DESIGN OF AN EPR BLANKET†

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Summary

A blanket concept is presented which meets typical requirements anticipated for an Experimental Power Reactor. Design alternatives are reviewed. One-dimensional neutronic and thermal hydraulic results are presented for the ORNL reference design. Design consideration was given for remote maintenance and assembly requirements. Modifications of the reference design first wall are necessary because of high thermal stresses.

Preliminary Scoping Studies

The EPR blanket design presented here is the result of a scoping study conducted at Oak Ridge National Laboratory in FY75[1]. This study included an investigation of seven different blanket concepts. Each concept was evaluated as to (1) fabricability, (2) temperature distribution, (3) coolant manifolding, (4) inner wall cooling, (5) power limitations, (6) material availability, (7) coolant pumping power, (8) breeding gain, and (9) tritium recovery. ~~AMS~~ TYPE 316 stainless steel was assumed as the structural material for all designs. No consideration was given to refractory metals as there seemed little likelihood that ~~these~~ THEY would be available for use ~~by 1985-89, in the quantities or complex geometries necessary for the EPR.~~ IN TIME FOR APPLICATION IN THE EPR.

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The blanket studies were concerned with examining mechanical designs, nonbreeding absorbers, breeding absorbers and coolants. The solid absorbers, B_4C, $LiAlO_2$, and beryllium metal were considered, but were all rejected. ~~We~~ IT WAS found that solid absorber designs led quickly to complicated coolant manifolding and gas diffusion problems. Also, the scarcity of beryllium makes its use unattractive. Both molten salt and liquid metals were considered as absorbers. However, scarcity of materials, MHD corrosion, and inadequate breeding, ruled against the molten salts. Water, circulating liquid metal, circulating molten salt and helium gas were evaluated as coolants.

Of the seven concepts considered, all but one were discarded for failing to meet one or more of the nine requirements. Some of these eliminations were more a matter of judgement than a quantitative evaluation. As an example, the headering and manifolding to cool the solid absorbers ~~was~~ WERE judged to be intolerably complex. The choice of the reference design blanket was influenced by the objectives which the blanket was to meet. These objectives have not been unanimously accepted by the CTR community, and it is necessary to clearly state the objectives which resulted in the reference design chosen. These objectives are as follows:

The blanket must absorb at least 90% of the energy from the plasma, and convert it into heat. This conversion should result in a temperature high enough ~~to be able to produce steam of sufficient quality.~~ to drive a commercial steam turbogenerator. This requirement automatically eliminates simple water blankets unless high pressure tubes of rather complex configurations are used. In performing this function of converting plasma energy to heat, the blanket automatically provides much of the shielding necessary to protect the toroidal field coils.

The design of the blanket must be such that it can be installed and removed by remote means. This feature is required because of inaccessibility, and the intense induced radioactivity that will occur after only a few days of operation. The mechanical configuration of the blanket segments is strongly influenced by the necessity to perform all assembly operations by totally remote methods.

Another objective for the blanket design, was to utilize only those materials for which supplies and fabrication techniques would be adequate by the time needed for an EPR. It was also required that no materials would be used in the EPR for which supply would be impractical for a fusion power economy. This RESTRICTION ~~last criterion~~ eliminated further consideration of designs using beryllium as a neutron multiplier.

A further constraint imposed on the EPR blanket design, ~~is~~ WAS that it be extrapolatable to a demonstration ~~plant~~ reactor. At least one of the concepts considered was eliminated by this consideration, because it could not be extrapolated in power handling ability to a size for a ~~demo plant~~ DEMONSTRATION reactor.

A final objective for the blanket was that breeding be demonstrated. The mechanical design of the breeding and the nonbreeding modules is identical. This approach appeared to not complicate the overall design, and did give some real advantages in making the two types of modules totally compatible.

