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TRITIUM BREEDING BLANKET

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ABSTRACT

The terms of reference for ITER provide for incorporation of a tritium breeding blanket with a breeding ratio as close to unity as practical.[1-4] A breeding blanket is required to assure an adequate supply of tritium to meet the program objectives. Based on specified design criteria, a ceramic breeder concept with water coolant and an austenitic steel structure has been selected as the first option and lithium-lead blanket concept has been chosen as an alternate option. The first wall, blanket, and shield are integrated into a single unit with separate cooling systems. The design makes extensive use of beryllium to enhance the tritium breeding ratio. The design goals with a tritium breeding ratio of 0.8-0.9 have been achieved and the R&D requirements to qualify the design have been identified.

I. INTRODUCTION

The terms of reference for ITER provide for incorporation of a tritium-producing blanket for ITER. The main function of this blanket is to produce the necessary tritium required for the ITER operation and the test program. The limited tritium supply from the international market dictates this tritium breeding function. In addition, the use of an effective breeding blanket provides a substantial economic advantage based on the current unit cost for tritium. The other design goals for the blanket are the following: achieve a net tritium breeding ratio (TBR) of about one, operate at an average neutron wall loading of 1 MW/m^2, achieve an average fluence of at least 1 MWa/m^2 and up to 3 MWa/m^2, be compatible with an overall machine availability of at least 10% with a goal of reaching about 25% in the technology phase, and tolerate transient conditions with passive methods.

Three blanket concepts were considered during the concept definition process. These three are: ceramic breeder (solid breeder) concept, lithium-lead breeder concept and aqueous-salt breeder concept. A set of criteria was considered to select a driver blanket for ITER that includes the following: performance capability, safety and environmental aspects, cost considerations, R&D requirements, reactor relevance and benefits and reliability considerations. The ceramic breeder concept has been selected as the "first option" for ITER.

II. OPERATING CONDITIONS AND DESIGN GUIDELINES

Figure 1 is an isometric view showing the inboard and outboard blanket segments in one sector. The main operating conditions and design guidelines are summarized in Table 1.

