CONF-840614--111

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DE88 007358

Seismic and Layout Design for a Tank-type Fast Reactor

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MASTER

Presented at 1984 Annual Meeting

of

American Nuclear Society

New Orleans, June 1984

SEISMIC AND LAYOUT DESIGN STUDY FOR A TANK-TYPE FAST REACTOR

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1. INTRODUCTION

In May 1982 Hitachi Ltd. of Japan, with the assistance of the Bechtel Group, Inc. and the General Electric Company of the U.S., initiated a conceptual design study of a compact tank-type LMFBR. The Bechtel work concentrated on layout of the nuclear island (NI), and its orientation with respect to the Control (CB) and Turbine (TGB) Buildings.

This joint effort was carried out during 1982 and 1983 in four steps. Each step produced improvements in the design and reduced the plant size and cost. This paper describes the design evolution and the final result with respect to Bechtel's development of the NI layout.

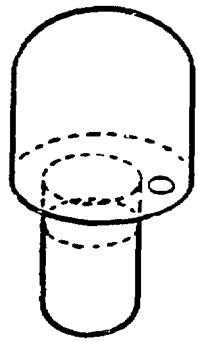
The basic NI consists of the reactor containment building (RCB), four steam generator buildings (SGB) and a fuel handling building (FHB) on a common basemat.

2. OVERVIEW OF THE PLANT LAYOUT

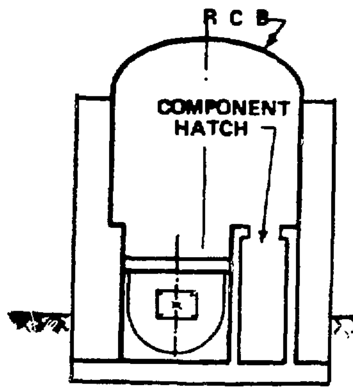
This section gives an overview of how the NI layout evolved during the study. The first step was devoted to developing the key specifications and parameters of this Hitachi tank-type fast reactor (HTFR).

Initially, the basic plant consisted of the reactor and, four intermediate heat transport system (IHTS) loops with three steam generators (SG) per loop. The three SGs were two evaporators and a superheater. The reactor vessel (RV) contained four pumps and eight intermediate heat exchangers (IHX). The tops of the IHXs extended above the reactor roof slab. The IHTS piping from the top of each IHX passed through the RCB boundary wall and was connected to the SGs.

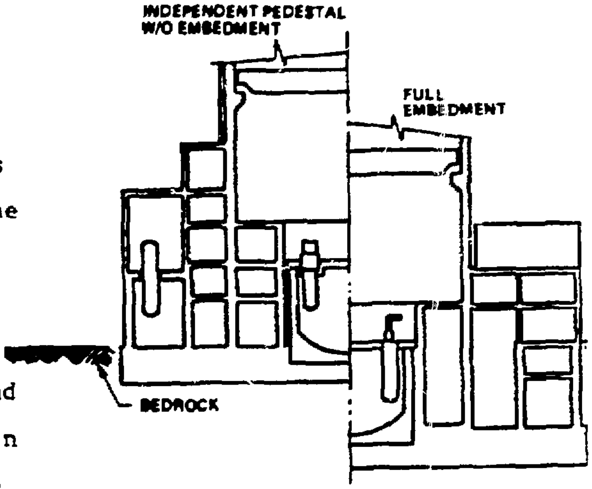
The other major feature which greatly affected the NI layout was the fuel handling system. This system includes the fuel transfer cell (FTC) to house the machine that transfers fuel between the RV and the ex-vessel storage tank (EVST). After some time to allow for decay of the fuel's radioactivity, fuel is transferred from the EVST through a fuel handling cell (FHC) to a facility where the fuel is cleaned and stored prior to offsite shipment. That portion of the NI housing the EVST, the FHC and systems for processing the reactor cover gas is designated the fuel handling building (FHB).



The basic design requirements of the RCB were also established at the beginning of the study. Its design pressure was 0.7 kg/cm^2 and was to be constructed of reinforced concrete. The basic RCB configuration consisted of two differing diameter cylinders joined by a horizontal step at the operating floor level. By offsetting the cylinder center-lines, the step can accommodate the openings needed for fuel and large component passage through the RCB boundary. The FTC and the opening for fuel transfers were located on one side of the RCB with the opening for large component removal diametrically opposite. The RV was to be located near the center of a near-square basemat and the SGBs were to be at each corner of the mat.

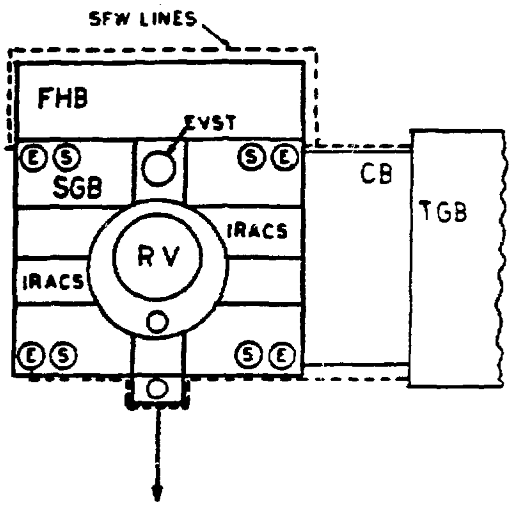


One other task was an initial study of the seismic inputs to the RV at its support points just beneath the roof slab. The intent was to determine how to minimize the seismic inputs. The study showed that either of two methods was effective for the reference site conditions (bedrock with a 1500 m/s shear wave velocity) and seismic inputs. In one approach the NI was to be founded at the top of the bedrock with the reactor supported on an independent pedestal. The pedestal was connected only to the basemat. The other approach was to have the reactor support pedestal an integral part of the RCB and NI, with all or part of the NI to be embedded in the bedrock. The embedment depth was chosen so that the RV supports were at an elevation equal to the top of bedrock.

