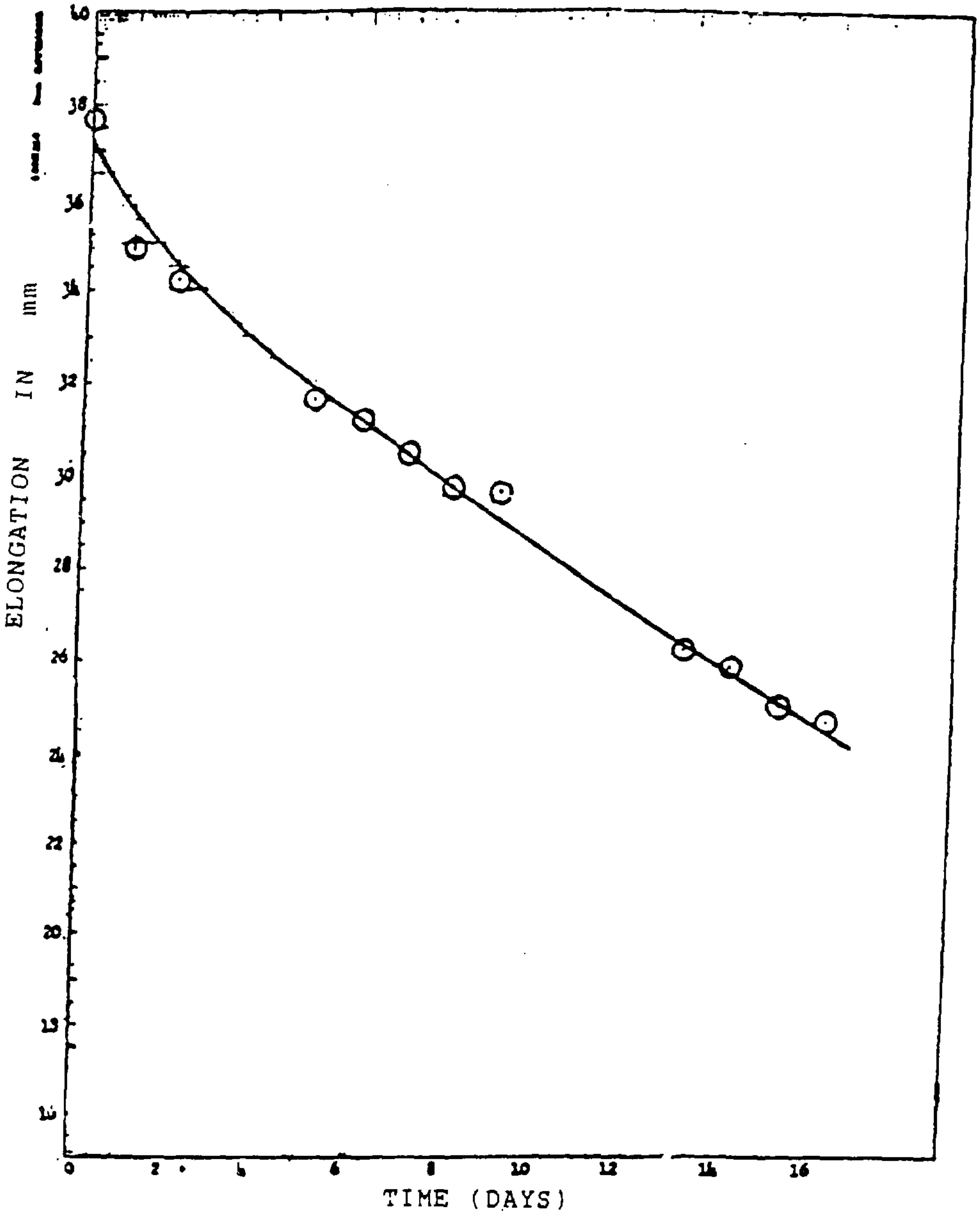


FIG.30 ELONGATION OF NEOPRENE EXPOSED TO TRITIUM

