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Vugraphs

Workshop on Beryllium for Fusion Applications

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ABSTRACT

Optimization of Beryllium for Fusion Blanket Applications

by

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The primary function of beryllium in a fusion reactor blanket is neutron multiplication to enhance tritium breeding. However, because heat, tritium and helium will be generated in and/or transported through beryllium and because the beryllium is in contact with other blanket materials, the thermal, mechanical, tritium/helium and compatibility properties of beryllium are important in blanket design. In particular, tritium retention during normal operation and release during overheating events are safety concerns. Accommodating beryllium thermal expansion and helium-induced swelling are important issues in ensuring adequate lifetime of the structural components adjacent to the beryllium. Likewise, chemical/metallurgical interactions between beryllium and structural components need to be considered in lifetime analysis. Under accident conditions the chemical interaction between beryllium and coolant and breeding materials may also become important.

The performance of beryllium in fusion blanket applications depends on fabrication variables (e.g., grain size, porosity, and impurity content) and operational parameters (heat generation rate and temperature profile, tritium generation rate profile, helium generation rate profile, displacement damage rate profile, external stresses, etc.). First the properties database is reviewed to determine our state of knowledge of beryllium performance as a function of these variables. Several design calculations are then performed to indicate ranges of fabrication and operation variables that lead to optimum beryllium performance. Finally, areas for database expansion and improvement are highlighted based on the properties survey and the design sensitivity studies.

DISCLAIMER

INTRODUCTION

- **Applications**

  - ITER/CDA

    Blanket multiplier and thermal barrier:
    68–85% dense sintered blocks (US)
    Pebble bed (JPN)

    Blanket multiplier:
    Dense hollow cylinder (EC)

  - EC/DEMO

    Blanket multiplier:
    Dense plates

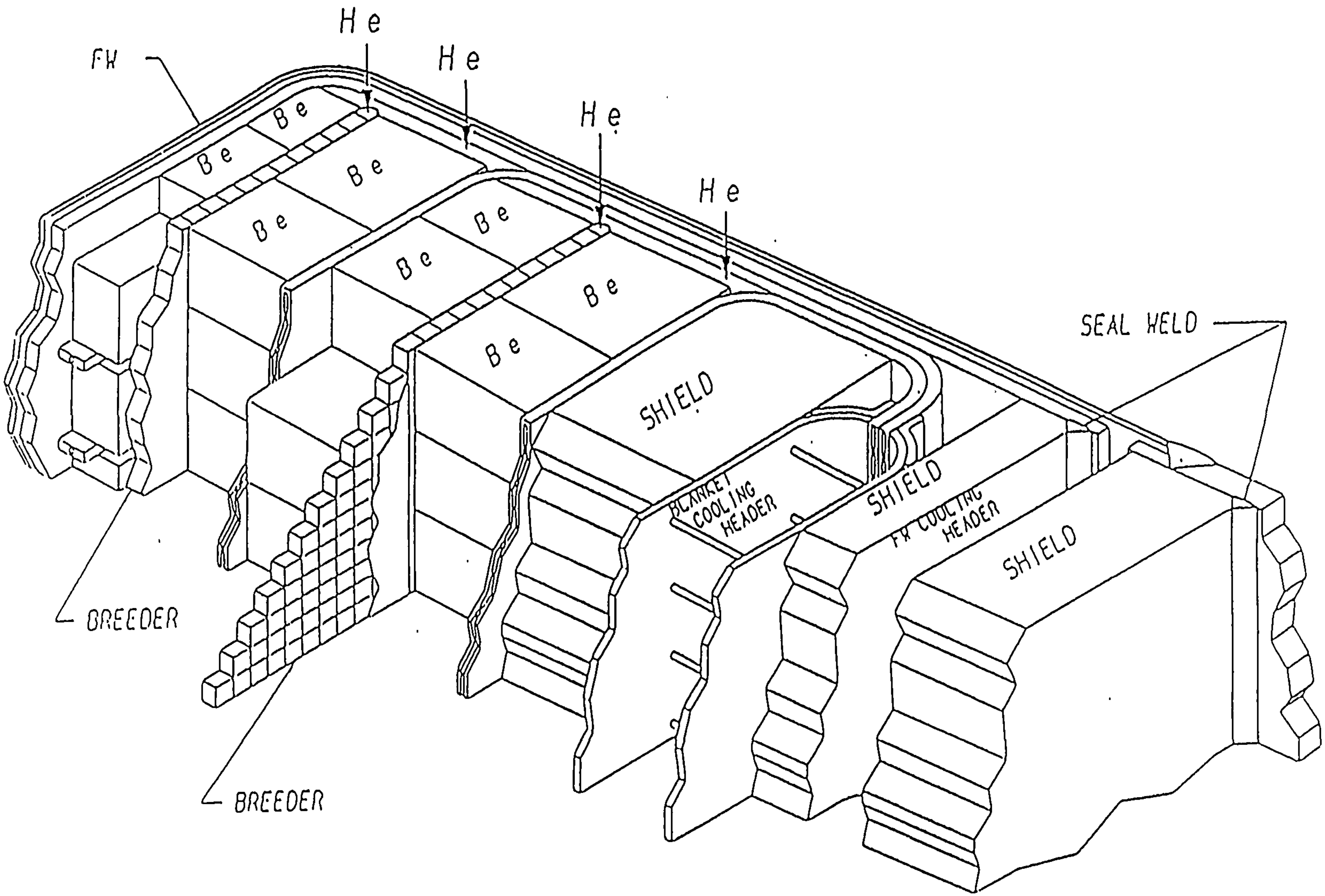
  - ITER/EDA

    Plasma facing component (PFC)