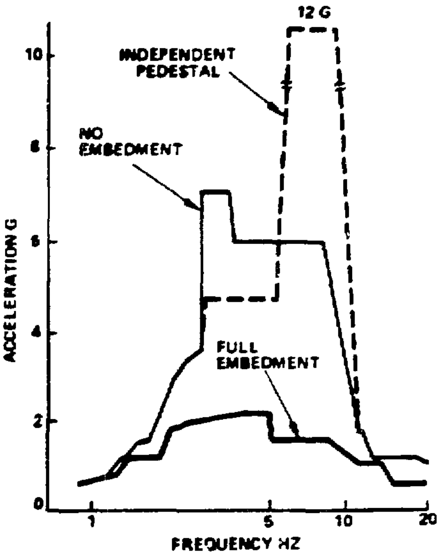


Given the above basic layout criteria, a first NI layout was developed with mat dimensions of 101 m by 86 m and 8 m thick. The thickness is typical of Japanese practice. In Japan, compared to the U.S., thicker mats are used to lower the elevation of the NI c.g., and thus reduce overturning moments during earthquakes. The upper RCB cylinder diameter was 40 m, the lower was 25 m. The total NI volume was 550,000 m^3 excluding the basemat. The average height of the NI above the mat was 63 m.

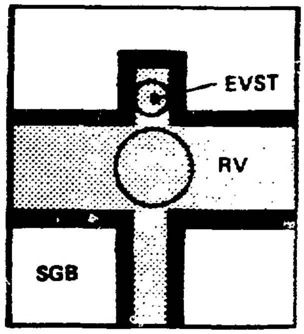
The study goal of a compact plant layout led to significant changes in the reactor size, the number of SGs, the crane height in the RCB and the arrangement of the IHTS and some major auxiliary systems. The RV diameter and height were reduced by one meter. One evaporator was eliminated. The hook height requirement for the polar crane in the RCB was reduced by 10 m. The pump and expansion tank in each IHTS loop were lowered in relation to the SGs. The number of large IHTS drain tanks was halved by having them shared between two loops. And, crane bays atop each SGB were eliminated.



Also, new analyses showed that embedment was the better method of reducing the seismic input to the RV. The original plan was to embed only a central cross-shaped portion of the mat containing the RV, EVST and the areas between the SGBs. Further evaluation of this plan indicated it was neither economically nor functionally desirable. A compromise was established such that the part of the mat below the FHB would remain at the top of bedrock while the rest of the mat was embedded 18.5 m below the top of bedrock. The RV supports are 18.5 m above the top of the mat. Thus, a stepped basemat was created.



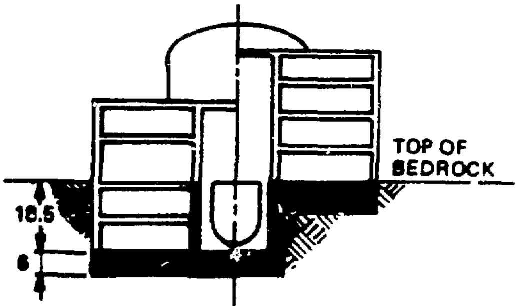
The resulting NI dimensions were 86 m by 78 m with the mat still 8 m thick. The upper RCB diameter was reduced to 39 m. The total NI volume was now about 310,000 m^3, excluding the basemat. The average NI height above the mat was 46.5 m.



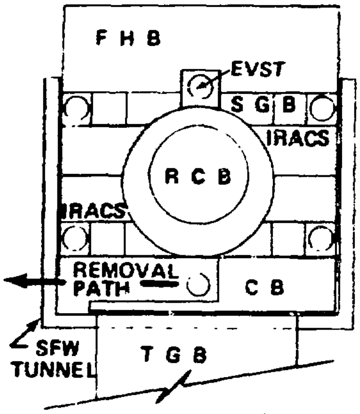
EMBEDDED CROSS

The final changes, though less dramatic, were still significant. The steam generating system was changed to a single SG per loop, combining evaporator and superheater into a single unit. This change coupled with the resulting reduction in IHTS piping reduced the size requirements for the IHTS drain tanks. These changes greatly reduced the size of the SGBs.

A second major change was elimination of the step in the basemat beneath the FHB and a reduction in mat thickness to 6 m. This change also resulted in a smaller FHB.



The combination effect of reducing the SGB size and eliminating the step produced an eccentric location for the RV on the mat. This was considered undesirable. The general concentricity was reestablished by adding the control building (CB) to the mat.



The result of these changes was a fully embedded NI (flat mat) shown in Figure 1. The NI dimensions are now 86 m by 78 m. The NI volume is now 320,000 m^3 including the 50,000 m^3 CB. The average height above the mat is about 48 m.