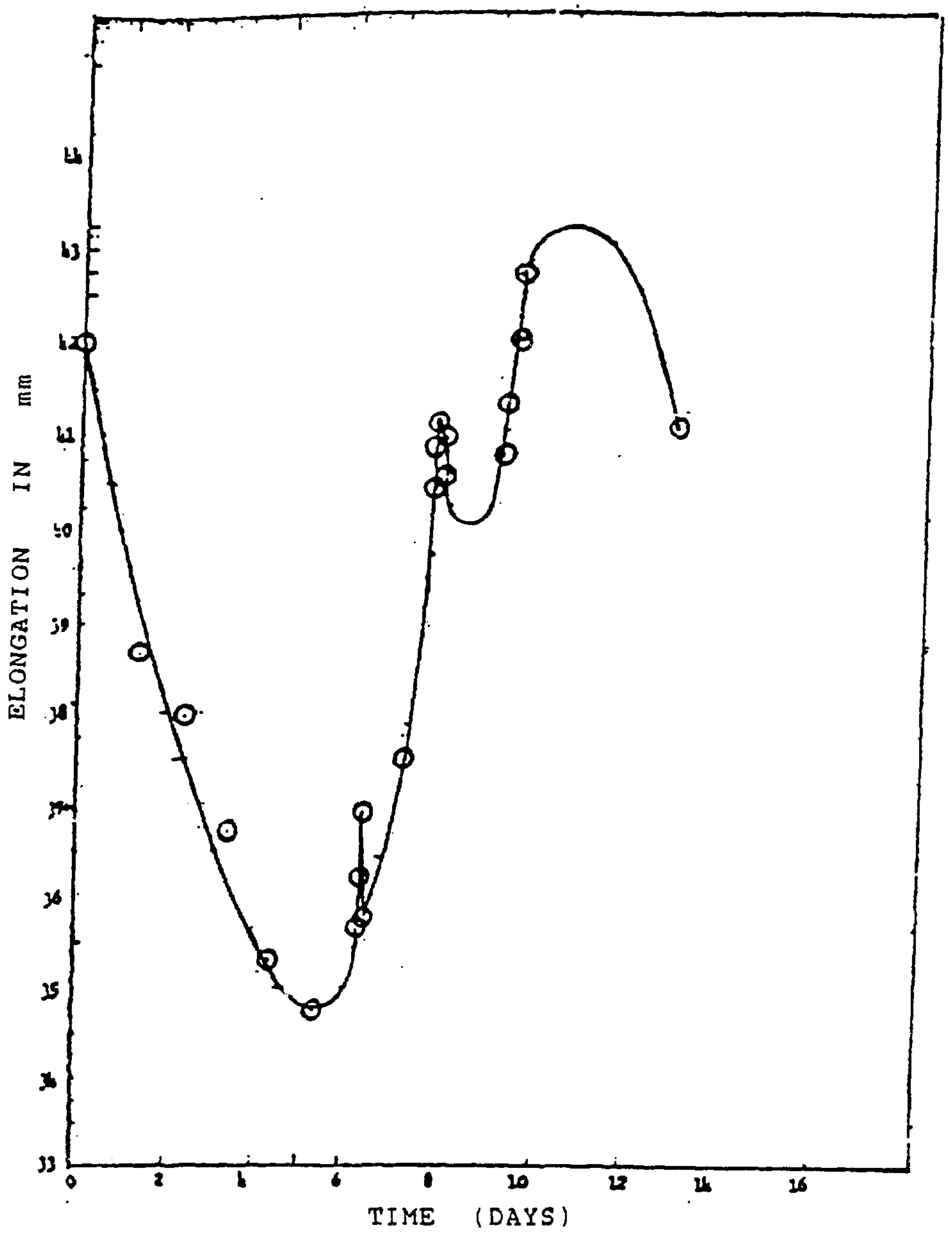


FIG.31 ELONGATION OF NATURAL RUBBER EXPOSED TO TRITIUM