- **Performance Parameters**

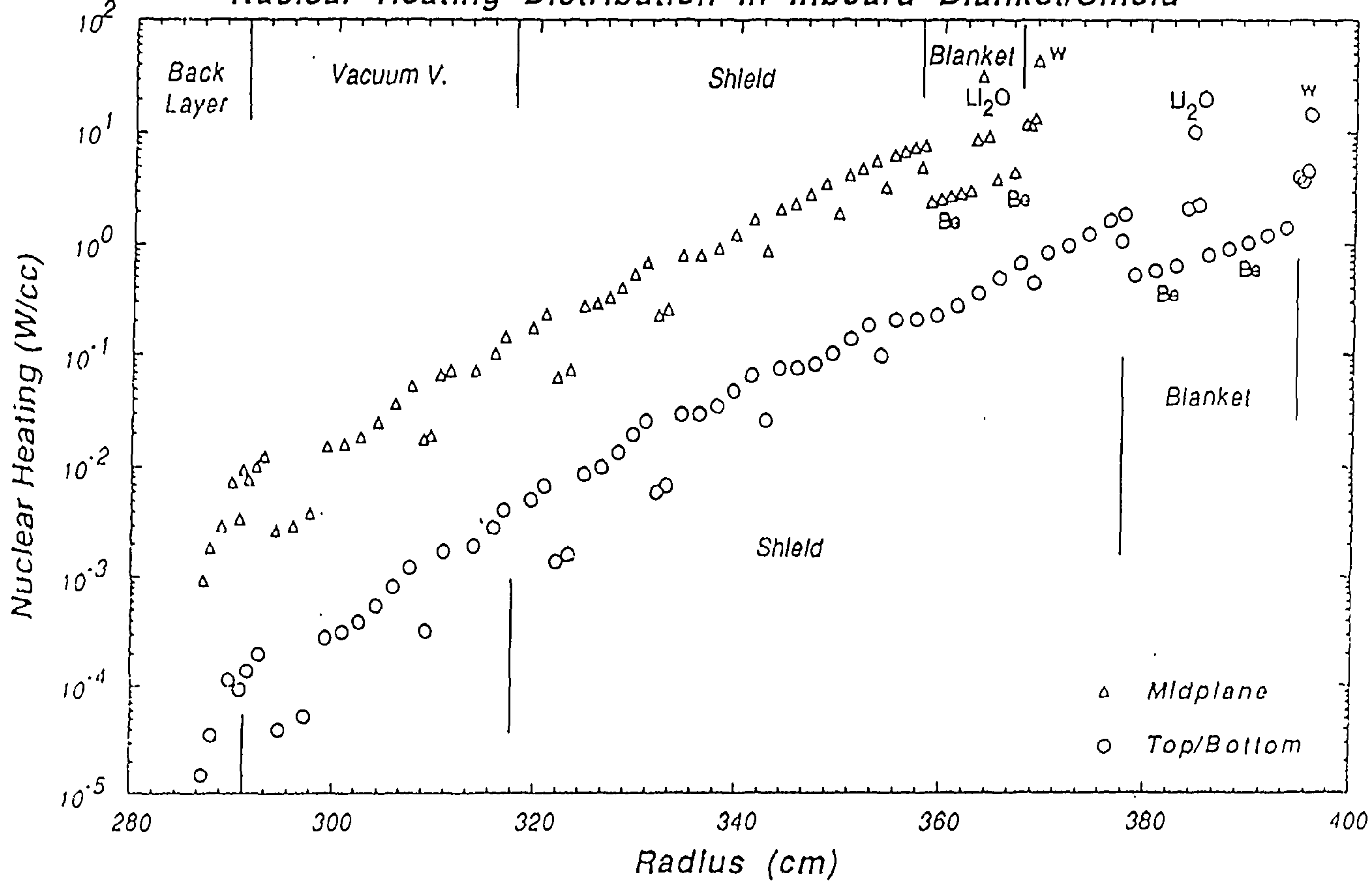
  - Thermal
  - Tritium
  - Helium
  - Mechanical
  - Compatibility