All of the NI layouts discussed in the above paragraphs were developed to comply with a set of design requirements and criteria (R&C) being developed by Bechtel for LMFBR layouts.

These R&C can be placed into one or more of six categories to resolve any conflicts between the R&C. In order of precedence, the categories are: Space and Function, Safety, Radiation Protection, ISI and Maintenance, Constructibility, and Operability. When conflicts arise between R&C, priority should be determined by the category into which the R&C are then placed. For example, a requirement related to Safety would outweigh one related to ISI and Maintenance. In general, the Space and Function and the Safety categories must be considered of equal rank.

3. STEPPED VS FLAT BASEMAT CONSIDERATIONS

As discussed earlier in Section 2, a stepped basemat was examined for the NI layout. The step was to allow for an 18.5 m deep embedment of that portion of the NI containing the RV and EVST. With the step, the lower

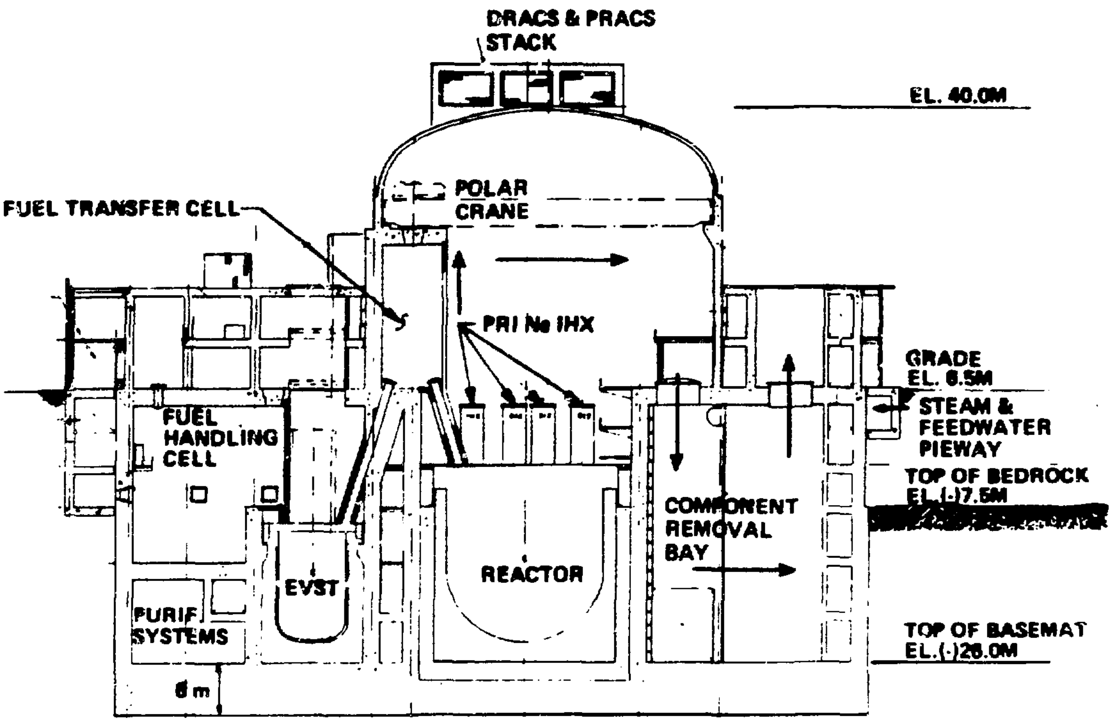


Figure 1. HTFR NI Section Through EVST and Reactor

portion of the mat was 18.5 m below the upper portion. This was a departure from the typical practice of having a flat mat or a much shallower step. Some evaluation of the impacts of the stepped mat on plant function and costs was needed.

The original plan for embedding only a central cross of the NI had two significant functional disadvantages. The SGs, the IHTS and the connected intermediate reactor auxiliary cooling systems (IRACS) would have received none of the seismic response reduction benefit. Non-embedded SGBs made replacement of SGs or primary pumps more difficult due to the crane height needed to remove them. These disadvantages indicated that embedding the RCB and the SGBs was the better functional approach. A cost comparison, similar to that explained in the following paragraphs, showed that the stepped mat also could cost less than embedding a central cross. Thus, the stepped mat was selected about halfway through the study.

The usual reason for embedding only part of an NI in bedrock is the acknowledged high cost of excavation in rock. The factor that can be overlooked when considering excavation costs is the greater amount of concrete required for partial vs. full embedments (flat mats). The unit cost ($\$/m^3$) of concrete (in place) can be 5 to 30 times the unit cost of rock excavation. Thus, the total costs of concrete plus excavation should be evaluated when deciding on partial vs. full embedment.

The major source for the potentially large differences in concrete quantities relate to the design of the mat. Typically, an 8 m thick mat is used at the top of bedrock to reduce overturning moments during earthquakes. With deep embedment, the sides of the excavation can provide the overturning resistance so a thinner mat is possible. Also, with partially embedded mats, 4 m to 6 m thick walls are required to connect the upper and lower portions of the mat. The combination of these thick walls and the thicker upper mat will require significantly greater concrete quantities than will a thinner, flat, fully embedded mat.

