Maintainability Considerations for the Central Cell in WITAMIR-I, A Conceptual Design of a Tandem Mirror Fusion Power Reactor

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MAINTAINABILITY CONSIDERATONS FOR THE CENTRAL CELL IN WITAMIR-I, A CONCEPTUAL DESIGN OF A TANDEM MIRROR POWER REACTOR

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Summary

The concepts for maintaining the central cell reactor components for WITAMIR-I are described. WITAMIR-I is a conceptual tandem mirror fusion power reactor utilizing thermal barriers designed by the University of Wisconsin-Madison. Unique solutions to the difficult problems of routine blanket replacement and maintenance are proposed. Solutions are also proposed for maintaining the central cell coils and the shield.

Introduction and Maintenance Philosophy

The tandem mirror concept employs the positive electrostatic potential of two standard mirrors to plug the end losses from a long solenoid. This solenoid, hereafter referred to as the central cell, produces essentially all the fusion power, and is the region which is subjected to the highest neutron flux and consequently, the highest radiation damage.

The central cell in a tandem mirror consists of a long cylindrical blanket and shield region surrounded by discrete solenoids uniformly spaced. In the case of WITAMIR-I, the blanket is comprised of several banks of seamless tubes running from the top of the reactor to the bottom. A high lead content $Li_{17}Pb_{83}$ eutectic is circulated through the blanket to remove the nuclear and surface heating, and to breed tritium. A single set of supply and return headers is needed for each module. Fig. 1 is a cross section of the central cell showing the blanket.

There are 33 blanket modules in the central cell, each 463 cm long. They are supported on rails fixed to the reflector part of the shield and are capable of being translated axially within it as can be seen in Fig. 1. This feature will be relied on in the plans for the maintainability of the reactor blanket. Routine blanket module changeout will constitute the bulk of the maintainability within the central cell. However, provision will also be made for maintaining the central cell coils and the shield.

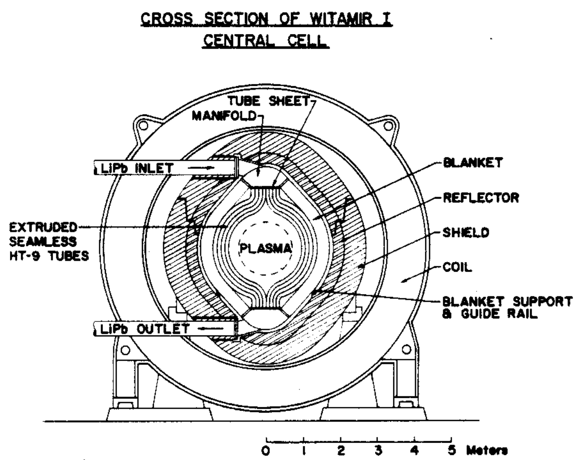

Figure 1. Cross Section of the WITAMIR-I Central Cell

In order to avoid making seals between adjacent blanket modules, we have decided to adopt the idea introduced in NUWMAK[1] which has since caught on in several other designs,[2,3] namely that of providing a vacuum seal at the back of the shield. There are several possibilities for implementing such an idea. It is possible to have two seals in series with the space between pumped out. It is also possible to contain the central cell within an evacuated tunnel in which the pressure need not be any lower than ~ 70 torr. In this design we chose to have the central cell tunnel evacuated. The vacuum system needed here doubled as the emergency detritiation system which can be used in the event of T_2 release within the reactor building, and therefore, does not add substantially to the cost of the reactor.