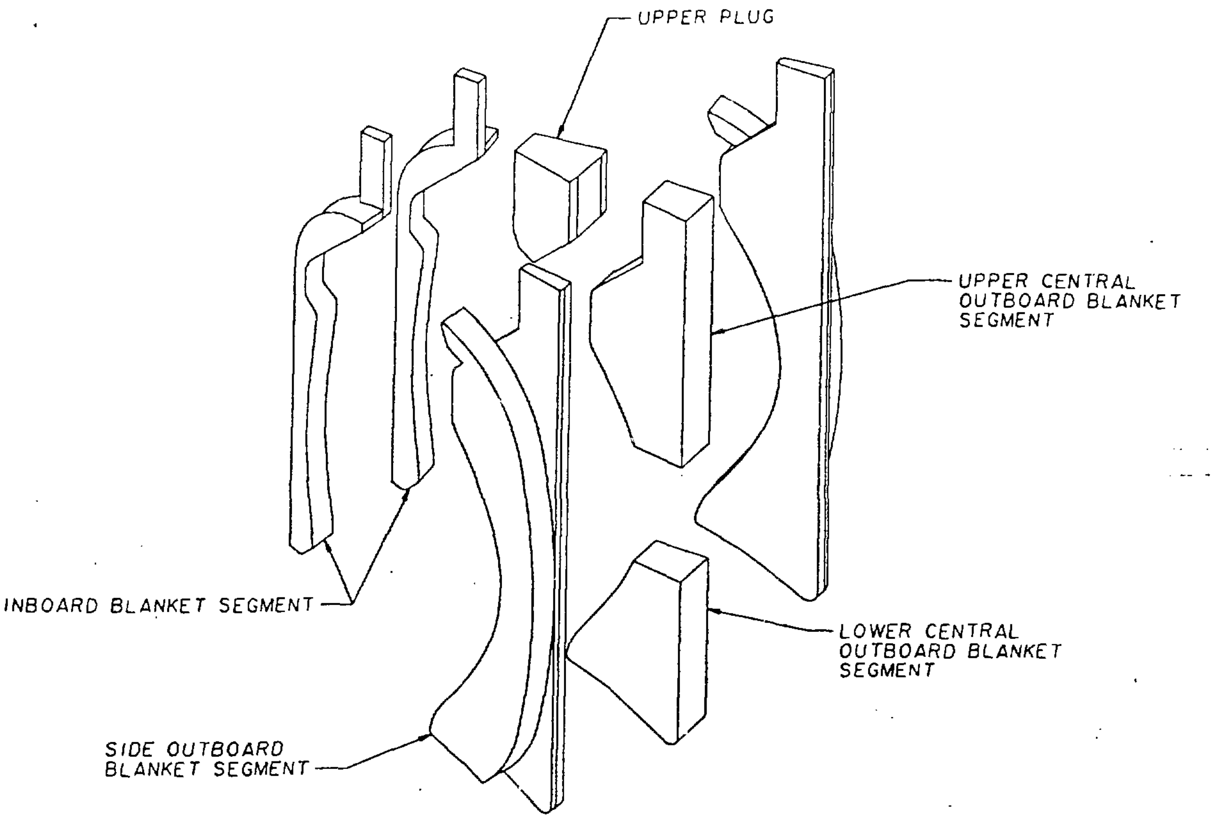

Fig. 1. Isometric view showing the inboard and outboard blanket regions.

Table 1.
Operating Conditions and Design Guidelines

Phase	Physics Phase	Technology
Fusion Power, MW	1100	860
Neutron Wall Load, MW/m²		
Inboard (Min/Max)	0.42/1.13	0.33/0.88
Outboard (Min/Max)	0.77/1.54	0.60/1.25
DT Flat Burn Time, s	UP TO 400	2300
Minimum Dwell Time, s	200	200
Number of DT Pulses	10^4	5×10^4
DT Fluence Goal, MWa/m²	0.05	3

The blanket is designed to operate for the full lifetime (3 MW-a/m^2) and to accommodate the change in power levels between the two operating phases and significant variations in fusion power within each phase. The blanket must also be designed to accommodate the poloidal changes of the neutron wall loading which are reduced to 0.38 and 0.50 of the values at the midplane for the inboard and outboard regions, respectively. Also, the blanket must accommodate the twin loop copper stabilizer and the sixteen ports at the outboard midplane. Operating temperature windows are defined for each material to satisfy the different design criteria. The minimum temperature limits for breeder materials are based on tritium recovery issues while the maximum temperature limits are based on mass transfer and material sintering considerations.

The blanket performance during the off-normal conditions (plasma disruption, loss of coolant, or loss of coolant flow) is another key factor in the blanket design process. The design philosophy is to accommodate such conditions with passive methods. For example the inboard blanket is segmented to accommodate the electromagnetic forces during the plasma disruption. Internal reinforcement ribs are used to provide additional support for the outboard blanket. Also, the safety analyses for the other off-normal conditions show that design modifications can be used to keep the maximum temperature and stress values within the design guidelines.

III. BLANKET DESIGN

The ceramic breeder concept has been selected as the first option with either Li_2O or a ternary ceramic (e.g., $LiAlO_2$ or Li_2ZrO_3 as the breeder material. The design specifications for the first option are given in Table 2. Austenitic steel (Type 316 solution annealed) was selected as the reference structural material on the basis of an extensive database and ease of fabrication. Low temperature (60-100° C), low pressure water is specified as the coolant to reduce safety concerns with pressurized water. The desire to achieve a tritium breeding ratio of about one with limited breeding volume because of inboard shielding requirements, numerous penetrations, and provisions for nuclear testing; requires the extensive use of beryllium as a neutron multiplier.

The first wall, blanket, and shield are integrated into a single unit with separate cooling systems. Poloidal and toroidal coolant flow were chosen for the inboard and outboard first wall, respectively. Both poloidal and toroidal cooling were considered in the blanket designs. The inboard blanket is divided into three electrically insulated submodules per segment with two segments per sector in order to accommodate electromagnetic loads predicted during a disruption. The outboard blanket is divided into three poloidal segments per sector with the central segment divided into upper and lower modules to provide for the major penetrations. All blanket segments are manifolded at the top except for the lower central outboard segment which is manifolded at the bottom.

