He-Cooled Solid Breeder Blanket Concept for ITER

(Developed by UCLA FNT Group)

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- ITER will Require a Tritium-Producing Blanket

- Top Requirements:

  <u>Minimize Risk</u>

  - First Experience with Fusion Environment

  <u>Maximize Reactor Relevance</u>

  - ITER is a step in fusion development
  - Only fusion facility year 2000-2020

Objectives of the Work Design an attractive blanket for ITER that minimizes risk and maximizes reactor relevance

Key Considerations in Selecting ITER Blanket

1. **Engineering Feasibility**
   - Tritium breeding
   - Design margin
   - Flexibility, including ±50% power variation
   - Engineering complexity
   - Maintenance and repair

2. **Safety and Environment**
   - Routine tritium release
   - Accidental release (tritium activation products)
   - Decay heat
   - Waste disposal
   - Chemical and thermal reaction potential
   - Fault tolerance

3. **Economics**
   - Change in reactor capital cost
   - Change in reactor operating cost
   - Change in cost of test program

4. **R&D Requirements**
   - Cost of R&D required prior to ITER (only incremental increase required beyond existing R&D programs)
   - Cost of R&D required after ITER (for DEMO)

5. **Benefits**
   (Value of information obtained from operation)
   - Impact on blanket R&D after ITER (includes consideration for all testing in ITER)
   - Reduced risk for DEMO

Helium-Cooled Solid Breeder Blanket Design for ITER

Reasons for considering such a Blanket

- Materials and configurations of highest interest and well studied in all major world fusion programs

- Large Design Margin
  - Commercial: 5 MW/m^2 20 MW•y/m^2
  - ITER: 1-2 MW/m^2 3 MW•y/m^2
  - Need to use only a part of SB temperature window

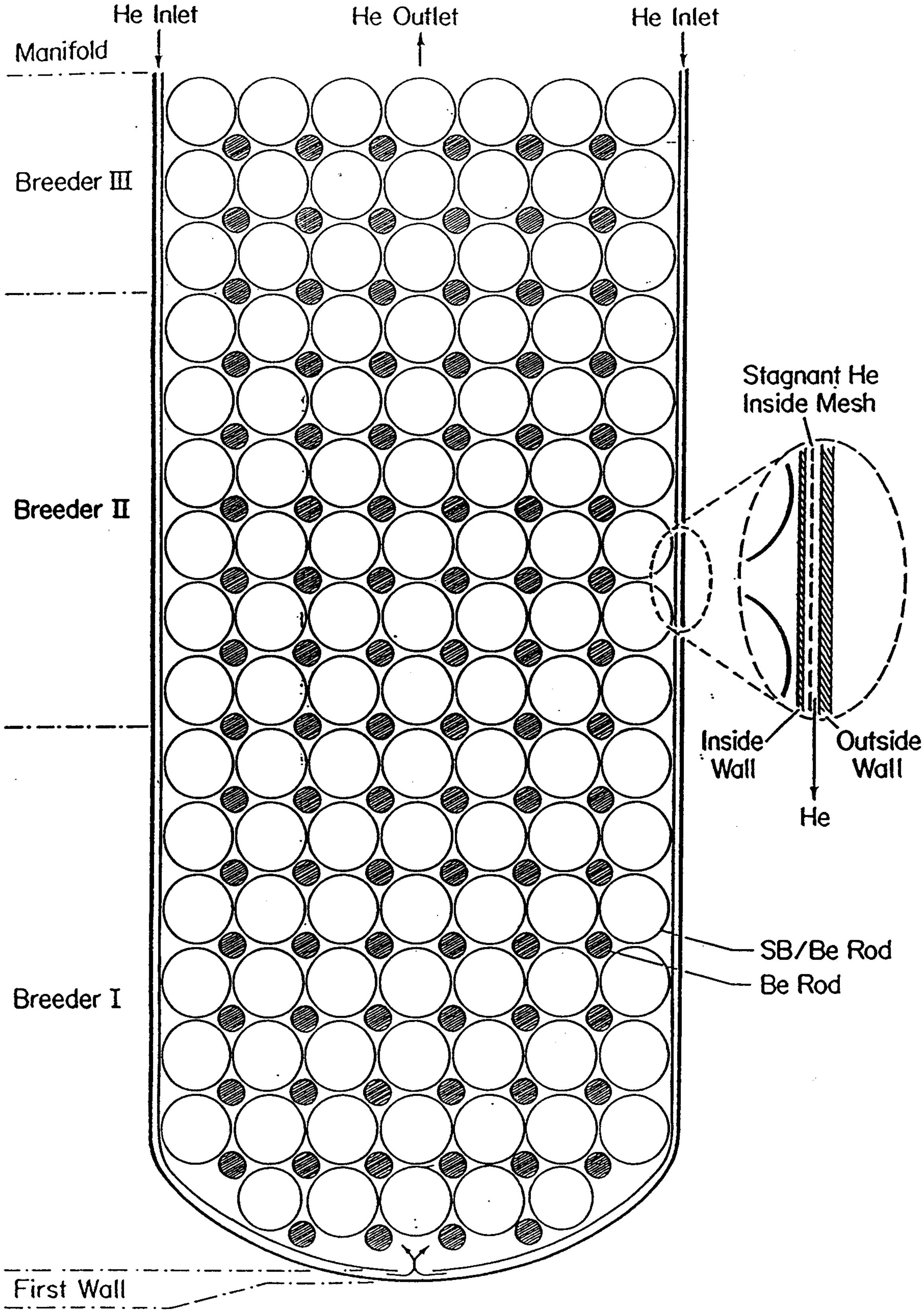
- Data Base for Solid Breeder
  - Major progress over past few years from increasing number of solid breeder experiments
  - Data will be available from experiments in fission reactors for ITER-type fluence