The partially embedded configurations (central cross or stepped) were compared for cost differences with a fully embedded NI. Depending on the unit costs for excavation and concrete in place the savings with full vs. partial embedment were from zero (highest excavation, lowest concrete cost) to $\$20 \times 10^6$ (lowest excavation, highest concrete cost).

Thus, functional and cost considerations indicated that a fully embedded, flat mat NI was the better choice for the final layout.

4. THE FINAL NI LAYOUT

There was no change in the RCB configuration during the study. The basic concept of differing diameter cylinders joined by a planar step is still in use.

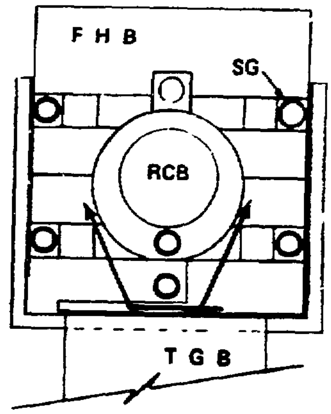
The major change on the NI was the size reduction and the rearrangement of the SGBs due to the elimination of another SG. With only one SG/loop, each SGB is now much smaller than in the earlier steps.

A major revision within the FHB resulted from elimination of the step below the FHB. The FHC was lowered by 18.5 m and the use of a top loading cask for shipping spent fuel became impractical. An undesirably tall structure would be required to house another cell to raise the fuel high enough to use a top loading cask, since the top of the FHC is now at ground level. A bottom loading cask became the reference concept.

The basic requirements and criteria (R&C) used to establish the arrangement of the NI, CB and TGB (see Figure 2) are the following:

- Access to an outer wall of the SGB is desired to facilitate SG replacement. In the current HTFR layout this is met by having unobstructed access to the top of the embedded SGB.

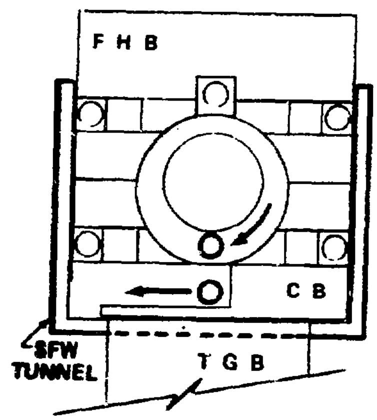
- Locating the CB with respect to the NI should facilitate personnel access between CB and NI. The location also must enable separating the parallel trains of safety-related cabling between CB and NI. These R&C are met by locating the CB on the side of the RCB containing the component removal hatch. This allows for ease of movement and cable routing around both sides of the RCB without passing through potentially hazardous areas.



- The TGB should be located to minimize the length of cabling from the NI to the CB and from the TGB to the CB. This is met by locating the CB between the NI and TGB.

- Large component removal paths must not pass over safety-related equipment that is in operation. A 9-m-wide path has been provided between the CB and one side of the NI for large component removal.

- The NI, CB and TGB orientation should allow for minimizing steam/feedwater (SFW) line lengths. This is also met by locating the CB and TGB adjacent to the component removal hatch. This avoids forcing the SFW lines to go over or around the FHB.



- The SFW lines should not interfere with large component removal. The embedment of the NI places the SFW lines in below-grade tunnels so there should be no interference.

- Use a peninsular TGB to avoid turbine missile strikes on the NI.

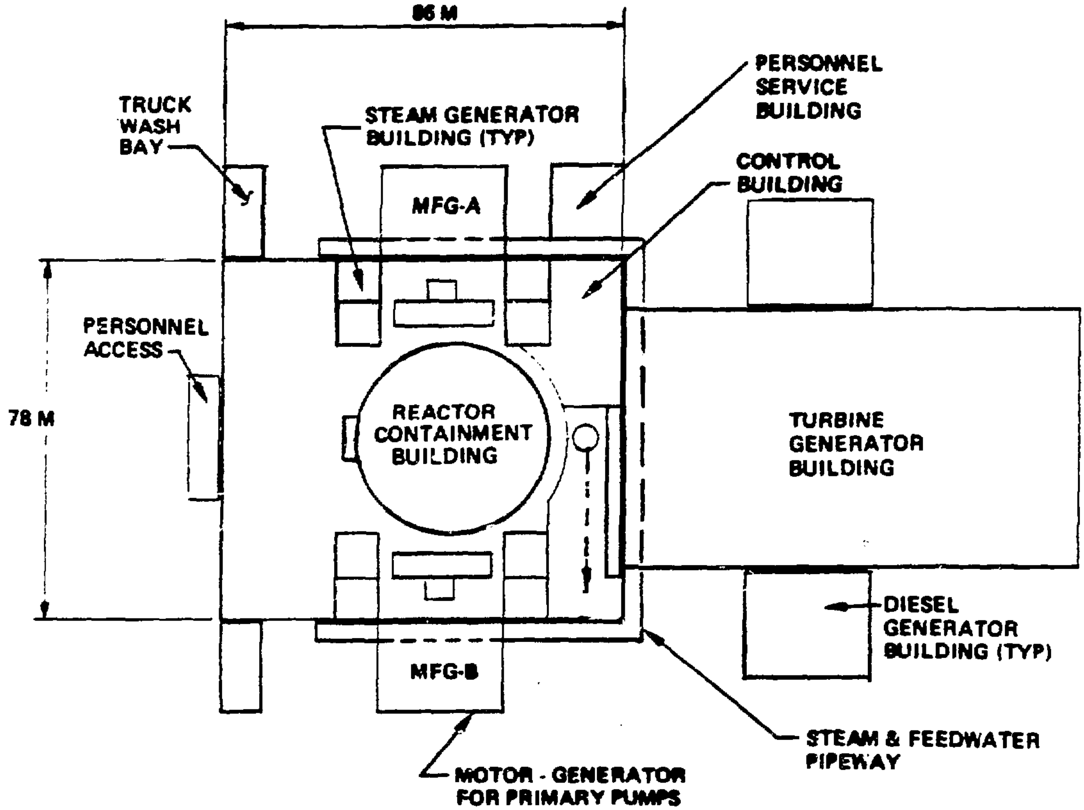
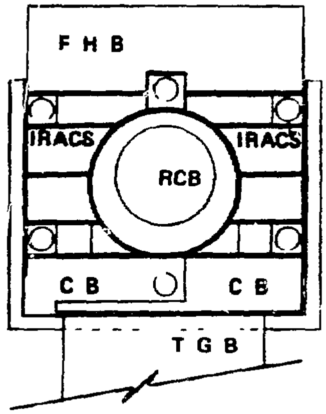