Two solid breeder configurations are considered for the detailed blanket design, viz., a multilayer configuration shown in Figures 2 and 3 and a breeder-in-tube configuration shown in Figure 4 A major

Table 2.
Tritium Breeding Blanket Design Specifications

FIRST OPTION BLANKET	**CERAMIC BREEDER**
Structural Materials	Austenitic Steel (316)
Coolant	Water: 60-100°C, <1.5 MPa
Breeder Material	Li_2O or Ternary ($LiAlO_2$, Li_2ZrO_3)
^6Li Enrichment	50-95%
Neutron Multiplier	Beryllium
Breeder Configuration	Layered or Breeder-in-Tube
Breeder and Multiplier Clad	Austenitic Steel (316)
Breeder Temperature Control	Thermal Gradient in Beryllium or
Helium Gas Gap	
Tritium Recovery Method	Continuous In-Situ Recovery Purge
Gas: He + (0.2-1%) H	
Coolant Flow Direction	
Inboard-First Wall	Poloidal
- Blanket	Poloidal or Toroidal
Outboard-First Wall	Toroidal
- Blanket	Toroidal or Poloidal
ALTERNATE BLANKET OPTION	**LEAD-LITHIUM BREEDER**
Structural Material	Austenitic Steel (316)
Coolant	Water: 60-100°C, <1.5 MPa
Breeder	83Pb-17Li Eutectic Alloy
Tritium Recovery	Batch Processing
Coolant Flow	Poloidal

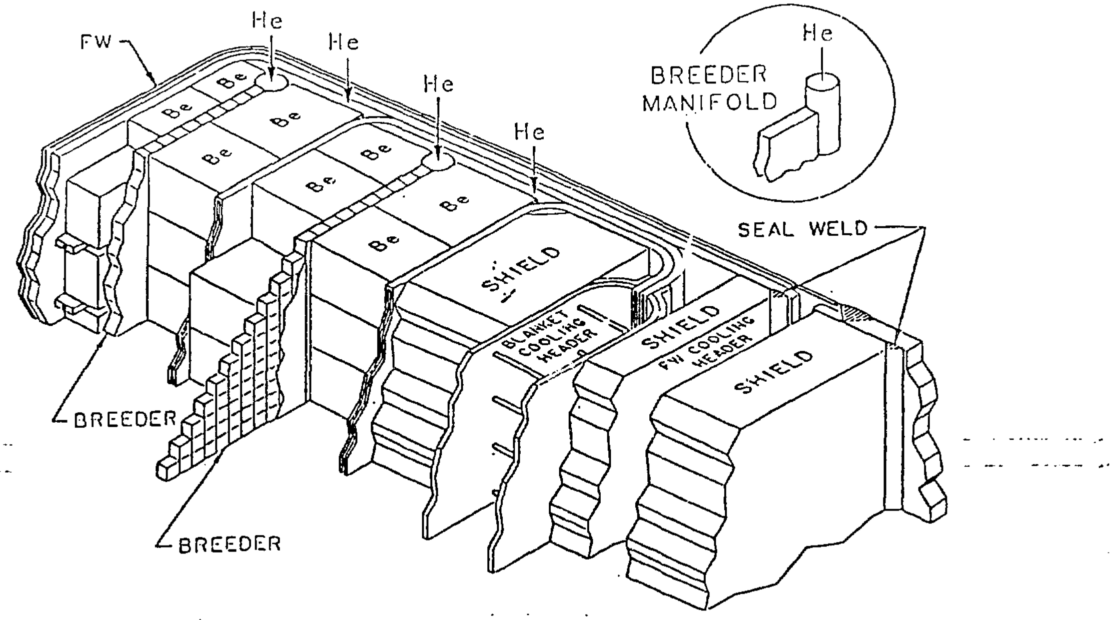

Fig. 2. Isometric view of multilayered ceramic breeder blanket design with toroidal cooling and both Li_2O breeder and beryllium in the form of sintered blocks.