- R&D and Testing Benefit
  - Substantially reduces R&D before and after ITER
  - Could reduce the risk for DEMO

- Design/Operation Flexibility

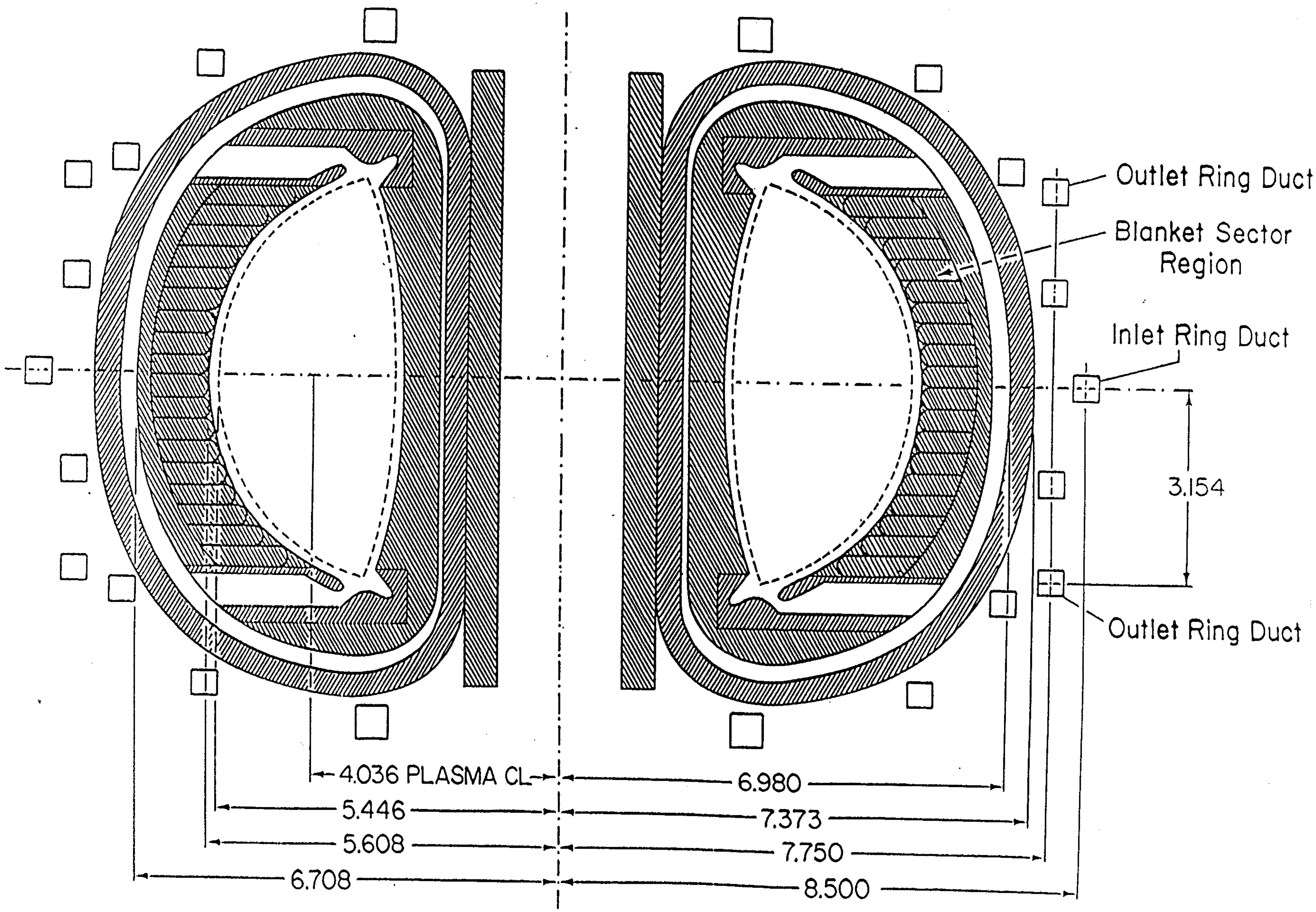
  He coolant-temperature virtually decoupled from pressure
  - Can run He to optimize structure temperature (~300°C?)
  - Can accommodate power variation

- Safety
  - Inert He gas - no chemical reaction, no corrosion
  - Low activation SB material - Li_4SiO_4, Li_2O
  - He at moderate temperature and pressure