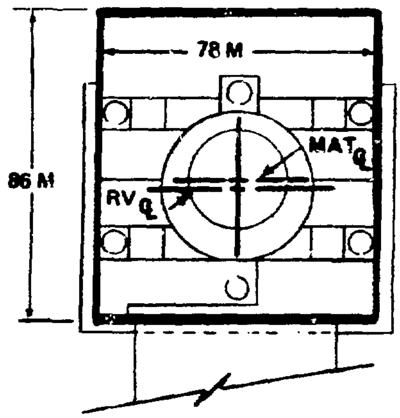
Figure 2. HTFR Plan

Some of the major R&C guiding the layout of the NI itself, and how they were satisfied, are presented in the following paragraphs, and shown in Figures 1 and 3.

- Physical barriers, such as walls and floors, shall separate various safety-related systems to prevent common cause failures. The SGBs and IRACS cells are well separated by walls and the RCB.

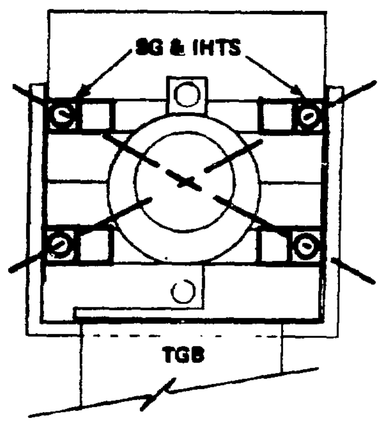


- Minimum eccentricity of the RV and RCB with respect to the base mat is needed to reduce amplification of seismic responses. The maximum eccentricity of the RCB and mat is about 8 percent of the mat width. The maximum amplification is only 13 percent above standard U.S. design practices. This is reasonable for a conceptual design.



- A regular shape, square or circle, for the mat is needed to minimize horizontal, asymmetric motions during earthquakes. The lower cost approach is a square mat. The final mat of 86 m x 78 m is reasonably square.

- Plant safety is improved by having identical or mirror-image layouts for duplicated systems and components. This also reduces plant costs. This has been accomplished by locating the SGs, IHTS piping, IRACS, etc., in a uniform pattern around the RCB.



- Tanks are required to drain an IHTS loop and to collect reaction products in the event of a Na/H_2O reaction. Initially, a set of large tanks was located at the bottom of each SGB. Later, smaller tanks were relocated to the space beneath the IRACS cells. Here, a single set could be shared by two IHTS loops.