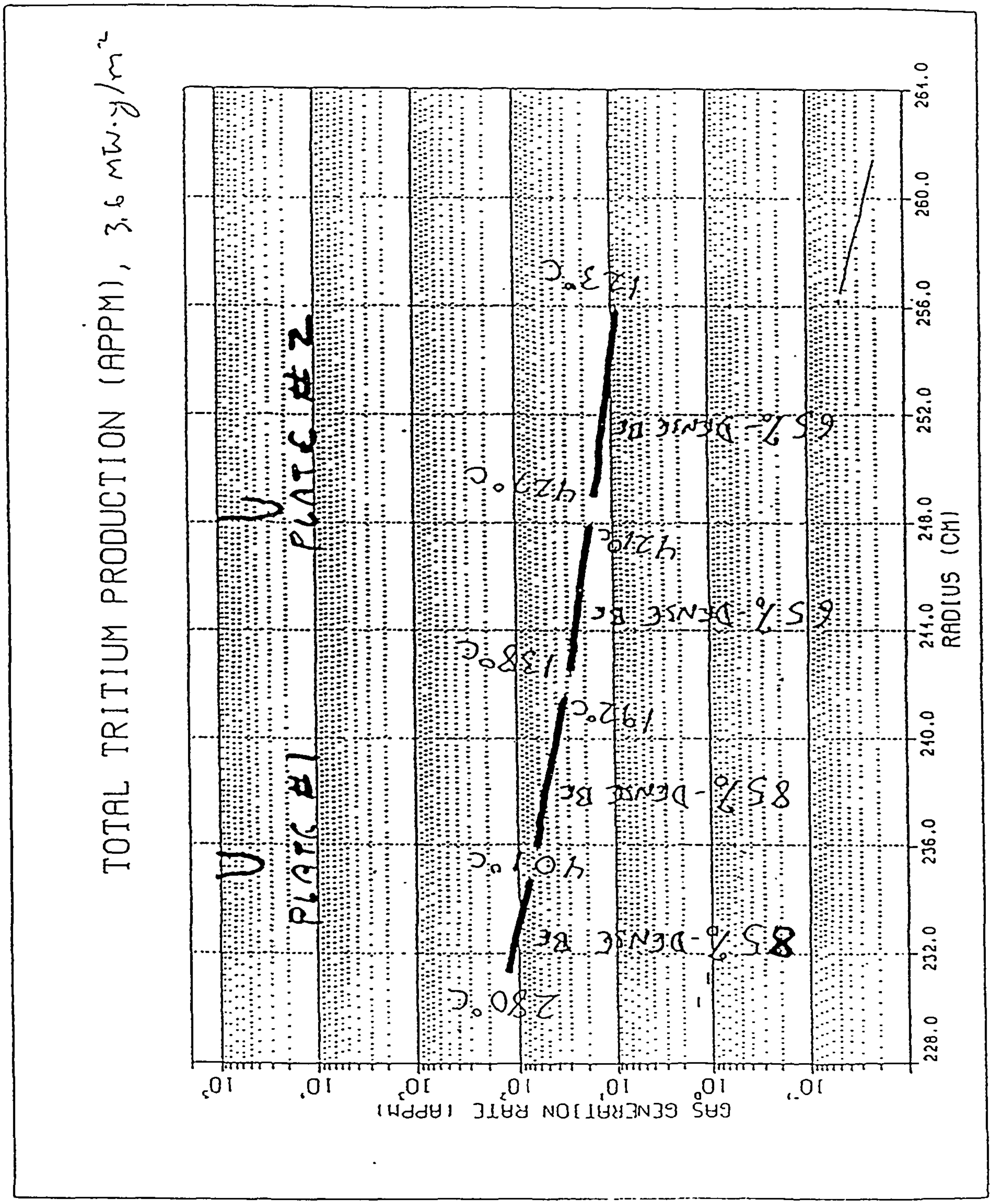
- **Optimization**

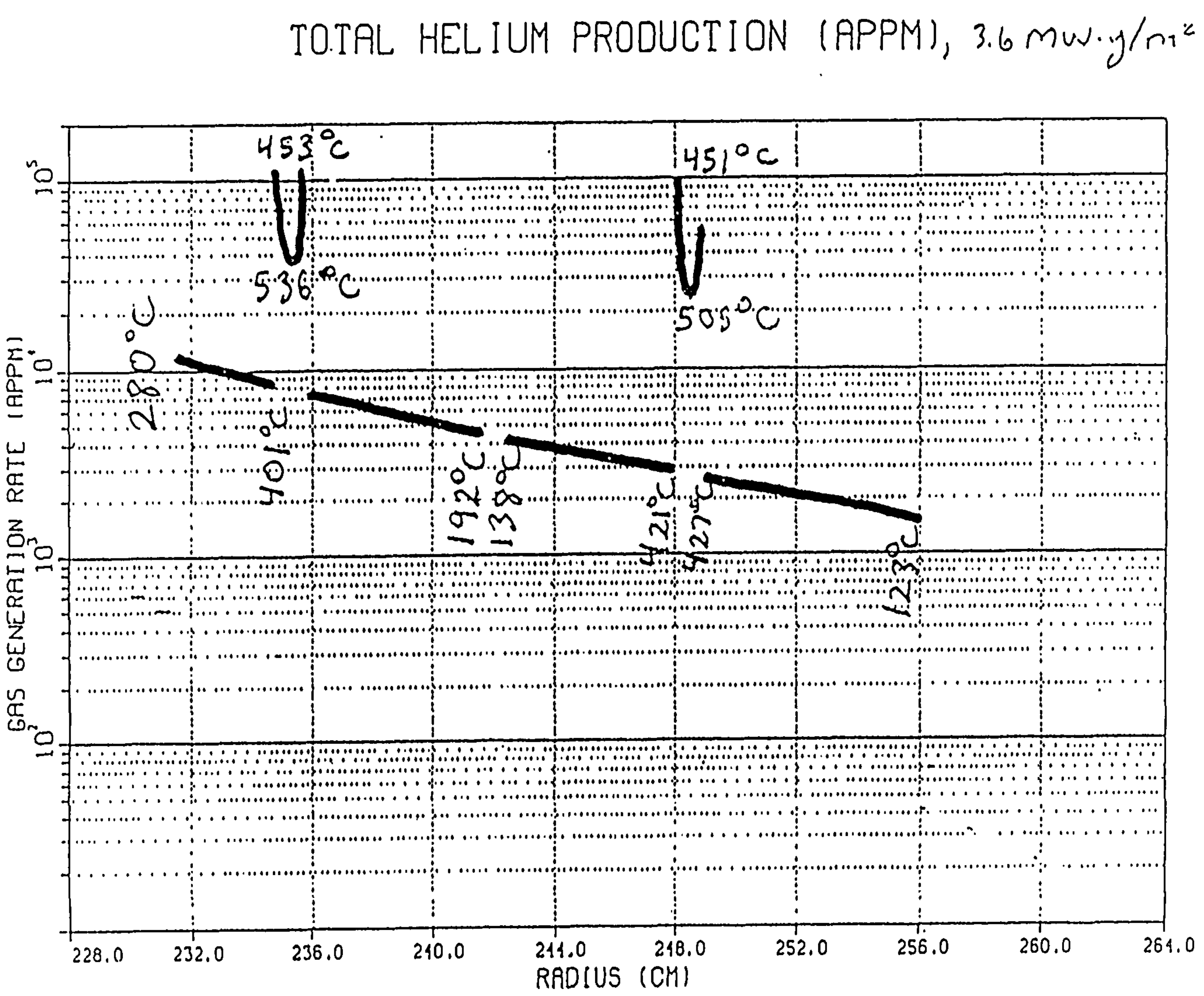


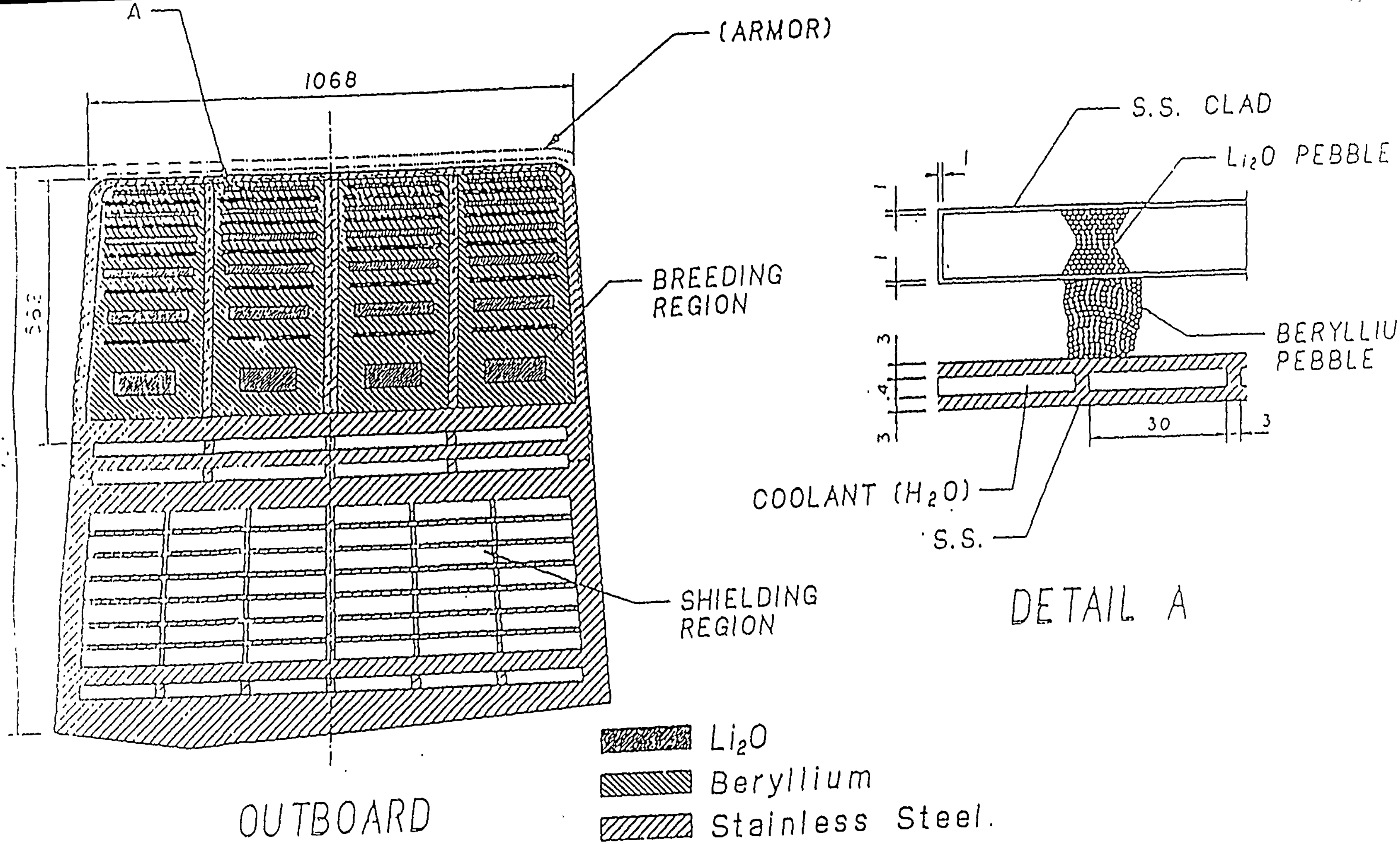
Layered ceramic blanket design.