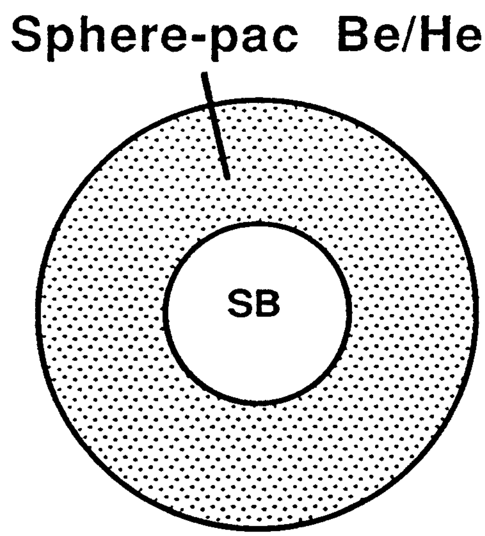


Helium-Cooled Solid Breeder Blanket Canister for ITER

Cross-Section of ITER Showing Canister Layout



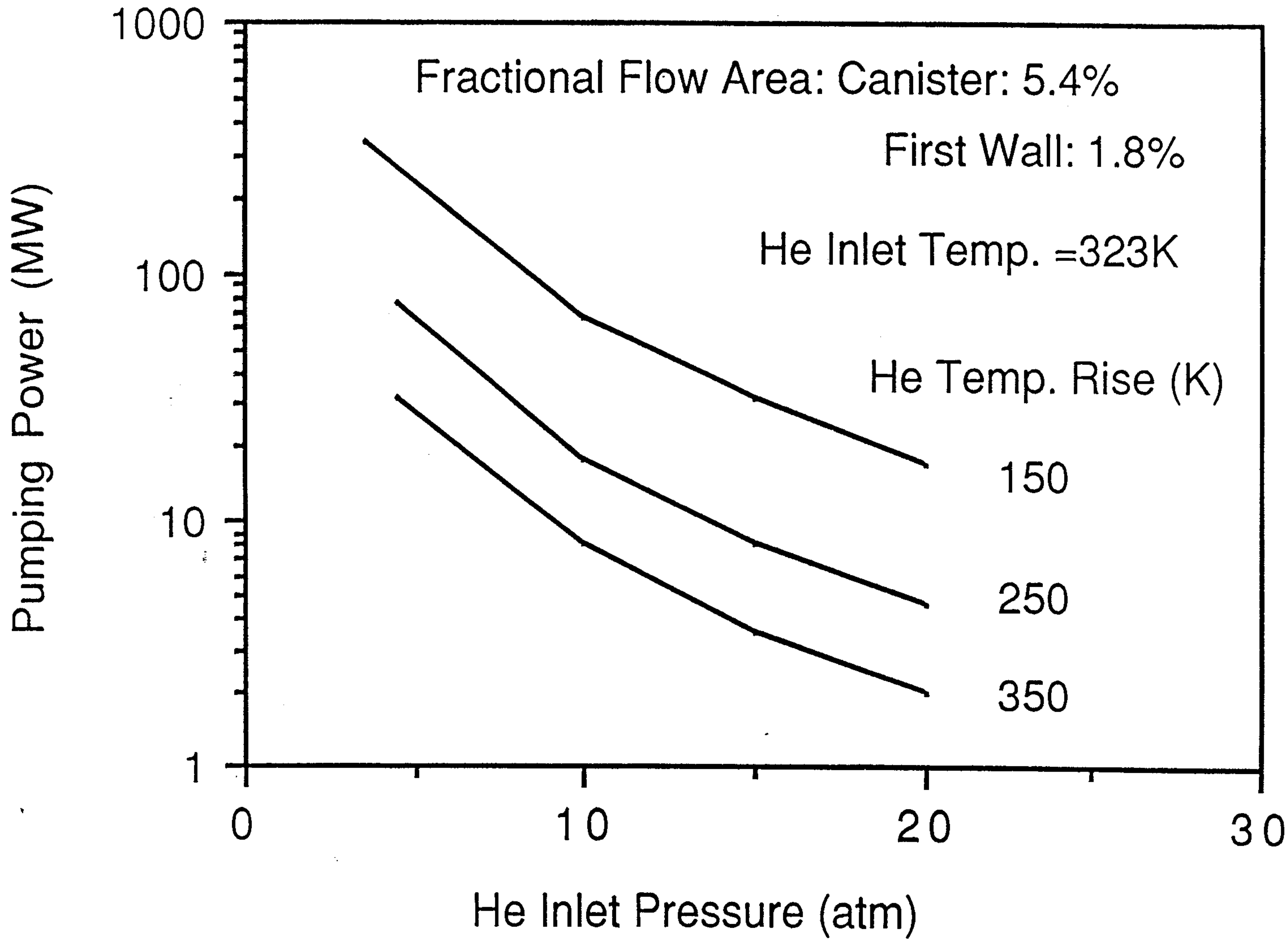
Solid Breeder/Multiplier Rod Configuration