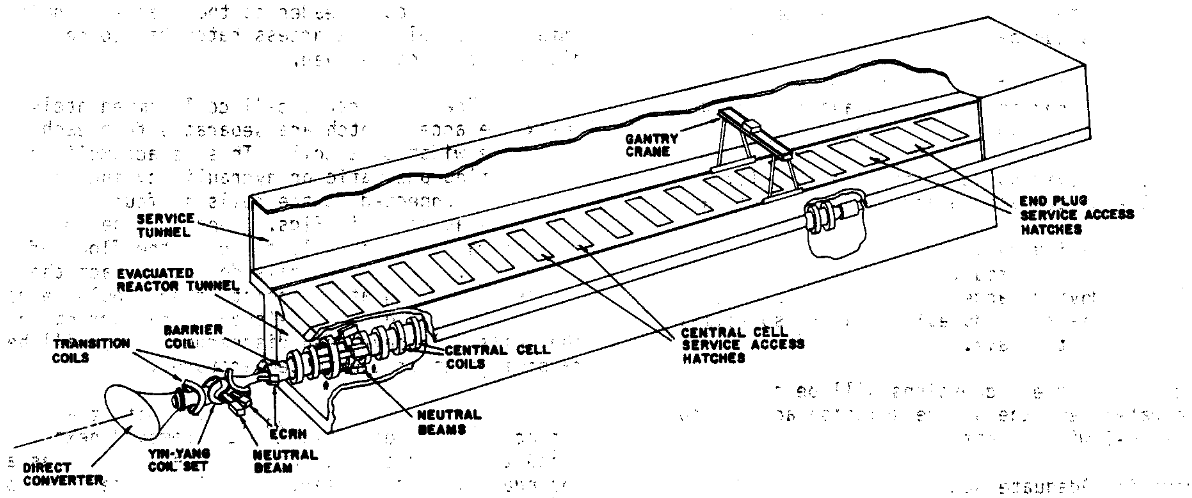

Figure 2. Perspective View of WITAMIR-I Showing Access Hatches for Servicing the Reactor Components

The general philosophy for maintaining the various elements of the central cell is to provide access at predetermined locations along the reactor tunnel as shown in Fig. 2. Access hatches in the roof of the tunnel dedicated for servicing blanket modules will be ~ 23 m apart such that they will coincide with every fifth blanket module. Thus, there will be seven access hatches used for servicing and maintaining the blanket modules. Five blanket modules will be capable of being maintained from a single access hatch. To make it possible for extracting a full sized blanket module between central cell coils, it is necessary to displace the two coils immediately below the access hatch apart the width of one coil (each coil has to move 75 cm). To do this, enough flexibility has to be built into the service lines for the coils such as the liquid helium supply line and the vapor exhaust line. Once the coils have been separated, the upper part of the shield/reflector can be unbolted and lifted out through the hatch. As soon as the breeding/cooling material is drained from the blanket module, the supply and return lines are disconnected and the module is allowed to cool down, it too can be lifted out through the access hatch. Figure 3 shows a blanket module being removed from the reactor. Other blanket modules in either direction can now be translated axially to the extraction point and removed in the same way.

It is envisaged that a 350 tonne gantry crane capable of handling the heaviest component in the reactor will travel along the top of the tunnel as shown in Fig. 2. Positioning itself over an access hatch, the crane manipulators will unfasten the seal on the hatch door and remove it, thus gaining access to the central cell. The capacity of the crane is dictated by the mass of one-half of a shield module which weighs ~ 300 tonnes.

In the following sections we will discuss the maintenance procedures for the blanket modules, the central cell coils and the shield. Emphasis will be made on routine blanket maintenance.

Routine Blanket Maintenance

Although initial indications are that the martensitic alloy HT-9 has superior radiation damage characteristics to 20 CW 316 stainless steel, the blanket modules will, nevertheless, have to be replaced at least once in the projected 30-year lifetime of the reactor. The downtime needed to replace the blanket modules has to be minimized in order to keep the cost of electricity down. Furthermore, it may be beneficial to replace a fraction of the blanket modules on an annual or bi-annual basis in such a way that all the modules will have been replaced at the projected end of life for the blanket material. Thus, for example, if for a given neutron wall loading the projected blanket material lifetime is 9 years, then one-third of the modules can be replaced every three years.

The four most difficult problems that have to be addressed in extracting and replacing blanket modules in a reactor are:

1 - Providing adequate accessibility
2 - Disconnecting and connecting coolant lines
3 - Making vacuum joints between adjacent blanket modules
4 - Moving large awkward objects (the blanket modules) which are sometimes quite heavy.

Each one of these questions will be addressed separately and the unique solution adopted for WITAMIR-I will be discussed.

Providing Adequate Accessibility

This is one area in which the tandem mirror has a clear advantage over tokamaks because of its simple geometry in the central cell. As we have mentioned earlier, the full length of the central cell will be accessible through discrete hatches in the roof of the tunnel. There will be seven such hatches at ~ 23 m intervals, with each hatch dedicated to servicing five blanket modules (four modules will be serviced by each of the end hatches). An additional eight hatches will be available for maintenance of the shield and central cell coils as will be discussed later.