Nuclear Heating Distribution in Inboard Blanket/Shield

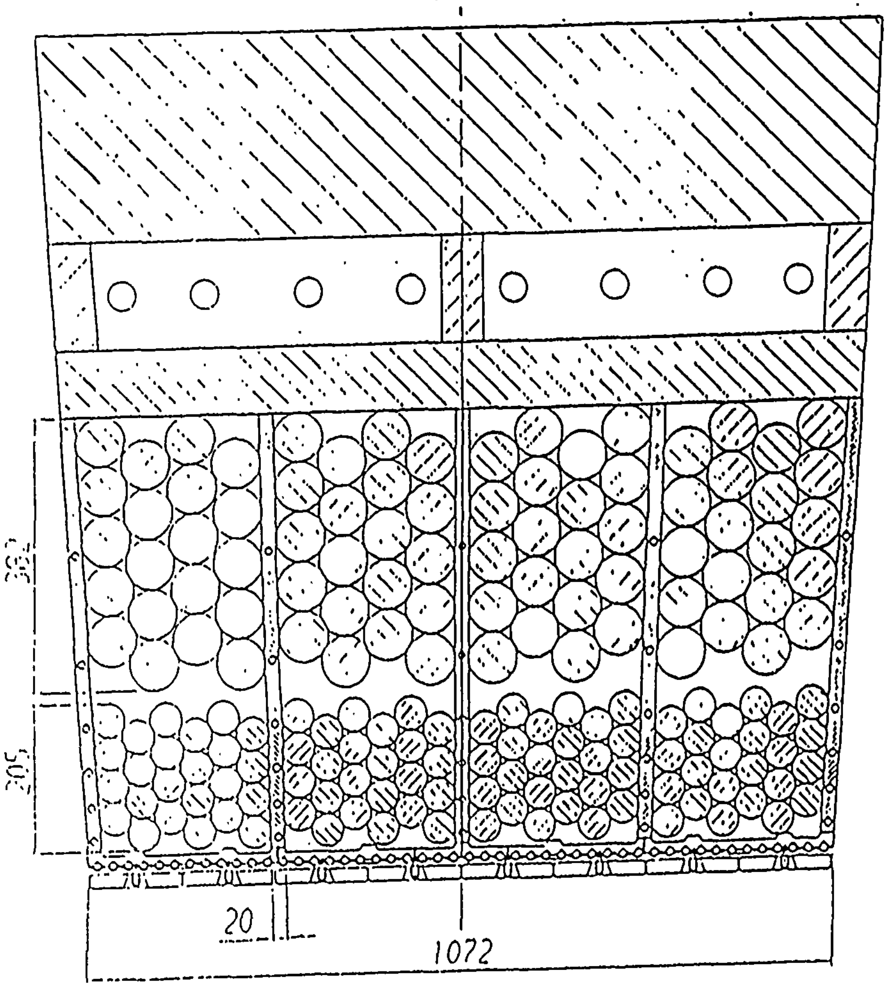



TOTAL TRITIUM PRODUCTION (APPM), 3.6 MW·y/m
PLATE #1
PLATE #2
85%-DENSE Be
65%-DENSE Be
280°C
192°C
138°C
421°C
429°C
123°C
RADIUS (CM)
GAS GENERATION RATE (APPM)

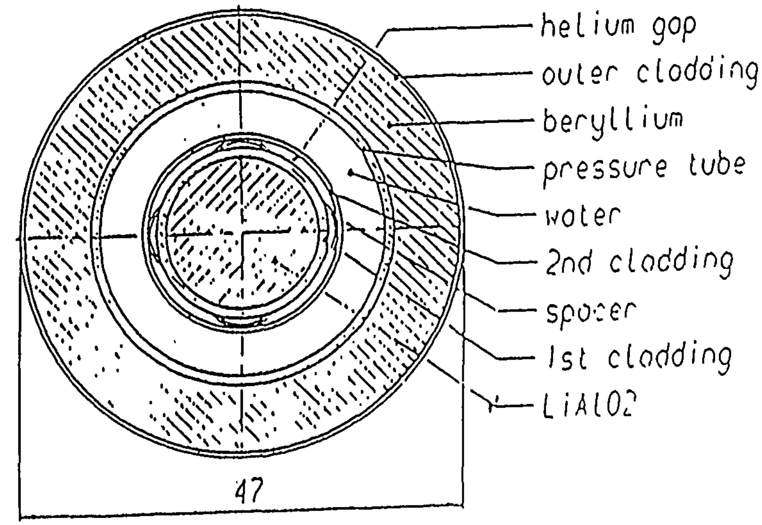

TOTAL HELIUM PRODUCTION (APPM), 3.6 MW·y/m²
GAS GENERATION RATE (APPM)
10^5
10^4
10^3
10^2
RADIUS (CM)
228.0
232.0
236.0
240.0
244.0
248.0
252.0
256.0
260.0
264.0
453°C
536°C
451°C
505°C
280°C
401°C
192°C
138°C
421°C
427°C
123°C



Ceramic blanket "layered" concept --pebble bed design--.