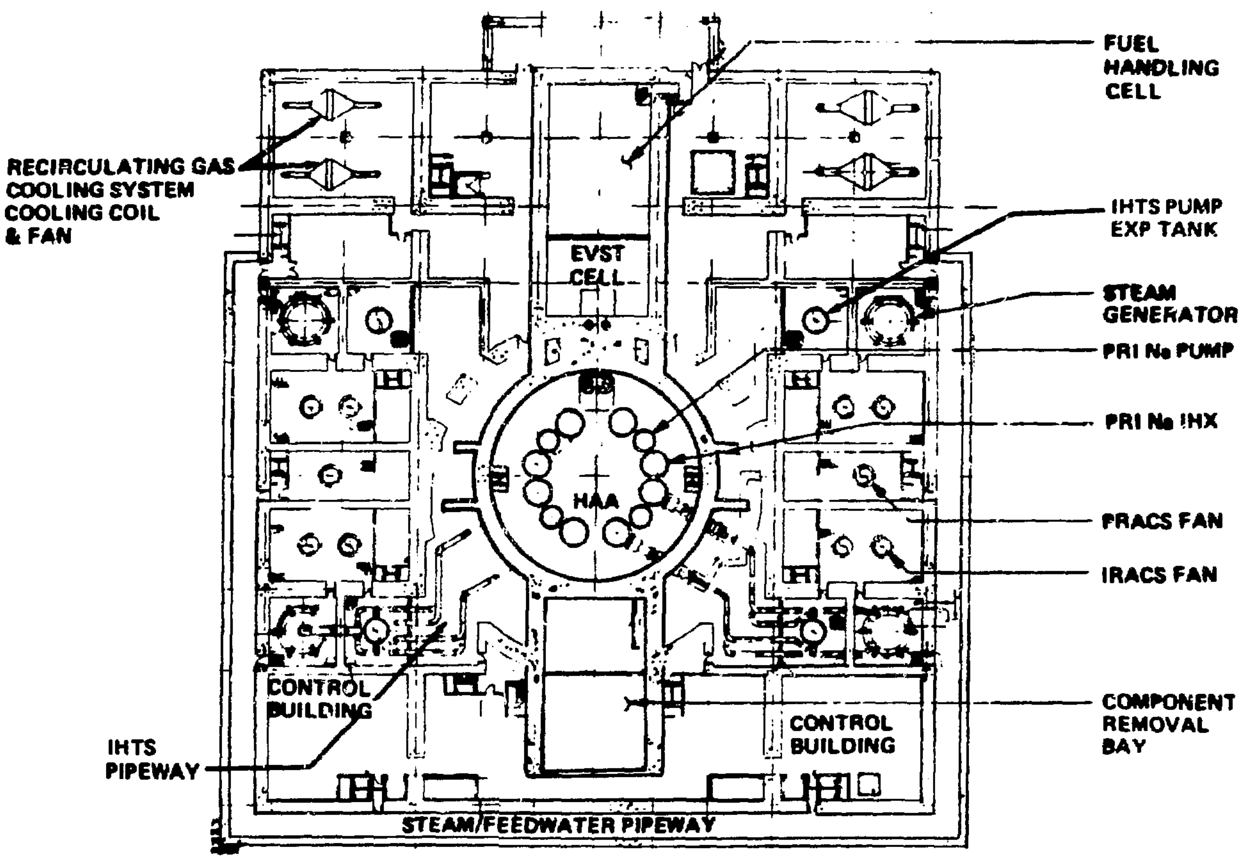
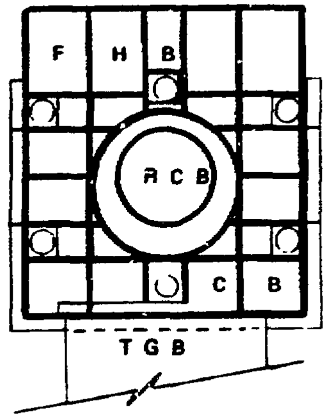
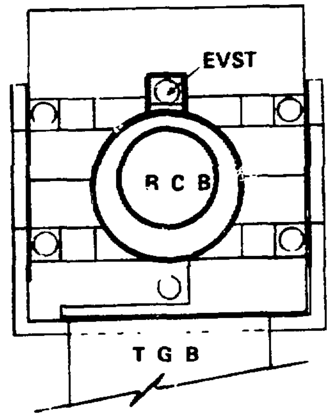


Figure 3. HTFR NI Plan Below EL 4.5 M

- The seismic resistance of the NI and the systems it contains is greatly improved by forming the walls of the NI into a stiffening grid. The interior and exterior walls of the NI do form such a grid.



- Virtually all radioactivity in the NI will be contained within the RV and EVST. In the event of an accidental release from the RV, the radioactivity will remain inside the RCB. Basic radiation protection is provided by thickening the concrete walls of the RCB and those surrounding the RV and EVST.



The use of embedment for seismic response reduction imposes a penalty avoided by mats placed at the top of bedrock. It is probable that the exterior walls and mat will have to be waterproofed. Bechtel experience shows that this can be done using either or both of two concepts. (1) A chemically reactive material can be applied to the NI exterior and below the mat to seal the concrete porosity to form a waterproof barrier. (2) Two or three layers of a waterproof membrane can be applied to the NI exterior and below the mat to provide an impervious barrier to water intrusion into the NI. Neither of the barrier materials requires maintenance following installation.

5. LAYOUT OF THE HEAD ACCESS AREA (HAA)

The HAA is that area above the top of the roof slab. Because of the large number of systems and their components that this area contains, it tends to be the most congested area in the plant (see Figures 4 and 5). The systems and components to be included in the HAA layout were established by Hitachi.

Space is needed for systems and components devoted to fuel transfer, heat removal (pumps and IHXs), plant control and HVAC. Equally important, space is needed for personnel access and equipment for operations and maintenance activities. The space must be adequate and the equipment must be located to assure that the activities can be performed safely and effectively. There must also be enough space and clearance to allow unimpeded motion for those components that move during operation. All the specified components did fit within the HAA, and there are no impediments to motion of the rotating plugs or the fuel handling machine (FHM).

The major safety concerns in laying out the HAA were: to avoid locating large or heavy components directly above the roof slab or the IHTS piping, to prevent a Na fire in the event an IHTS pipe leaked, and to enable large component (IHX or pump) replacement without crossing over the HAA.

All of the larger components on the operating floor above the HAA have been located so they are as far as practical from the edge of the HAA. Inerted-atmosphere enclosures surround any Na or NaK-filled piping within the RCB to prevent fires. Space is available around the outside of the HAA to provide a component removal path that does not require crossing over the HAA.