Description of Blanket

For assembly reasons, the blanket is comprised of 60, 6° wedge shaped circular segments having an inner diameter of 4.5 meters. These segments are mechanically clamped together, and a seal weld is made between a thin bellows on each segment to form the vacuum vessel. This clamping and welding is done on the outer circumference at the juncture of each segment. There is a radial clearance between the blanket and the shield to permit a remotely operated ~~jig~~ fixture to perform these operations. The blanket portion of each segment is 51.5 cm thick. The blanket and shield together are 1 m thick.

Figure 1 is a section through one blanket segment showing its mechanical arrangement. THE PLASMA IS AT THE BOTTOM OF THE FIGURE.

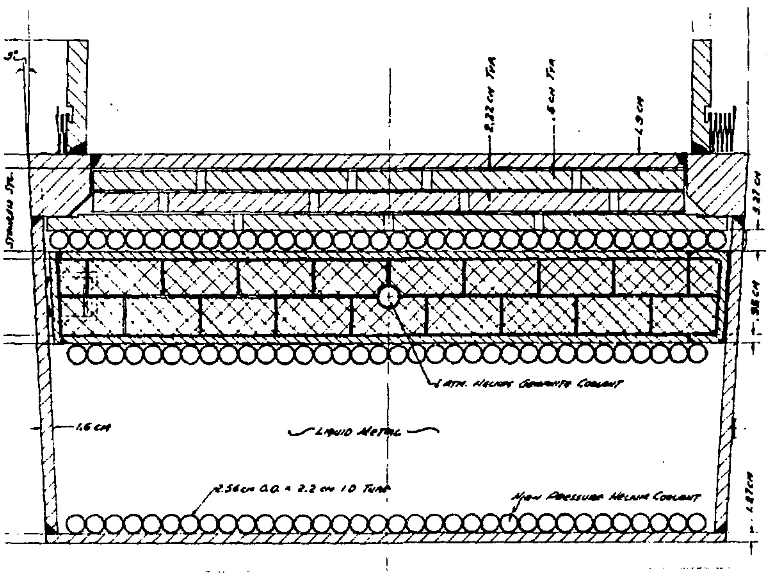

Fig. 1 Section of Blanket Segment

~~The plasma is at the bottom of the figure.~~ Adjacent, but not attached to the wall facing the plasma, is a row of coolant tubes 2.54 cm in diameter, and having a wall thickness of .17 cm. These tubes carry the helium coolant at a pressure of 70 atmospheres. Surrounding these tubes, is a 25 cm thick compartment filled with liquid metal. For the nonbreeding segments, this metal is sodium or potassium. For the breeding modules, lithium is used. At the opposite wall of this compartment is another row of coolant tubes. The coolant enters the first row from a helium header, flows 180° around the first wall, and returns through the second row, and is collected in an outlet header.

The graphite reflector, immediately back of the front liquid metal section is contained in a sealed compartment. This reflector is 10 cm thick. A gap on each side of the reflector container permits the liquid metal to communicate with the back compartment of the blanket where it fills all interstitial spaces between tubes and the stainless steel rings. A third row of coolant tubes is located in this rear compartment, and provides cooling of this section.

The back section of the blanket consists of stainless steel rings about 2.2 cm thick with spacer buttons and holes to permit filling all interstices with liquid metal. The row of coolant tubes in ~~the~~ THIS section is fed from a separate set of headers from the tubes in the front section. Fig. 2 shows an elevation of a blanket segment.