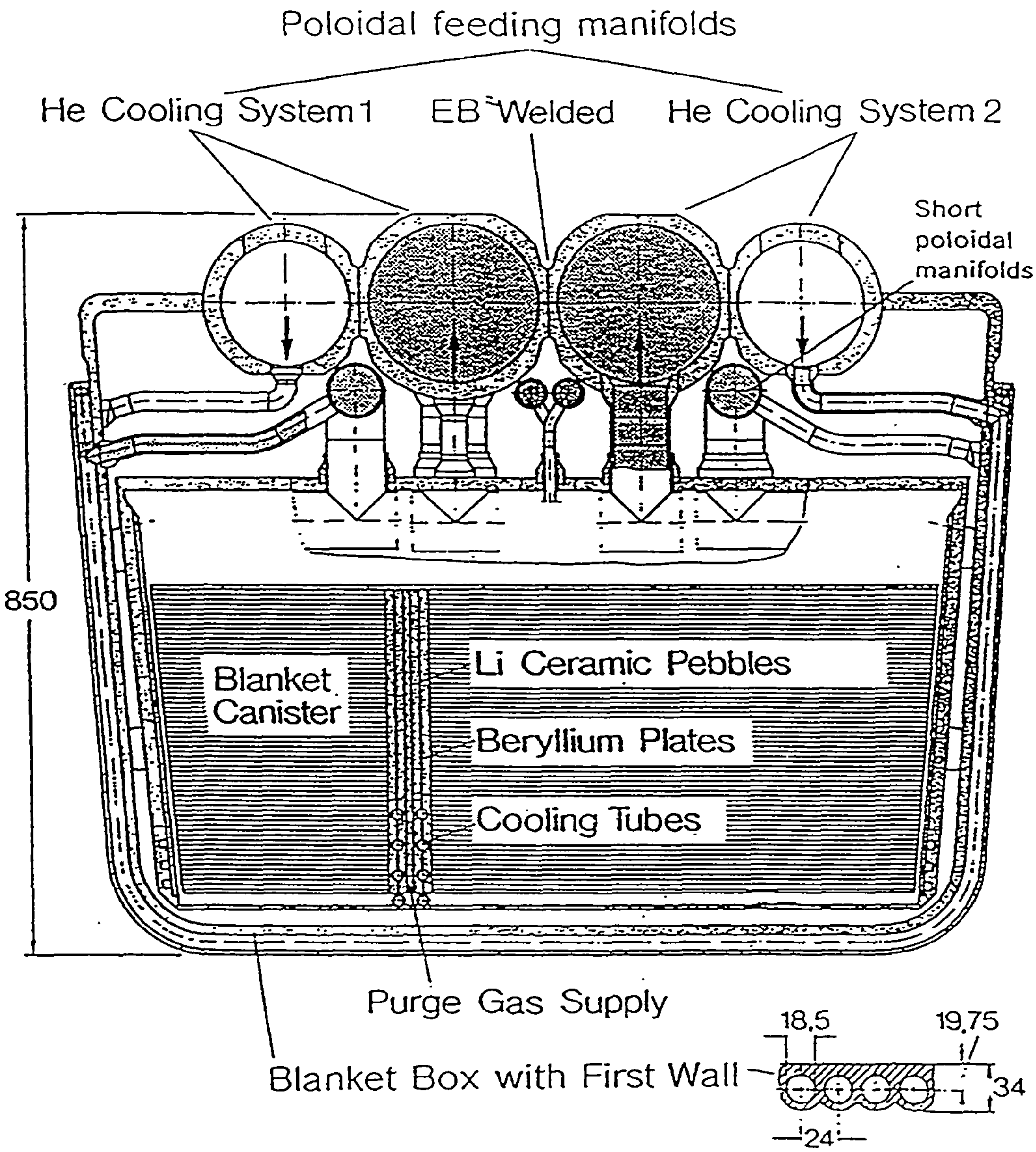


OUTBOARD BLANKET MIDPLANE SECTION



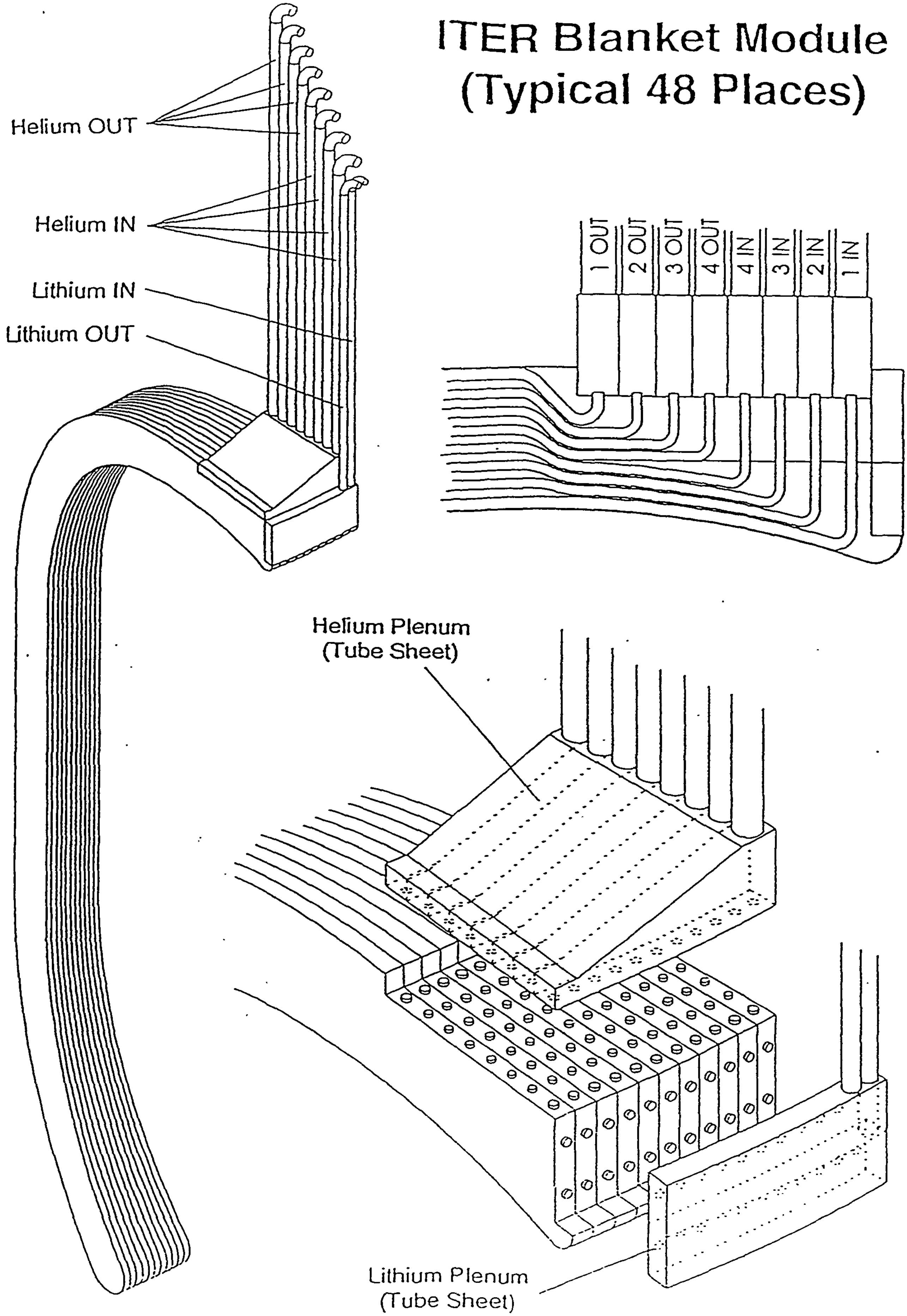
BLANKET MODULE - DETAIL

BIT blanket design.



Radial-toroidal cross section at the equatorial plane of the outboard blanket box and (below) radial-poloidal section of the first wall (dimensions in mm).

ITER Blanket Module (Typical 48 Places)



PERFORMANCE PARAMETERS

Thermal Performance

- 100% dense Be: thermal conductivity well characterized; no degradation with neutron damage
- Porous Be: some "holes" in the data base
- Pebble–bed Be: new data

• Tritium Performance

- 100% dense Be

  Diffusivity: difficult to measure; probably higher than for ceramics

  Solubility: difficult to measure; probably lower than for ceramics

  Trapping: chemical? neutron–damage–induced? He induced? Higher than for ceramics

- Porous Be (80% TD)