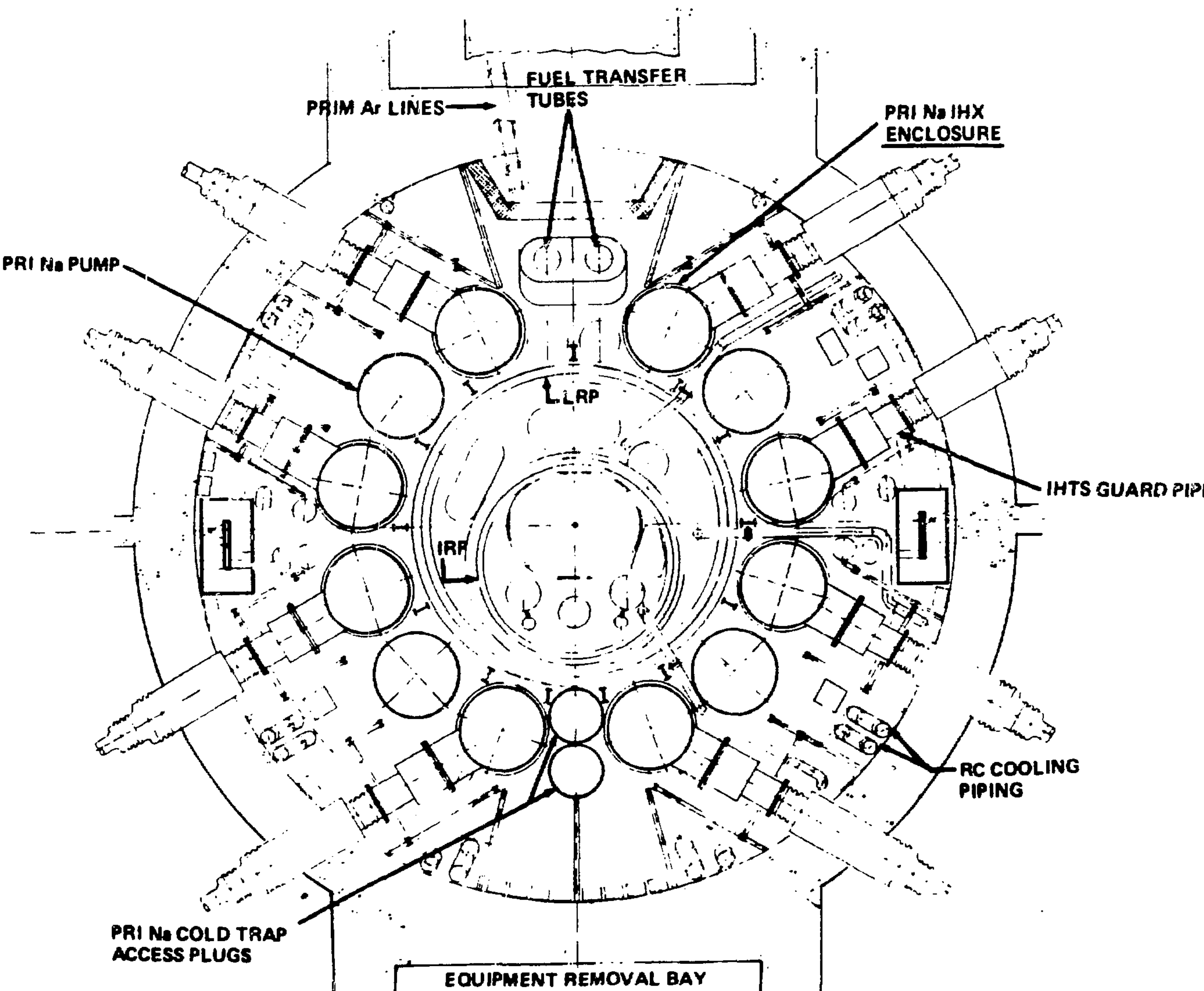


Figure 4. HTFR Head Access Area Plan Below Midplane

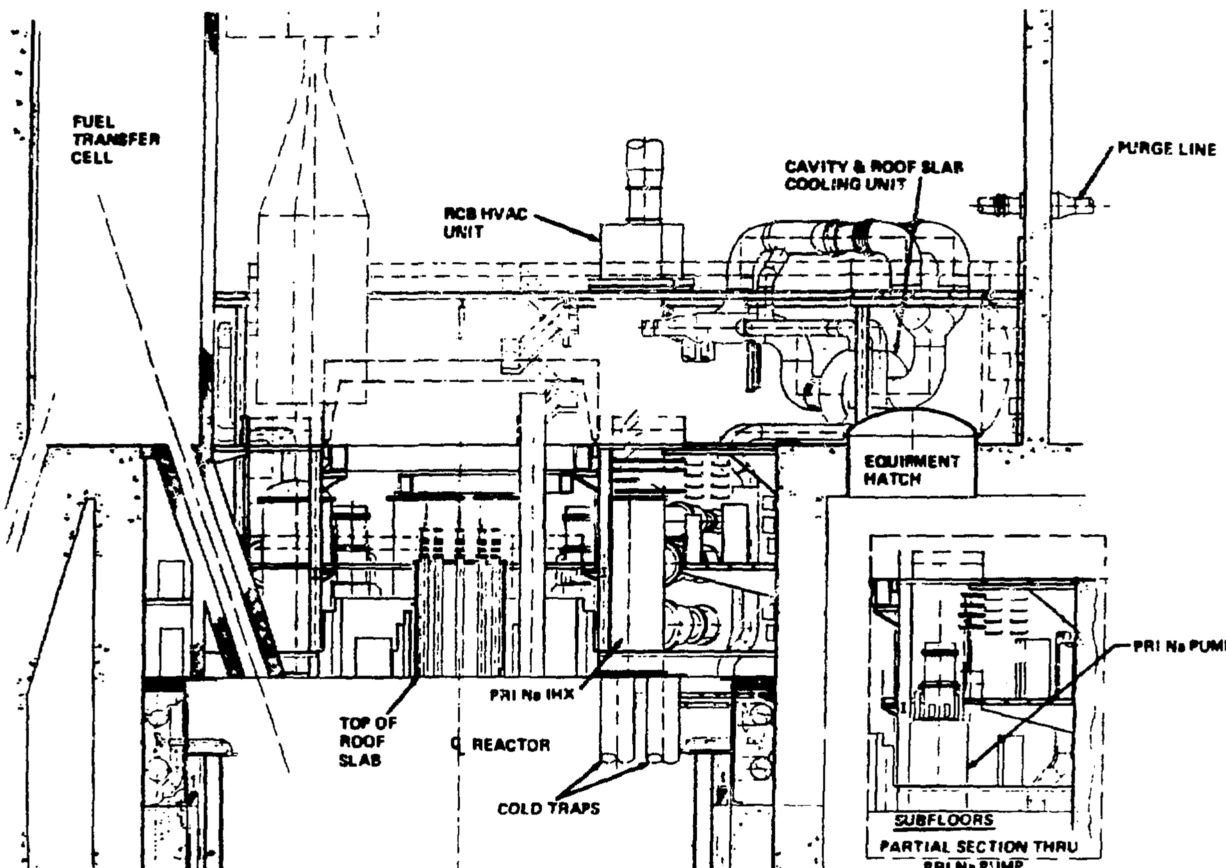


Figure 5. HTFR Head Access Area Section

The requirement for radiation protection in the HAA is fulfilled primarily by the shielding in the roof slab. However, in the event of any localized radiation, the layout maximizes accessibility to components in order to minimize the time spent by personnel getting to and from any component. The same philosophy of maximizing access applied for ISI & maintenance considerations. Also, space is provided to accomplish the currently identified ISI & maintenance activities. This includes considering the need for component replacement.

In summary, the current HAA layout appears suitable for the known functional, operational and maintenance requirements. Eventually these requirements will need to be developed in greater detail.

6. POTENTIAL COST REDUCTIONS FOR THE NI

Suggested changes in plant design that are worthy of consideration as means to further reduce plant costs are presented here. They are divided into two groups: those which could be incorporated most easily without significant changes to the existing layouts, and those which could require a major design change in the reactor or the NI.

The first group of potential cost reductions would be based on structural analyses that allow further use of the benefits which come from the deep embedment in solid bedrock. The cost benefits to be derived from additional analyses of the NI are in four areas:

1. The deep embedment limits the additional response amplification due to the flexibility of the NI building structure (cantilever effect) associated with founding the plant atop the bedrock. This should allow reducing the NI rigidity by reducing the number and/or thickness of the interior walls.

2. The reduced rigidity requirement may also allow reducing the thickness of the exterior walls. Also, in sound bedrock these walls would not be called upon to resist limited static soil pressures.

3. The deep embedment will act to restrain the NI, greatly reducing concerns with overturning moments. This should allow further reduction of the basemat thickness to that required for proper load transfer to the underlying bedrock.