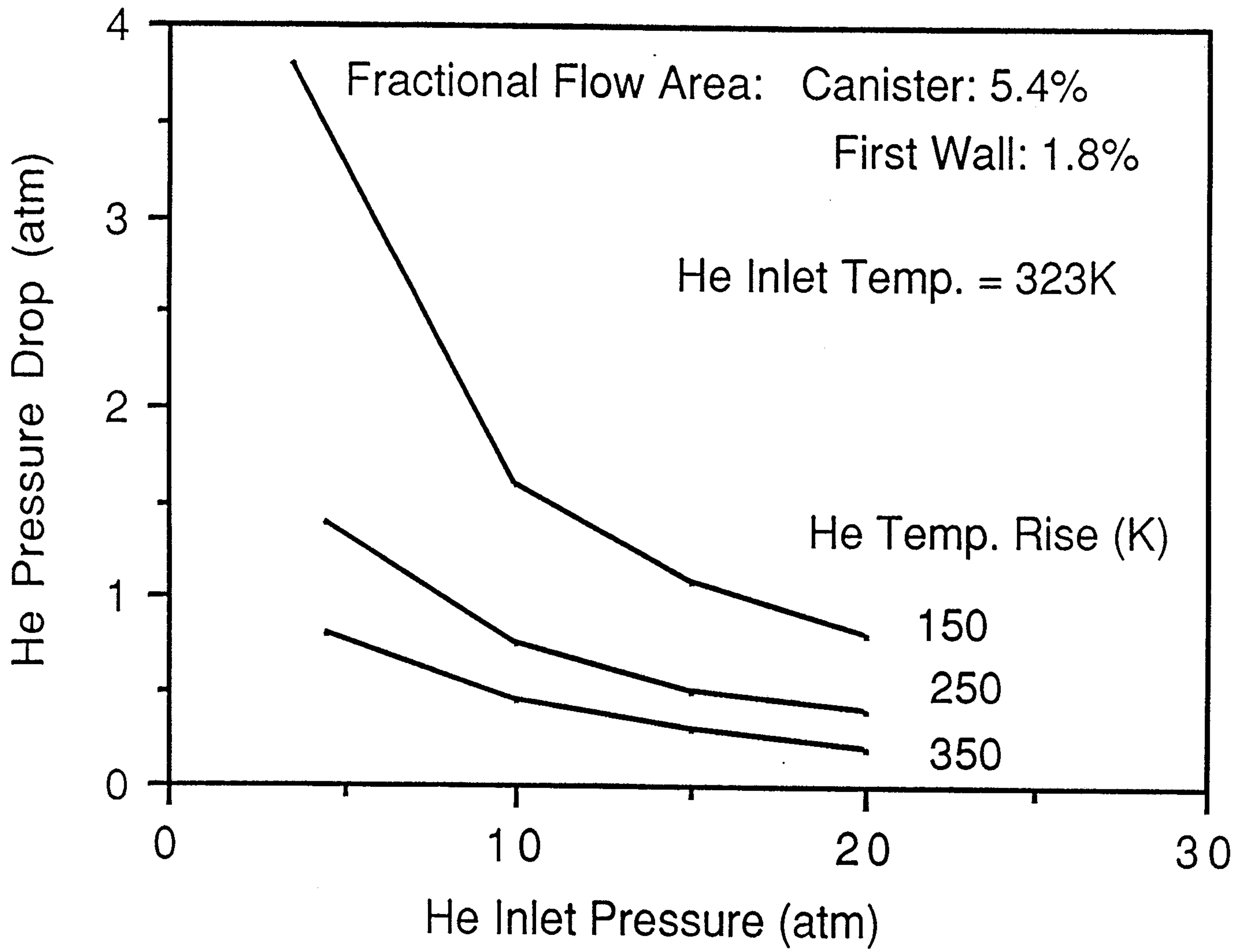
Advantages

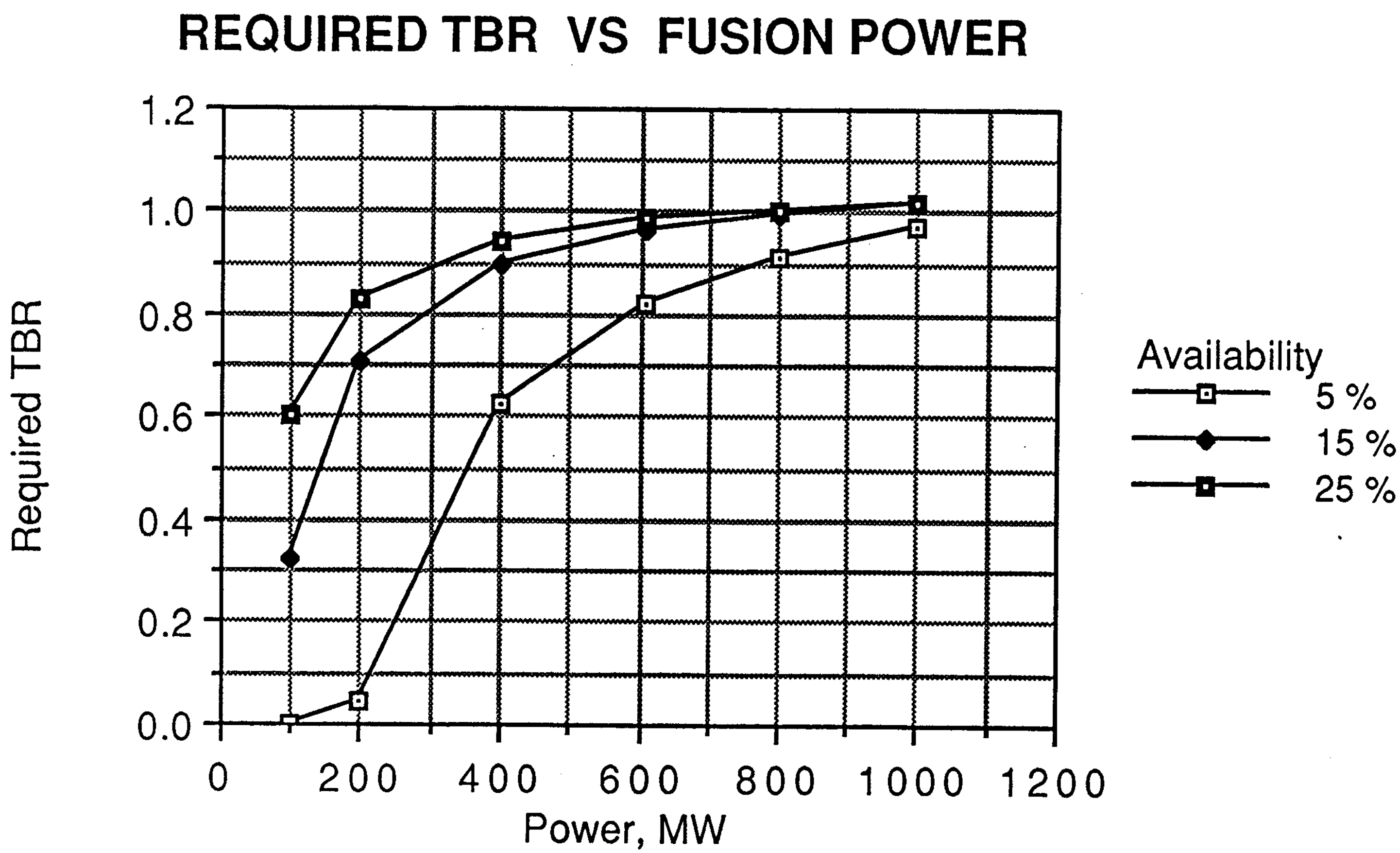
- Effective Decoupling of Breeder and Coolant Temperatures
- Be can be Purged
- Effective Barrier Against Permeation to the Main Helium Flow
- Be Sphere-pac Configuration Provides More Allowance for Swelling and Thermal Expansion
- Excellent Neutronics Performance

Canister Pumping Power vs. He Inlet Pres.