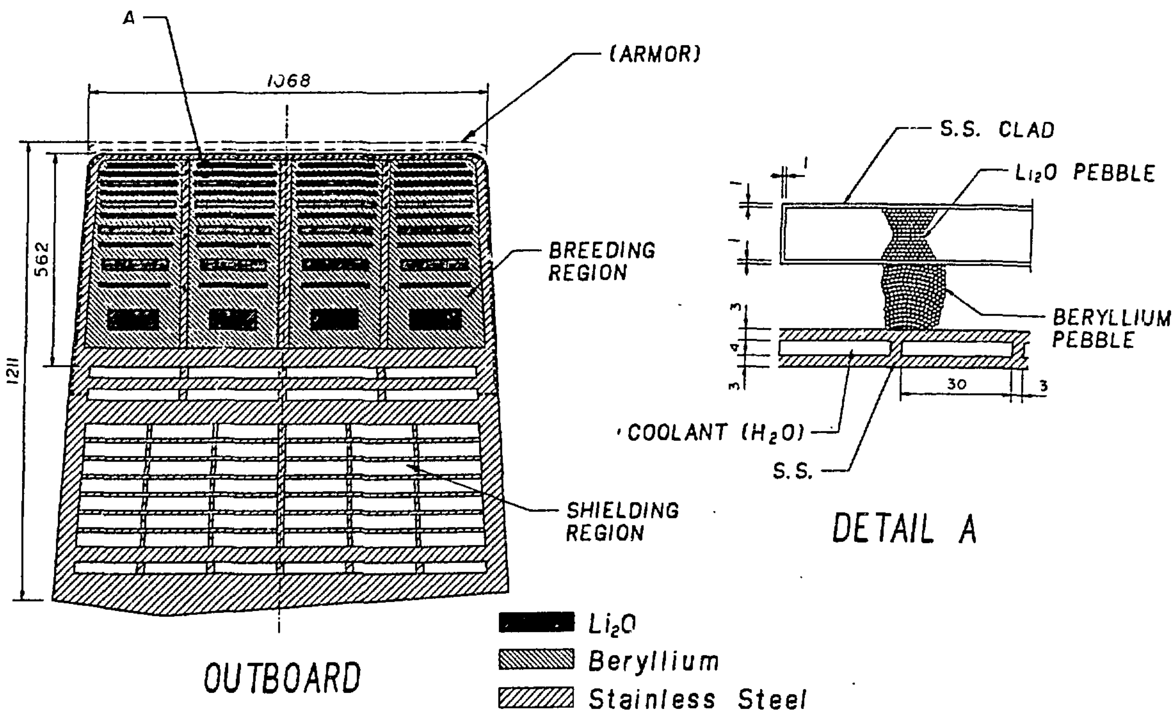

Fig. 3. Cross sectional view of multilayered ceramic breeder blanket design with Li_2O breeder and beryllium neutron in the form of small sintered pebbles.