4. Given the reduced seismic inputs inherent with the embedment, it may be possible to reduce the thickness of the cylindrical concrete pedestal, inside the reactor cavity, which supports the reactor vessel.

These suggested changes are intended to further reduce the concrete quantities and associated costs and, thus, further enhance the economics of deep embedment.

The major changes proposed for further study are based on 1) revising the basic design philosophy of the RCB, and 2)reducing the NI size by moving nonsafety-related systems off the NI.

RCB Design Philosophy: The 0.7 kg/cm^2 design pressure for the containment was selected based on a similar design requirement for the U.S. large plant studies at the time. The specific design basis accident for the HTFR has not yet been identified. However, there is incentive to strive for a lower pressure rating (0.3-0.4 kg/cm^2) for the containment, which allows for a much lower height, flat-topped and column-supported roof for containment. This has a significantly lower cost than the usual domed containment. An external crane above the roof is used to remove major components through roof hatches. This eliminates the need for an equipment hatch in the containment step and allows for a major reduction in the upper containment diameter. The lower design pressure also increases the structural practicality of the roof hatches. The external crane can be designed to provide coverage for the entire nuclear island, and be usable for all component installation/removal for maintenance or during construction. Of course, the cost of 8 or 12 roof hatches must be considered in evaluating this approach. Also to be considered is the cost of a confinement building to enclose the upper containment.

Relocation of Non-Safety Related Systems: Current U.S. LMFBR design approaches include eliminating any safety-related function for the IHTS, and using only in-vessel systems for decay heat removal in emergencies. The major cost savings would come from reduced stringency in engineering, fabrication and inspection of the IHTS. The use of expansion joints might then be more acceptable, allowing for possibly more reduction in plant size by moving the SGBs off the NI mat.

Similarly, other nonsafety-related components/systems could be moved off the NI, wherever practical, as an aid to reducing the NI size.