  Good tritium release

- **Helium Performance**

  - 100% dense Be

    Good swelling data base;~high He retention

  - Porous Be

    No swelling data base, high He retention

- **Mechanical Performance**

  - 100% dense Be

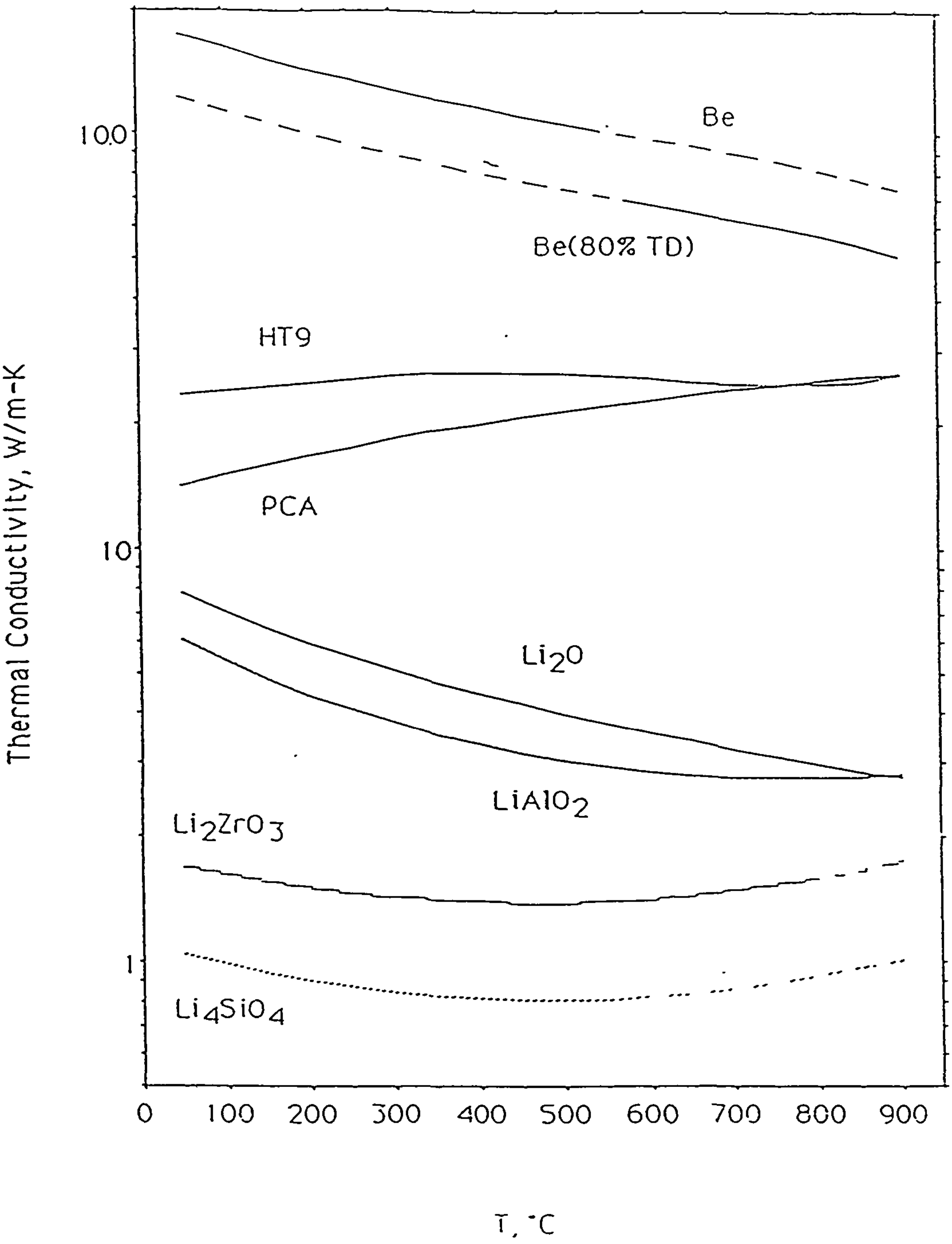
    Ductility very sensitive to impurities
    Neutron damage and He;
    No irradiation creep data