Canister He Pres. Drop vs. Inlet Pressure





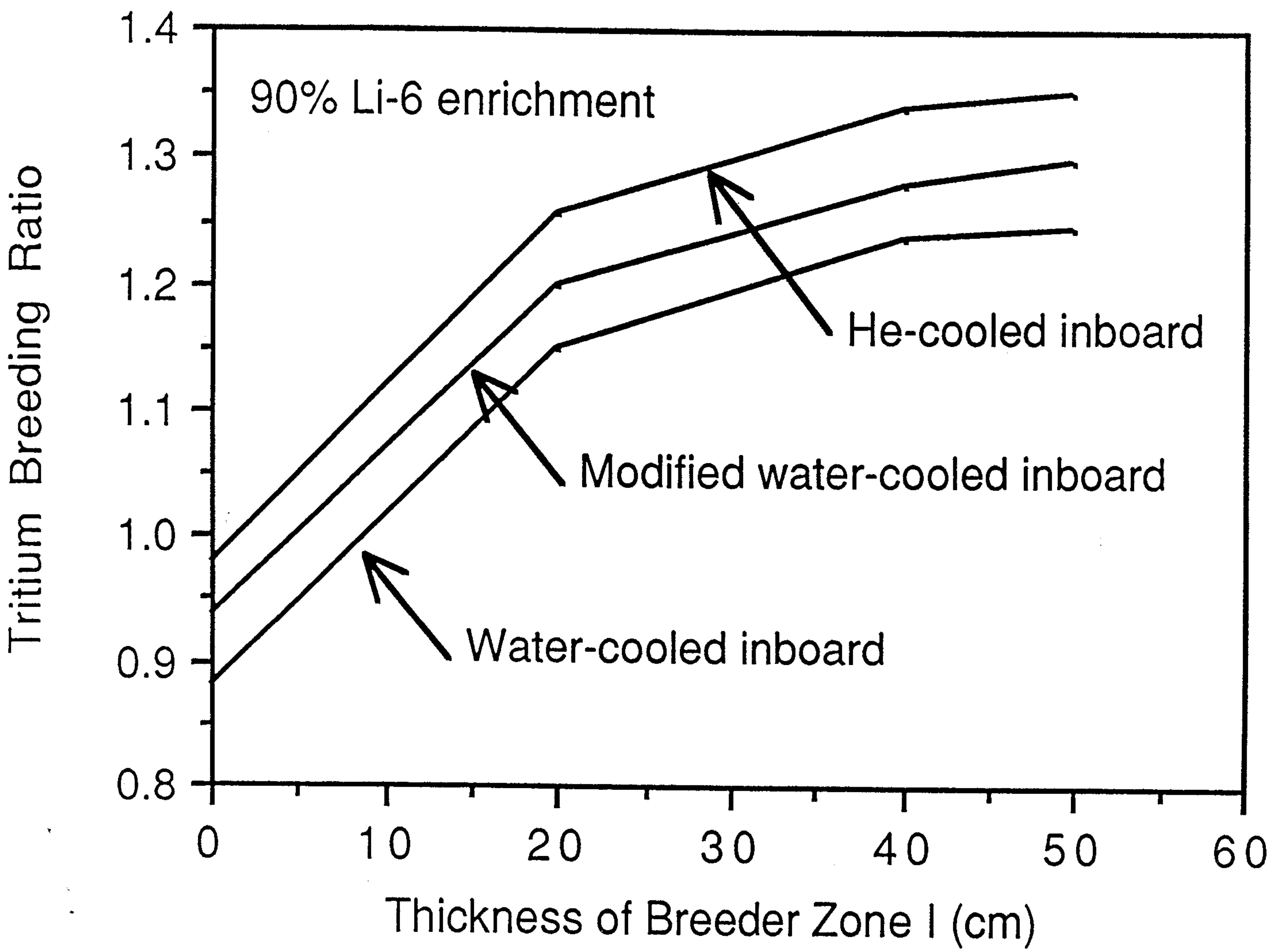
Lifetime = 6 Years

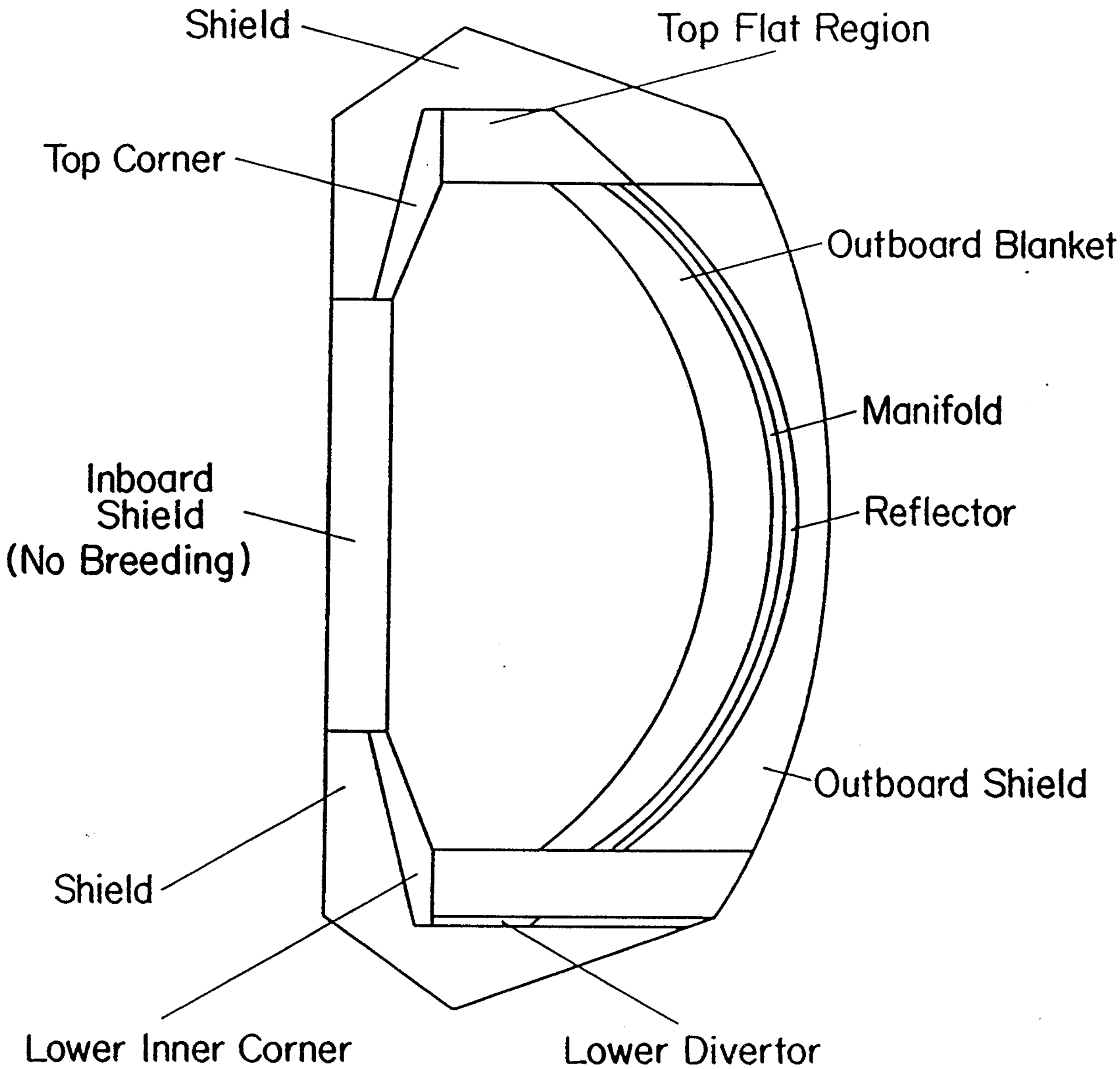
τ_b = 10 days $I_s(0)$ = 5 Kg
τ_v = 2 hrs. Δ = 30 days
τ_p = 1 day I_s, min = 0 Kg
f_b = 5%

Materials Compositions in Breeder Zones Used for Neutronics Calculations

Zone	% Volume Fraction
Breeder I	7.2% Li_4SiO_4 (80% TD) 45.3% Be (90% TD) 9.2% PCA 38.3% He
Breeder II	37.6% Li_4SiO_4 (80% TD) 14.4% Be (90% TD) 16.1% PCA 31.9% He
Breeder III	51.0% Li_4SiO_4 (80% TD) 20.6% PCA 28.4% He