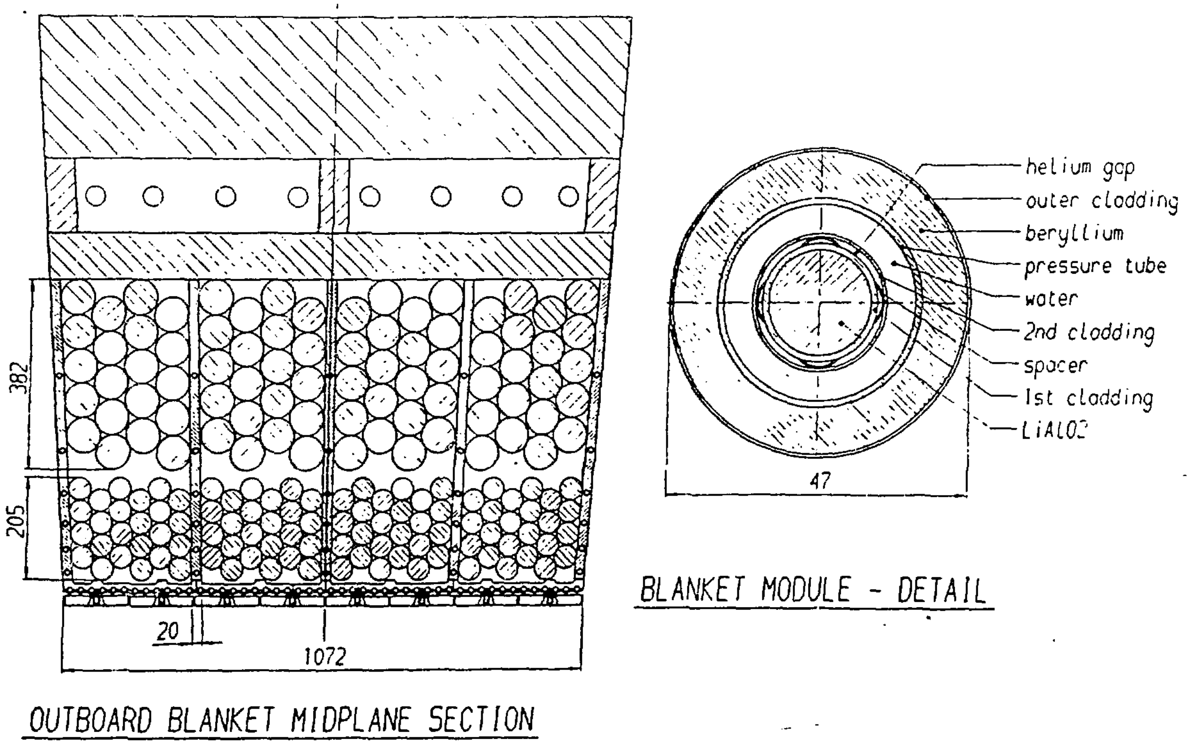

Fig. 4. Cross sectional view of BIT ceramic breeder blanket design with poloidal cooling and both $LiAlO_2$ breeder and beryllium in the form of sintered pellets.

issue in the ceramic breeder concept is the control of the breeder temperature within a specified range to provide for efficient tritium recovery and a low blanket tritium inventory. Figure 5 shows the calculated tritium inventory for a specific Li_2O blanket as a function of temperature with the effects of various tritium transport mechanisms indicated. The layered configuration utilizes the beryllium zones to provide the desired temperature gradient between the low temperature (60-100°C) coolant and the breeder. Figure 6 shows the calculated temperature profile across a multilayer blanket configuration with beryllium layers providing the desired temperature gradient between breeder and coolant. The temperature control in the breeder-in-tube configuration is achieved by a controlled helium gas gap. Figure 7 shows the calculated temperature profile for the breeder-in-tube configuration with a gas gap for temperature control.

Two forms of ceramic breeder and beryllium are considered: sintered product (blocks or pellets) and small (approximately 1mm dia) spheres. The ceramic breeder is highly enriched (50-95% ^6Li). Tritium is recovered from the breeder by a helium purge (He + 0.2 to 1% H_2). A net tritium breeding ratio of 0.8 to 0.9 is attainable. The calculated tritium inventory in the breeder can be maintained at less than 100 g. Based on very limited data and conservative estimates that include the chemical and irradiation-induced trapping of tritium in beryllium, the end-of-life total tritium inventory in the beryllium multiplier zones is less than 0.4 to 1.2 Kg for 1 to 3 MWa/m^2. The blanket is designed with separate helium purge loop for the beryllium multiplier.

An alternate blanket concept with 83 Pb-17 Li eutectic as the breeding material has also been developed as shown in Fig. 8. The lithium-lead blanket has poloidal breeding