  - Porous Be

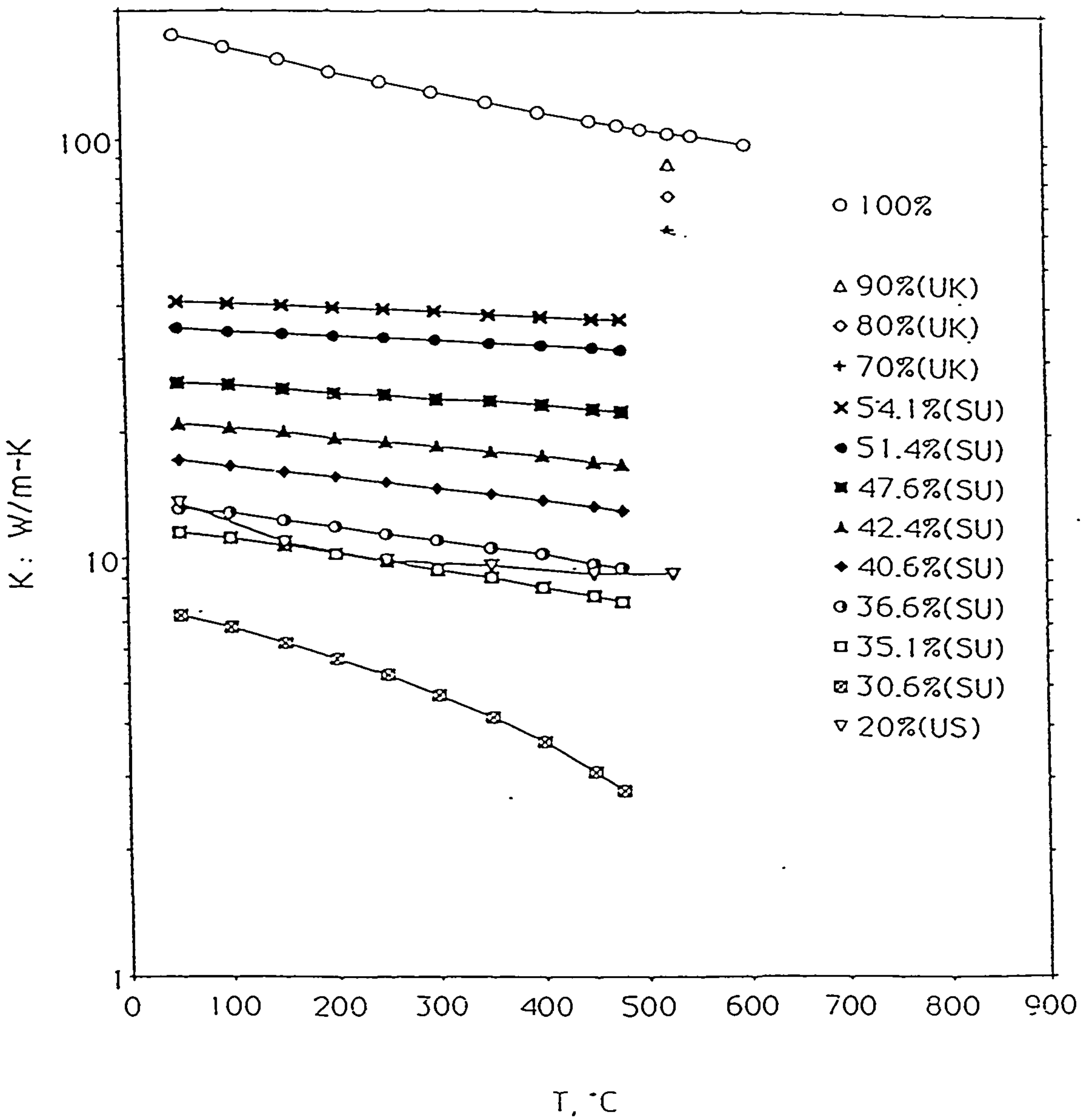
    Poor ductility; limited data base

- **Compatibility**

    Good data base

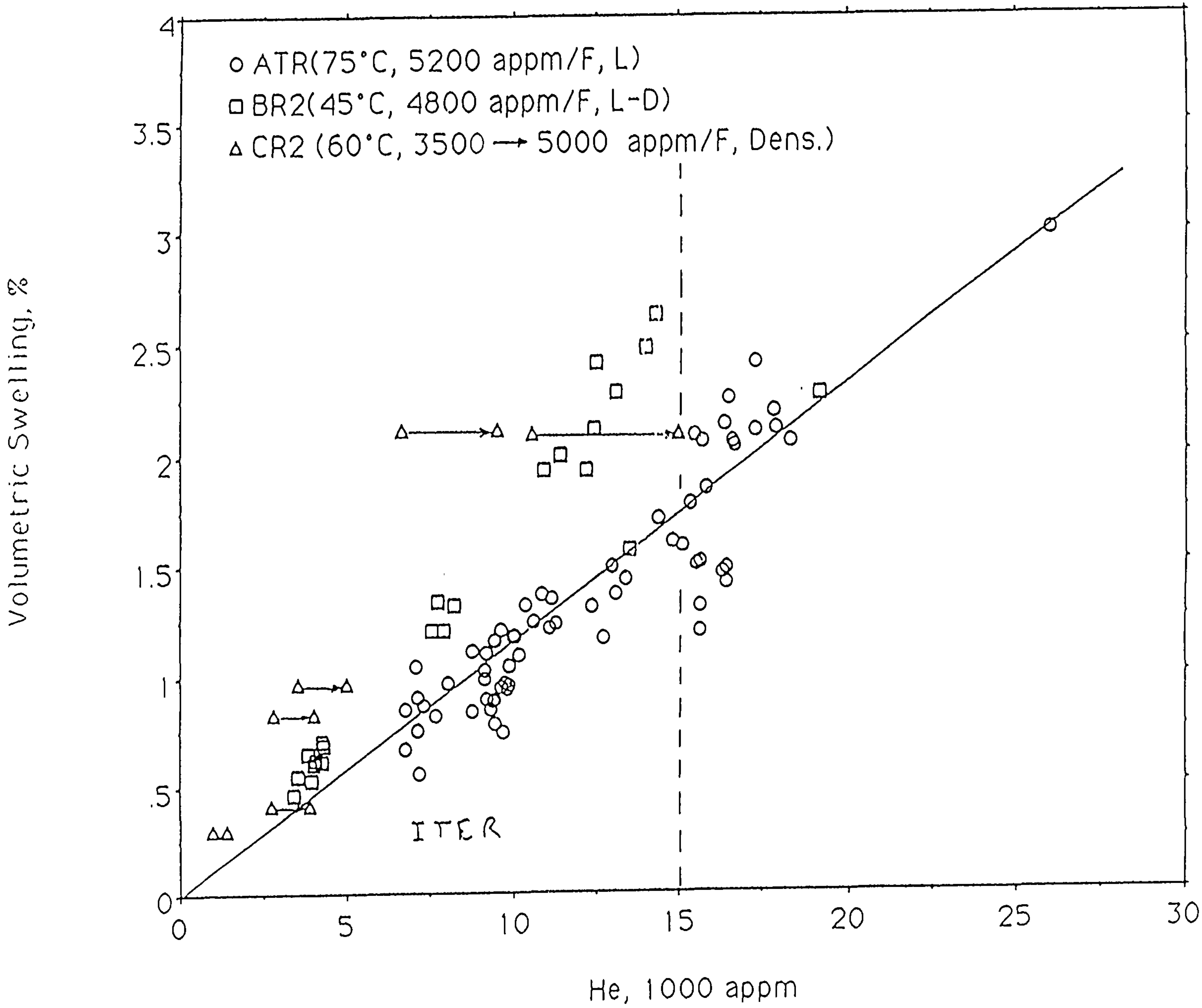


Thermal conductivity of 80%-dense solid breeder materials.