TBR vs. Breeder Zone I Thickness



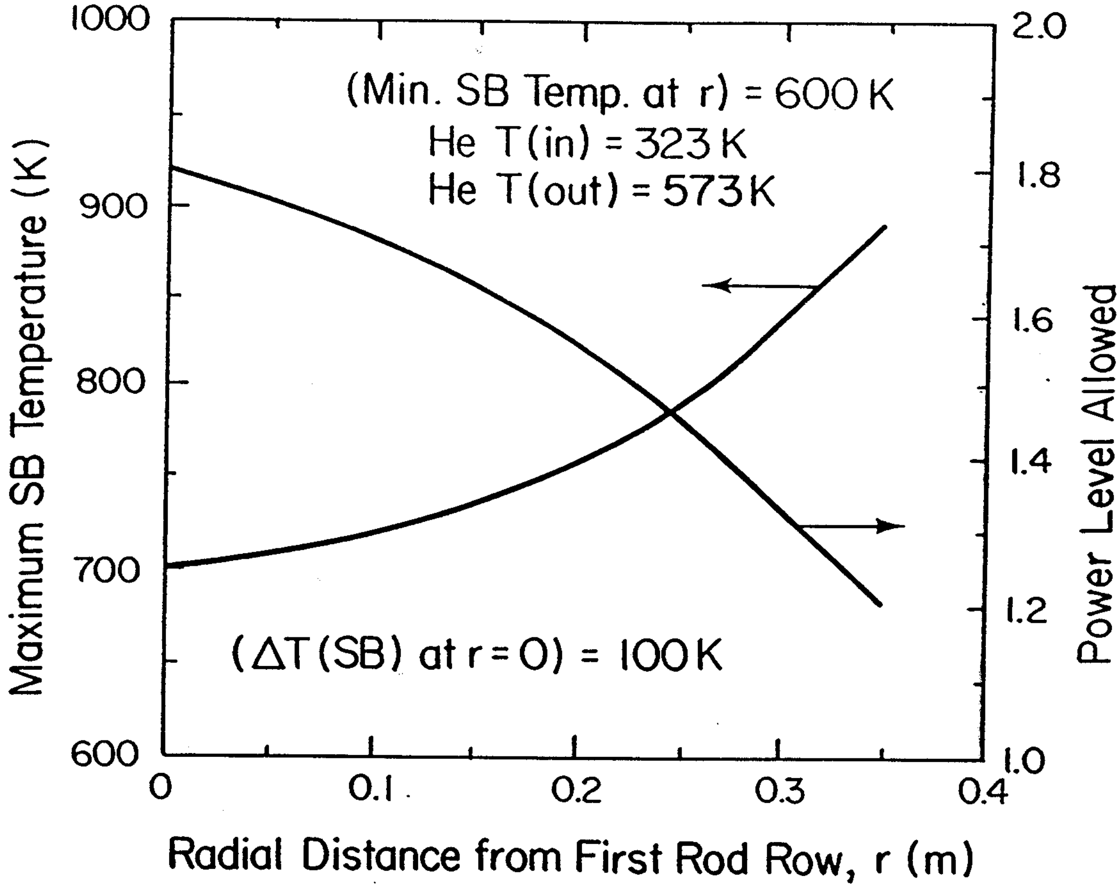


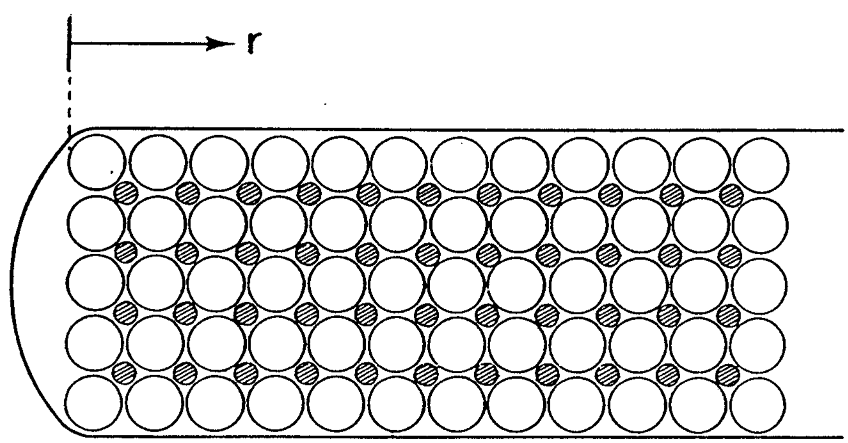
Configuration for 3-D Neutronics Calculations

He-Cooled SB Blanket Can Comfortably Meet ITER Tritium Breeding Needs

3-D Monte Carlo Results

Region	TBR
Outboard Blanket	1.01
Top Region	0.14
Inboard Shield	No Breeding
Lower Inner Corner	0.06
Lower Divertor	0.06
Total	1.27


(Min. SB Temp. at r) = 600 K
He T(in) = 323 K
He T(out) = 573 K