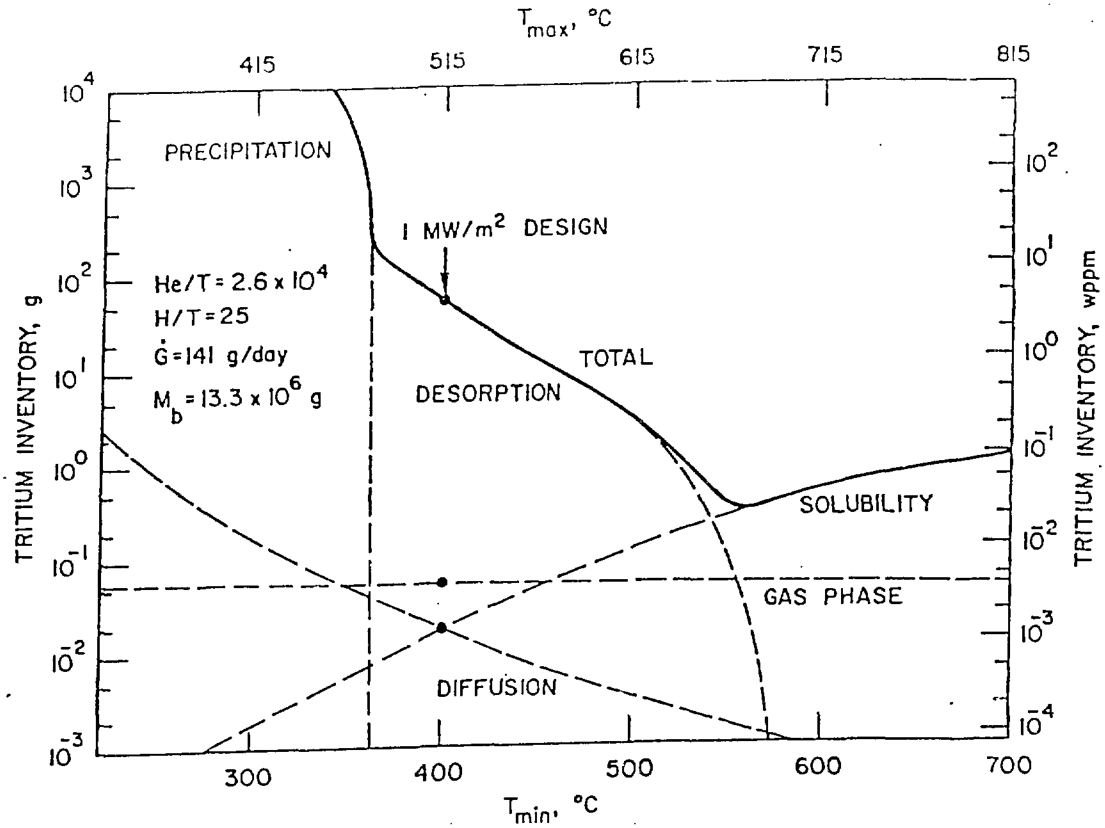

Fig. 5. Tritium inventory calculation for layered blanket concept showing sensitivity to the Li_2O breeder temperature.

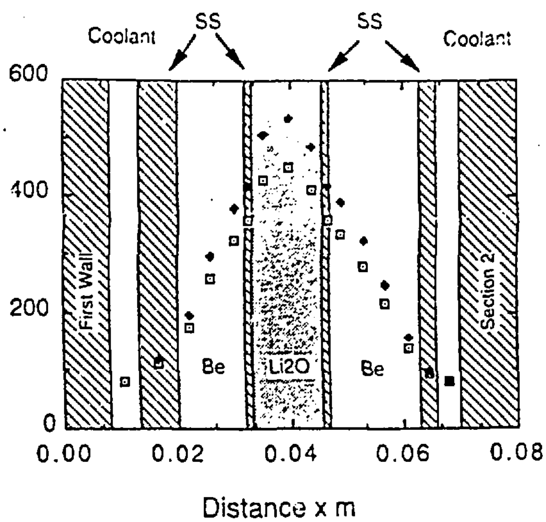

Fig. 6. Thermal analysis of first breeder region of layered blanket concept.

channels which follow the first wall geometry. Each channel consists of coaxial pipes where eutectic is separated in individual chambers. During operation, eutectic is in solid form and it is melted for in-situ tritium recovery.

IV. BLANKET ISSUES

The design analyses of the ceramic breeder blanket concepts indicate that the design goals can be achieved and the R&D requirements to qualify the design have been identified. Major R&D issues include:

Characterization of the ceramic breeder. Data on tritium release and irradiation effects on the mechanical properties are required to reduce the design uncertainties.

Characterization of beryllium. There is a need for data on fabrication techniques and irradiation effects such as swelling, tritium