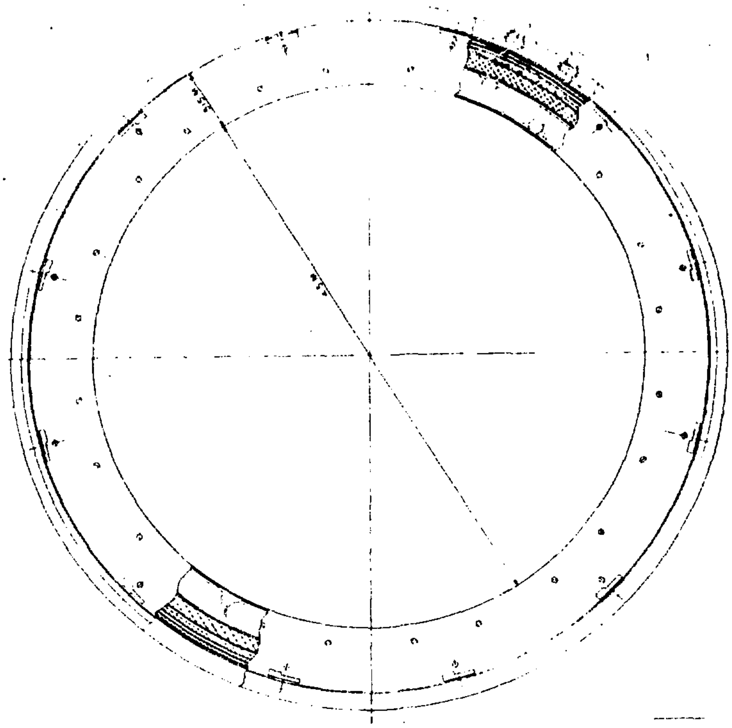

Fig. 2 Elevation of Blanket Segment

Results of Neutronic Analyses

The neutronics calculations were performed using the one-dimensional discrete ordinates code ANISN[2] using a P_3 scattering expansion, and S_{12} quadrature, and the coupled neutron-gamma-ray cross section library (100n -21γ) of; Plaster, Santoro and Foul.[3] Energy deposition in the reactor was estimated using coupled neutron-photon Kerma factors obtained from MACKLIB[4] and ~~SMOG~~[6] SAUG[5], respectively.

Typical results of these calculations are given in Fig. 3.

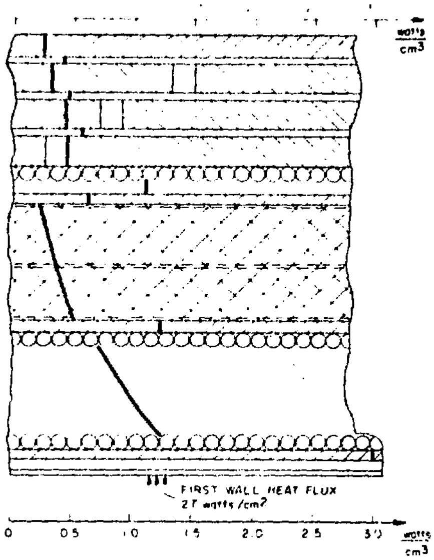

Fig. 3 Calculated Heat Deposition Radially Thru Blanket Section.

Here a representative section of the blanket is shown with the power density, in watts/cm^3 as a function of radius plotted on the blanket cross section. ~~The surface of the blanket facing the plasma is at the bottom of the figure.~~ This plot is for the breeding segment of the blanket, subject to a neutron wall loading of .4MW/m^2. The power distribution through the nonbreeding segments is similar.

A prime consideration in choosing the EPR blanket concept concerns the breeding of tritium in the blanket. Natural lithium metal is used and a calculation of the breeding gain was made. The breeding gain for this configuration is about 1.2, and does not represent an optimized blanket design.

Results of Thermal-Hydraulic Analysis

The energy deposition obtained from the neutronic calculations was used to calculate the temperature distribution in the blanket. A one-dimensional conduction model was used to calculate these temperatures. These radial calculations were made at three azimuthal locations: at the helium inlet header, a point 180° around the blanket and at the helium outlet header.

The thermal-hydraulic calculations ~~for which results are~~ presented, were based on a specific assumed plasma performance. ~~Specifically,~~ The first wall heat flux, (assuming a plasma driven with 100MW of neutral beam) power, amounted to 160 MW (.27MW/m^2). This loading consists of all types of energy, other than neutrons, which are deposited on the first wall surface. The plasma under these conditions has a neutron power of 240 MW (.4MW/m^2), and a total power of 400 MW.

The first analysis was made using a helium inlet temperature of 316°C and an outlet temperature of 538°C. These temperatures resulted in a maximum structure temperature of 790°C, considerably higher than tolerable. Accordingly, the helium temperatures were lowered to 260°C inlet and 371°C outlet and the temperature profiles were recalculated. Under these conditions, the maximum structure temperature was reduced to an acceptable 600°C. A plot showing the radial variation of these temperatures is shown in Fig. 4, superimposed on a blanket section. The three curves are for the three azimuthal locations indicated.