(ΔT(SB) at r=0) = 100 K
Maximum SB Temperature (K)
Power Level Allowed
1000
900
800
700
600
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
Radial Distance from First Rod Row, r (m)


r

Operating Temperatures (°C)

- Coolant

In/Out	50/300
(Pressure 1.5/1.4 MPa)	

- Breeder

Min./Max.	325/475

- Structure

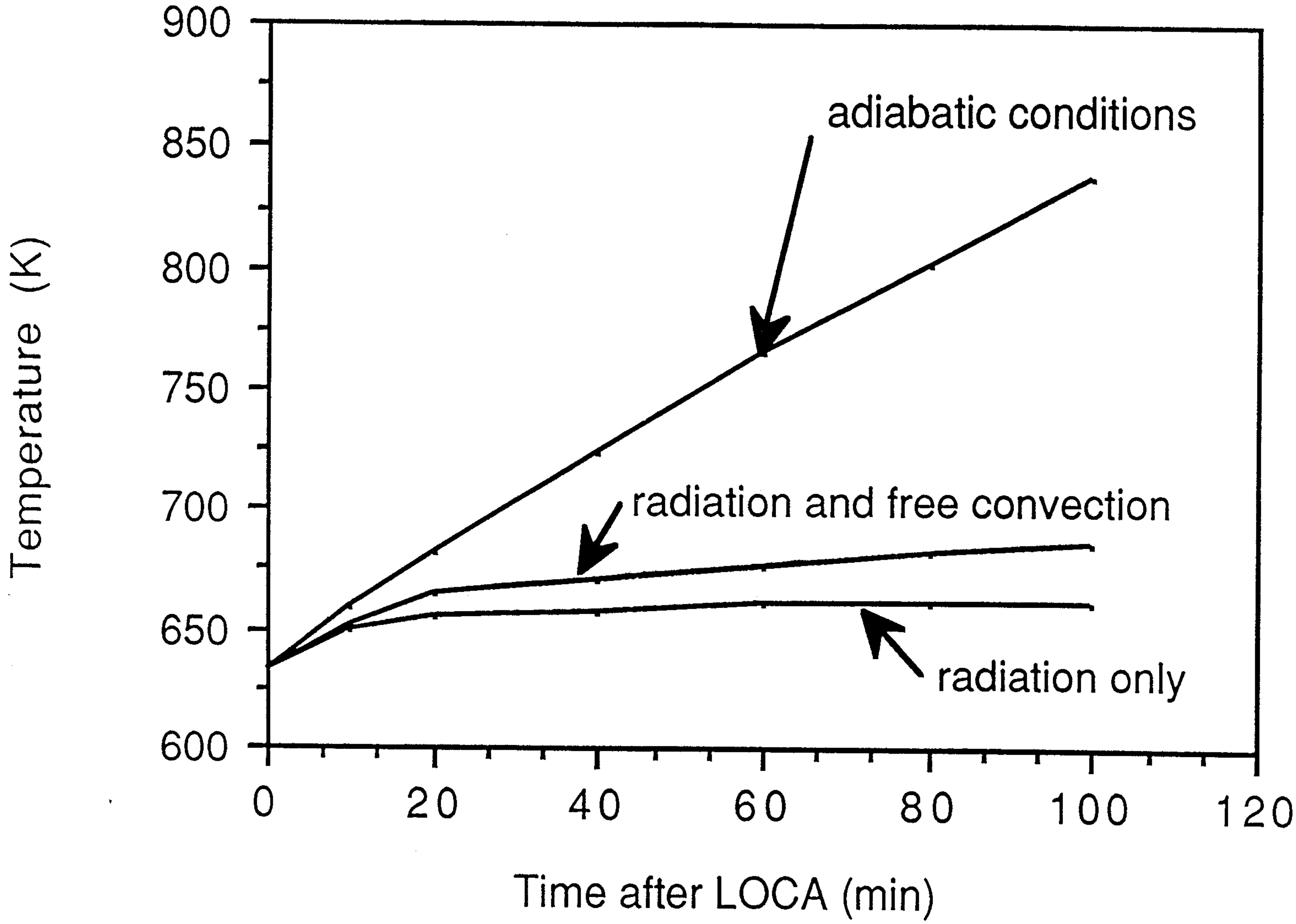
First Wall Max.	275
Coolant Interface Min/Max	50/300
Breeder Interface Min/Max	325/475
Multiplier Interface Min/max	150/475