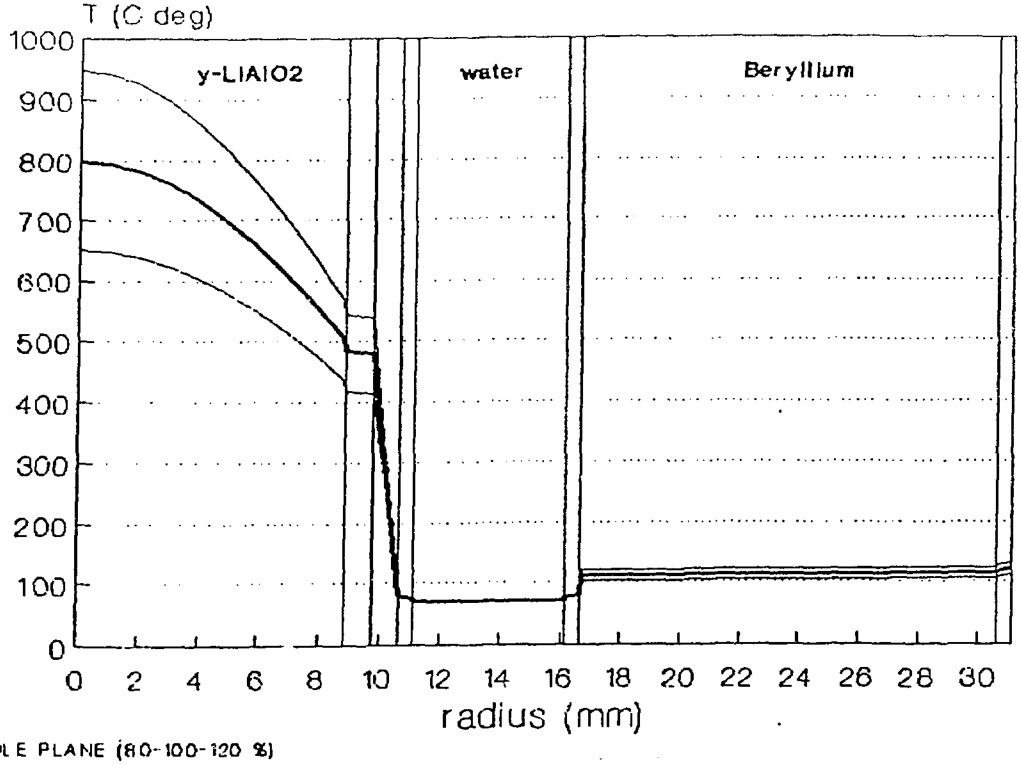

Fig. 7. Calculated temperature distribution in the BIT blanket pins showing the thermal response to 20% power variations.

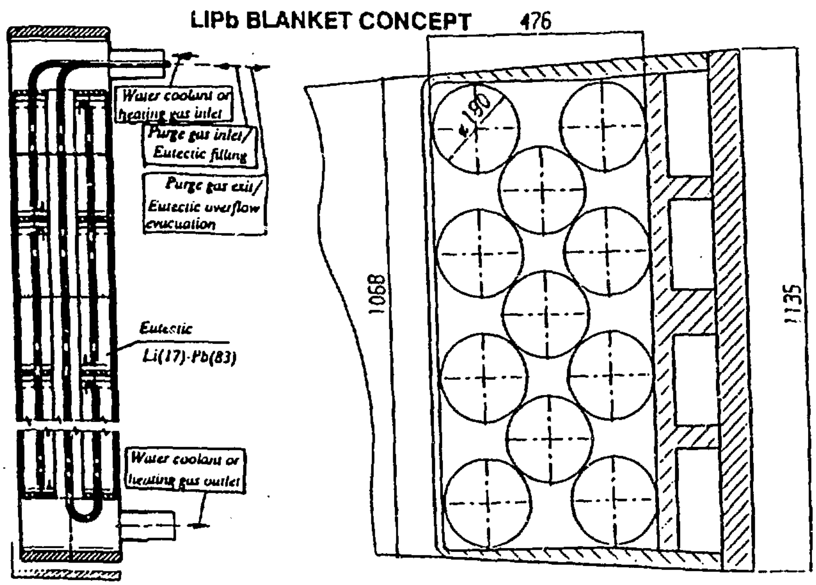

Fig. 8. Cross sectional view of Pb-17 breeder blanket design with breeder-in-tube configuration and poloidal cooling.

retention, and compatibility with the structure.

Temperature control. The methods used to provide a thermal insulation between the coolant and the ceramic breeder require testing under reactor conditions.

Structure. Primary issues include aqueous stress corrosion and irradiation effects on low temperature fracture toughness of Type 316 austenitic steel. Additional data are also required on the effects of irradiation on mechanical properties including weldments and braze joints.

Lithium-lead breeder. Additional data are required on the thermomechanical behavior of lithium-lead breeder concept.

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