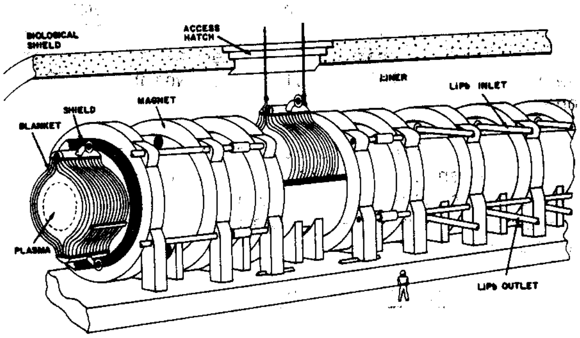

Figure 3. Isometric View of WITAMIR-I Central Cell Showing a Blanket Module Being Extracted

Aside from the obvious steps, such as emptying the blanket modules of breeding material and allowing them to cool down, the following additional steps have to be made in order to provide access to the blanket modules:

a. The supply header to the blanket module immediately below the access hatch has to be disconnected and removed.

b. The two central cell coils immediately below the access hatch are separated from each other the width of a coil. This is accomplished by actuating pneumatic or hydraulic cylinders which are connected to the coils in four locations as shown in Figs. 1 and 3. The coils ride on rails permanently fixed to the floor of the tunnel. Since the coils do not contact the blanket or shield at any point, there would be no problem in moving them. Although the current in the coils will have been discharged, they will be maintained at cryogenic temperatures.

c. The top half of the shield with the reflector attached to it will be removed next. Since the outer surface of the shield serves as a secondary vacuum barrier, it will be necessary to undo the clamps or bolts to disengage the seal. The upper half of a shield module with the attached reflector weighs on the order of 150 tonnes. It will be lifted through the access hatch and stored in the service tunnel for the duration of the blanket replacement operation. The first blanket module is now completely exposed and can be extracted from the reactor (Fig. 3).

Disconnecting and Connecting Coolant Lines

The breeding/cooling material chosen for WITAMIR-I, $Li_{17}Pb_{83}$, **is an excellent solder. We feel we should take advantage of this fact in designing the means for connecting and** disconnecting the coolant lines. The plan is to make a coupling with a wide enough flange such that the $Li_{17}Pb_{83}$ will form a frozen barrier at the outer periphery. In effect, the flange is a fin which is not insulated and thus will have a cold outer edge. The header itself will have trace heaters on it which will be used to preheat it before charging with the $Li_{17}Pb_{83}$. There will be a heater on the flange edge which will be turned on only when the seal has to be melted.

In a practical sense, for this scheme to work entirely automatically by remote control, the following sequence of events will have to take place:

Disconnecting a Header:

1. The breeding/cooling material is drained from the blanket.

2. The heater on the flanges is turned on, melting the frozen $Li_{17}Pb_{83}$ zone.

3. A mechanical latch is actuated which releases the pressure between the two flange faces and disengages them.

4. The header is withdrawn horizontally to provide clearance for the axial translation of the blanket modules.

Connecting a Header

1. The blanket module is moved into place and located correctly with optical instruments.

2. The header is inserted horizontally and guided for proper mating of the connector with a conical surface which is built into the flanges. The flange on the module side will be appropriately fluxed.

3. The mechanical latch is actuated, engaging the two flanges and applying a predetermined amount of pressure.

4. As the breeding material is pumped into the blanket, the heater on the flange is turned on momentarily to allow the $Li_{17}Pb_{83}$ to flow between the flanges. The heater is then turned off and the frozen seal is established.

Figure 4 shows a typical coolant line joint, in the connected and disconnected condition.

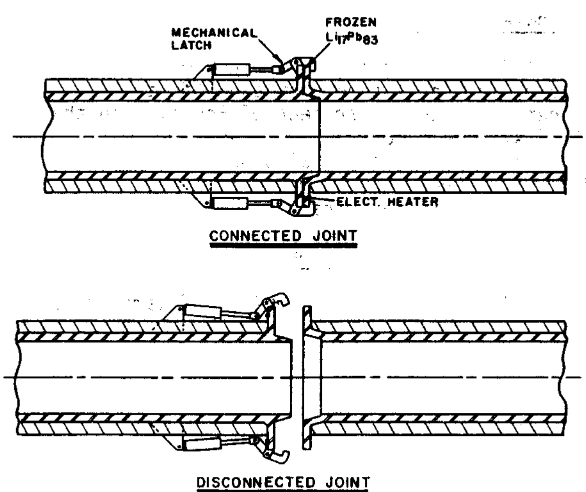

Figure 4. A Typical Coolant Joint in a Connected and Disconnected Condition

Joints Between Blanket Modules

Making vacuum tight joints between adjacent blanket modules is one of the most difficult tasks faced by a reactor designer. In WITAMIR-I, as in NUWMAK[1], we have chosen not to have seals between modules but instead provide a vacuum barrier at the back of the shield. The blanket module itself is transparent to the flow of gas as is the joint between modules. Modules are simply butted against each other. Shield modules are sealed to each other between blanket access hatches. Immediately below an access hatch, the upper part of the shield is removable. The seal, which can be an organic one, will be attached to the removable shield section. The point at which the headers enter the shield also has to be sealed. We envisage that a welded bellows can be used between the header and the shield which will allow horizontal translation of the header without compromising the seal.