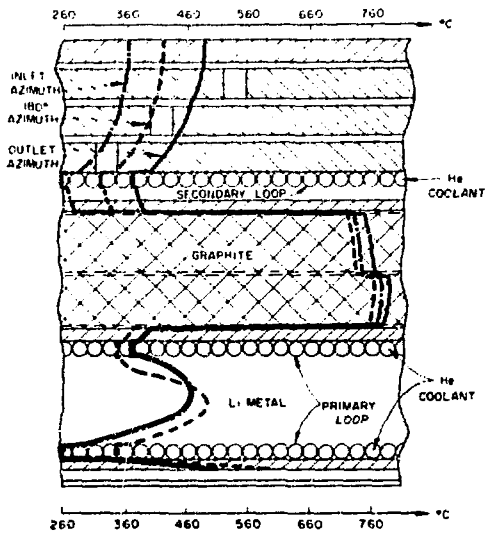

Figure 4 Calculated Temperature Distribution at 3 Azimuthal Locations.

In order to remove the total heat (400 MW) from the blanket with the temperature drop in the helium of only 111°C, the mass flow of helium was 658 kg/sec. Circulating this through the 2.2 cm DIAMETER cooling tubes requires about 5.5% of the thermal power of the reactor. This is a rather high pumping power, but it is thought that a more detailed design of the coolant circuit could reduce this to possibly 2 or 3%. The design as presented is adequate as far as temperature maxima and coolant parameters are concerned. However, the 200°C Δt through the first wall thickness is structurally unacceptable. To lower this temperature differential and obtain acceptable stress levels, a design change is required. This can be done by reducing the wall thickness WITH A rib reinforced front wall instead of a slab.

Future Blanket Design

As indicated above, the first change in the blanket concerns redesign of the first wall to bring the thermal stress into an acceptable range. If this cannot be done successfully by wall design, it may be necessary to add a water-cooled wall in front of the blanket first wall. Some initial work has been done in this regard, and it appears feasible. This water cooled design would be used to absorb the ~~non-neutron load from the plasma~~ PLASMA LOSSES, and would greatly reduce the first wall heat problem. This concept would take inlet water at ~~about~~ 35°C, and heat it to ~~about~~ 158°C at 90 psia. This heat could be used for feed water heating, and would not be wasted.

The blanket design presented here has not had a detailed thermal stress analysis. This is in progress, but ~~no~~ results are available at this time. Some analysis has been done on radiation damage on ~~this~~ THE first wall, but this too requires further study. Calculations have given 1.89 displacements per atom per year, the production of 4.73×10^{18} hydrogen atoms per cm^3 per year, and the production of 1.47×10^{18} helium atoms per cm^3 per year. What this means in ductility change and wall life are not yet entirely clear.

Both the neutronic ~~calculations~~ and the thermal hydraulic analyses have been one-dimensional studies. Multi-dimensional analyses in both areas are just now beginning. While, the one-dimensional studies have been informative, and the results are encouraging, final judgement on the performance of the blanket must await these multi-dimensional analyses.

A further unknown about the blanket concerns the effect of eddy currents generated in the lithium and also in the structure. These eddy currents could pose a problem, both regarding the penetration of the pulsed vertical field and the possible forces exerted in the blanket, as these eddy currents cut the various magnetic fields of their environment. Studies of these ~~efforts~~ EFFECTS are in progress.

A BLANKET CONCEPT USING A ~~Finally, the~~ static liquid metal absorber cooled by circulating high pressure helium, HAS ~~appears to have~~ the possibility of being satisfactory for an EPR. THIS CONCEPT ALSO ~~It~~ appears to be extrapolatable for use in a demonstration REACTOR ~~plant~~. Much more evaluation, however, is necessary before such a blanket can be PROVEN ~~proved to be~~ satisfactory.

References

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