Steady State Tritium Inventory in Li_4SiO_4 for Helium-Cooled Solid Breeder ITER Blanket

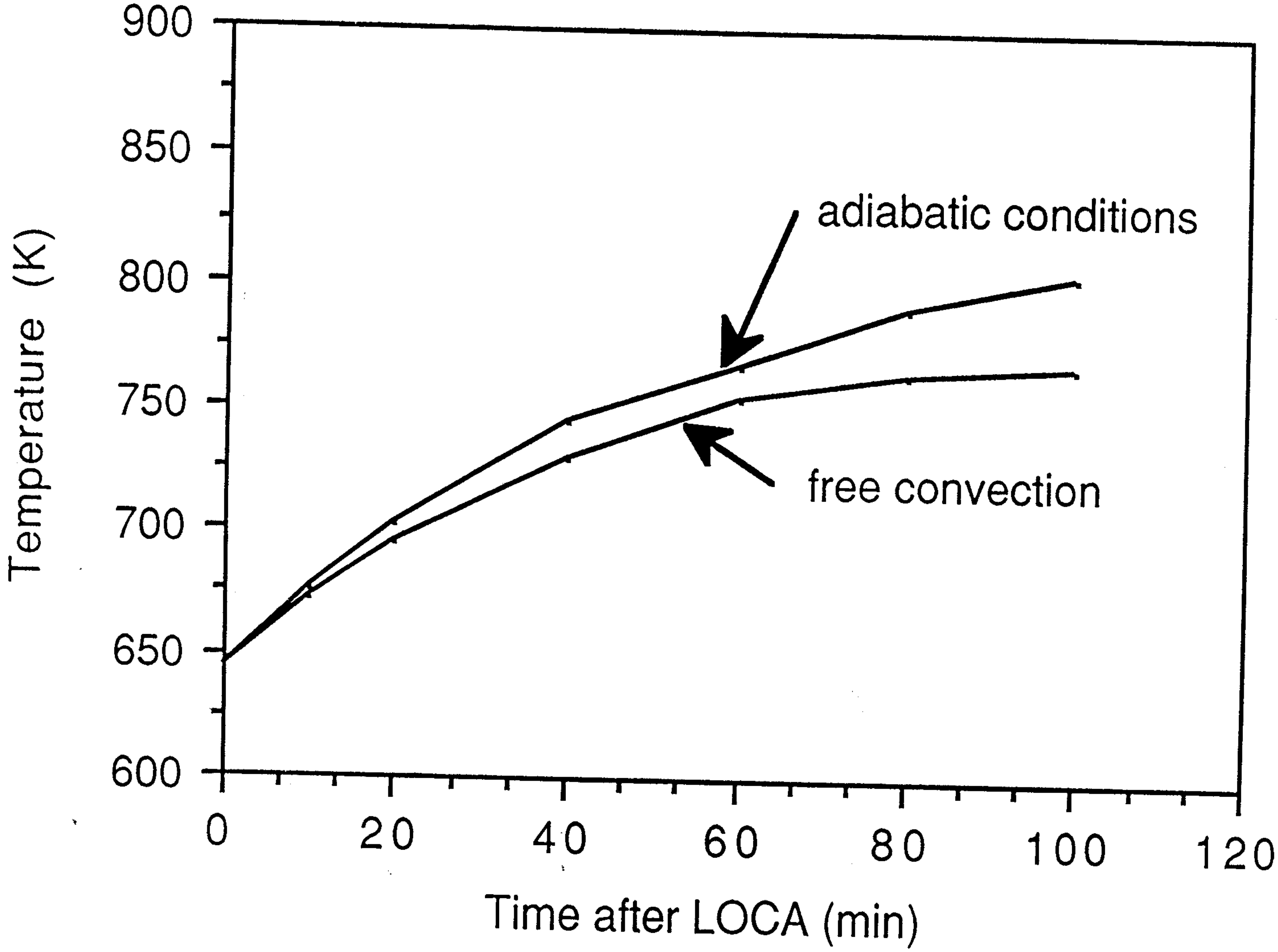
Diffusion	0.4 g
Solubility	1 g
Adsorption	0.1 g
TOTAL	1.5 g

Large margin for radiation effect uncertainty

First Wall Temperature after a LOCA



Solid Breeder Temperature after a LOCA



The He-Cooled Solid Breeder Rod Design is Very "Robust" Against Failures

- The rod design provides multiple barriers against contamination. (Also, there is a positive pressure difference into the purge system).

- The coolant is inert. Consequences of failure are not usually catastrophic. (Contamination is the more likely failure mode rather than acute failure).

- The rod design "dilutes" the source term. Each rod produces only about 1 g of tritium over the lifetime of the reactor (cf. 200 g inventory limit in H_2O). For non-fatal failures, increasing the number of rods can actually decrease the probability of exceeding contamination limits.

Concluding Remarks

He-Cooled Solid Breeder Blanket is a Very Attractive Candidate for ITER

- It Can Meet all Absolute Requirements

- Substantial Safety Advantages
  - Inert helium gas and low activation Li_4SiO_4
  - Minimization of tritium leakage
  - Robustness in ability to withstand failure
  - Possibility of passive LOCA accommodation

- Large Design Margin, Flexibility for Power Variation
  - Large SB temperature window
  - Pressure virtually decoupled from temperature

- Reactor-Relevant Materials and Configuration
  - Reduces R&D requirement after ITER
  - Could also reduce the risk for DEMO

- Well-Studied Material and Configuration with Expanding Data Base

- Innovative, Practical Concept for Gap Thermal Conductance