Removing Blanket Modules

It has often been quoted that one of the difficulties in maintaining fusion reactor blankets is the need to move large, unwieldy objects which are sometimes quite heavy. This is certainly true. In WITAMIR-I we have attempted to mitigate this problem in two ways:

a. Reducing the mass of the blanket module

b. Limiting the motions of the blanket modules to straight guided axial translation and straight vertical lifting.

The mass of a drained blanket module is ~ 33 tonnes. Moving the module axially on guide rails is a relatively simple task. Lifting a 33 tonne module vertically in a straight line by an overhead crane is also deemed relatively straightforward.

Figure 5 is a graphic diagram showing the blanket removal scheme.

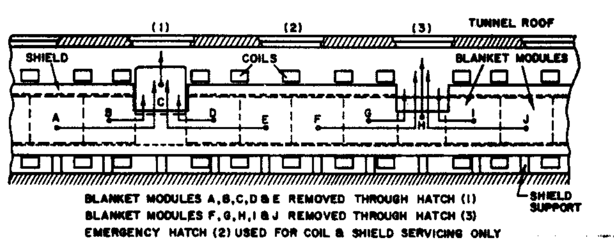

Figure 5. Blanket Maintenance Scheme

Maintaining Central Cell Coils

Although the failure of a central cell coil is going to be very rare, we have provided contingency plans for such an eventuality.

This is done by providing additional access hatches at intermediate locations between the routine maintenance hatches. Figure 6 shows such a hatch and the arrows indicate the movements needed to extract the various central cell coils which weigh on the order of 90 tonnes each. Obviously, this implies the disassembly and movement of blanket and shield modules. It will be assumed that the overhead crane capacity will be 350 tonnes, enough to remove one-half of a shield module. In this way, provision is made to extract and replace any coil within the central cell.

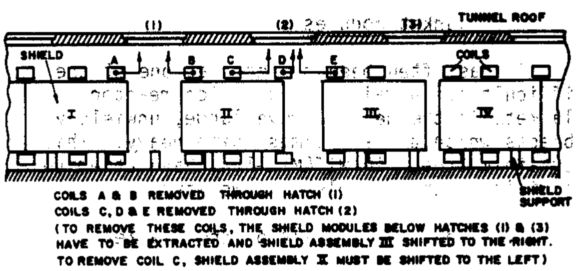

Figure 6. Central Cell Coil Maintenance Scheme

Shield Maintainability

There is very little that can go wrong with the shield except for developing coolant leaks. In most cases such leaks can most probably be fixed in situ. However, if the need arises for replacing a portion of the shield, then it is possible to do that through the access hatches described in the previous sections.

The mass of a shield module is 440 tonnes. A shield module is composed of an upper and a lower half as shown in Fig. 1. The lower half of the shield weighs ~ 290 tonnes and can be easily handled by the overhead crane. Figure 7 shows one possible way for extracting the shield modules.

Conclusions

The simple geometry of the central cell in a tandem mirror reactor with thermal barriers makes the maintainability of the blanket a relatively easy task. The task is further mitigated by the elimination of seals between blanket modules and by taking advantage of the properties of the

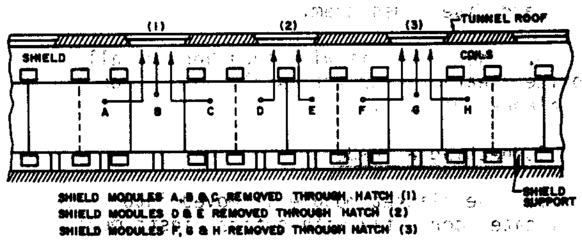

Figure 7. Shield Maintenance Scheme

breeding/cooling material ($Li_{17}Pb_{83}$) to make the connections to the blanket headers. It is felt that these improvements alone should increase the availability of the reactor and, therefore, result in lower busbar costs.

The blanket maintenance concept also makes it possible to service the central cell coils and the shield modules in the rare cases when such servicing will be required. Because there are no interlocking coils in a tandem mirror, these functions, although complicated, will not require excessive downtime. This too will benefit the cost of electricity produced by the tandem mirror.

Acknowledgement

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