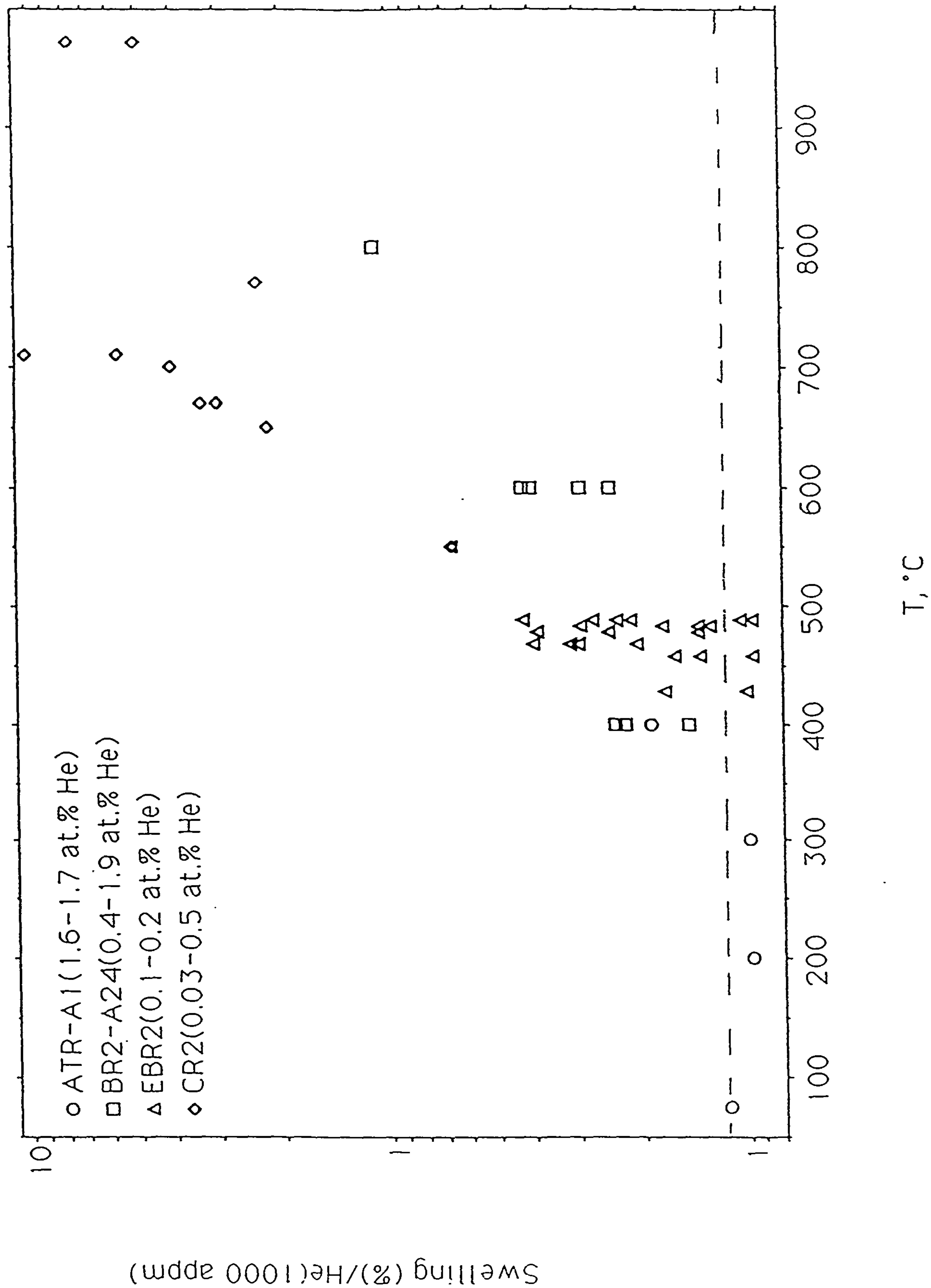


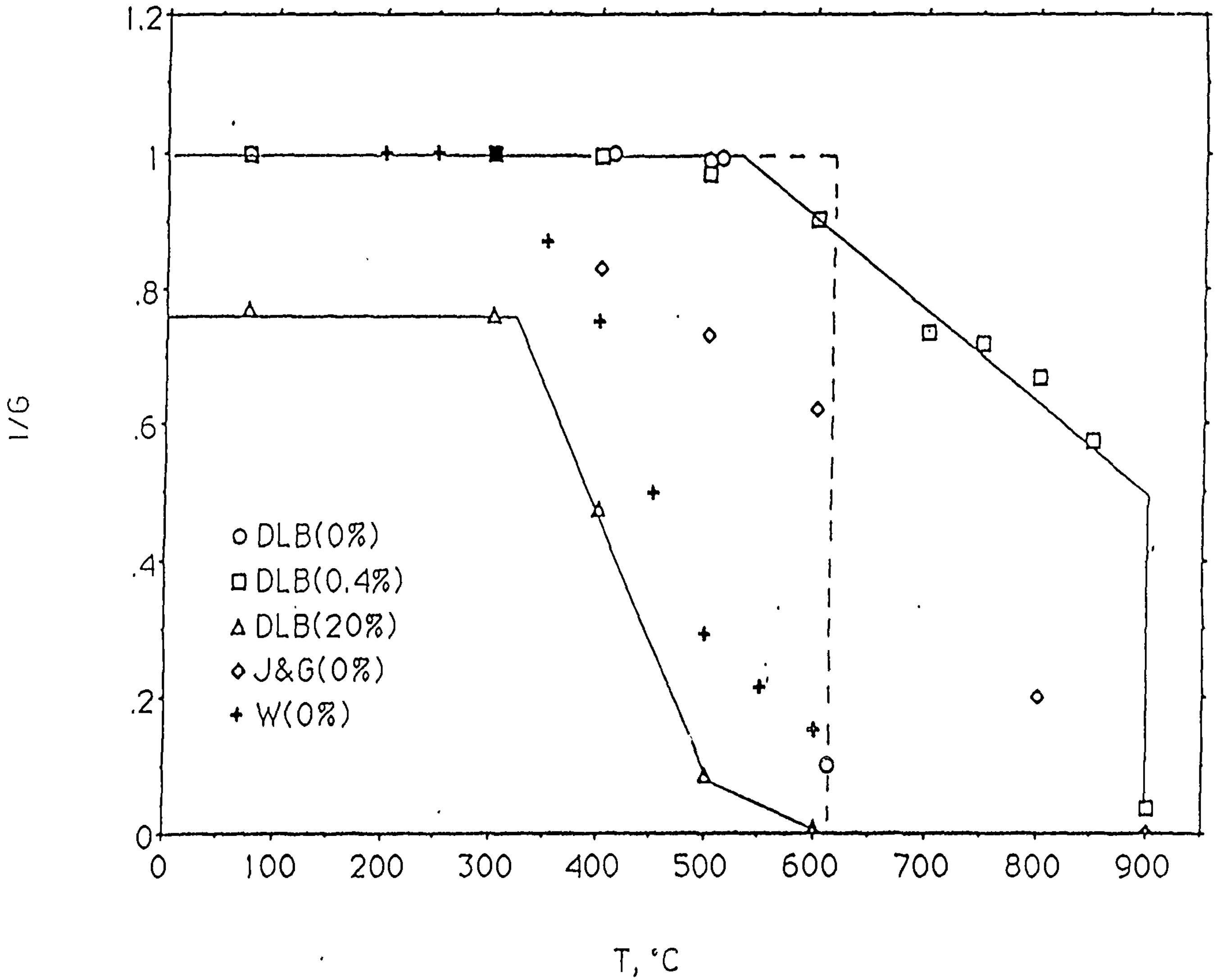
Beryllium thermal conductivity data vs. temperature and density (in % TD)

Low temperature swelling data for 100% dense, hot-pressed beryllium.

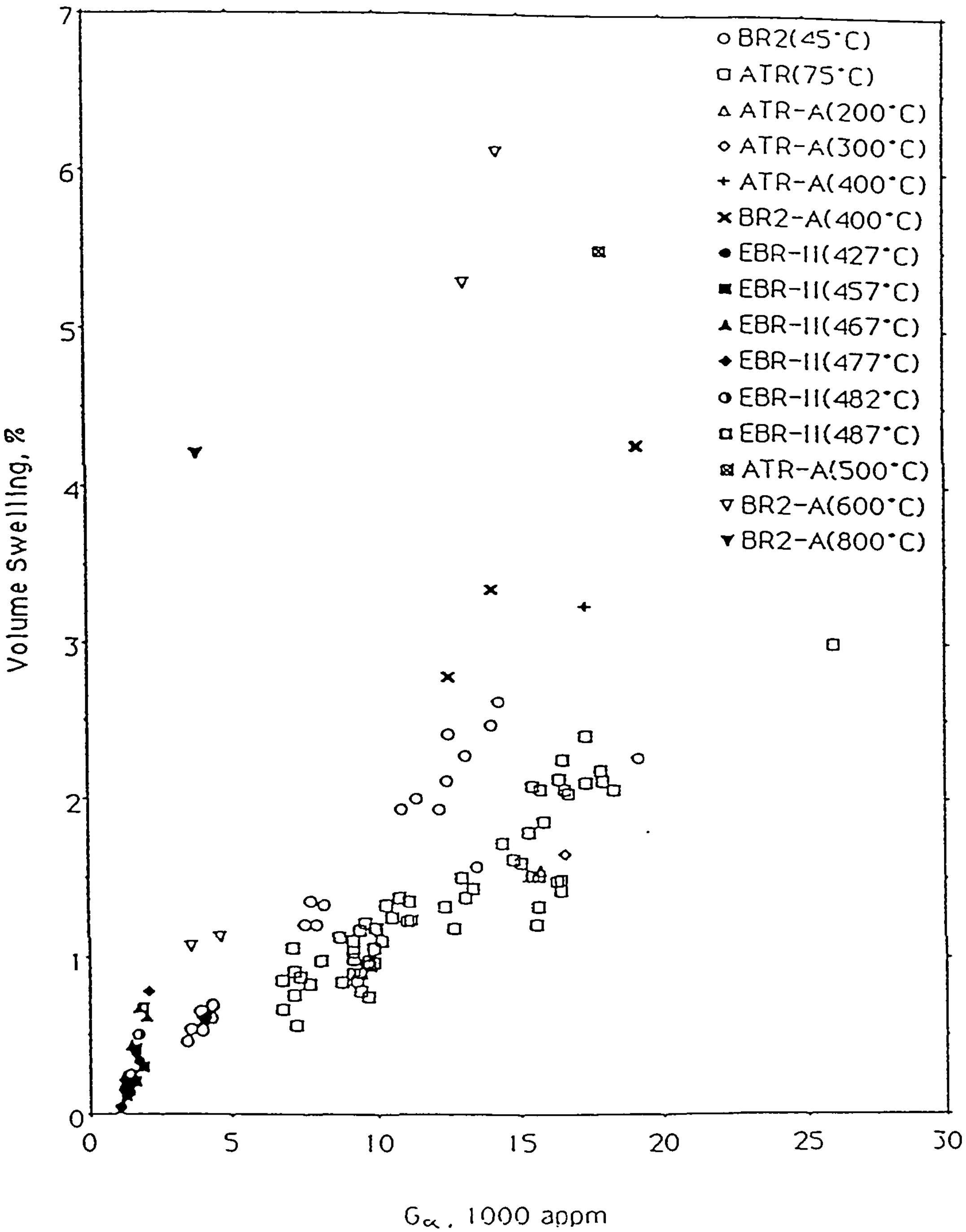


High temperature swelling data for 100 % dense, hot-pressed beryllium.

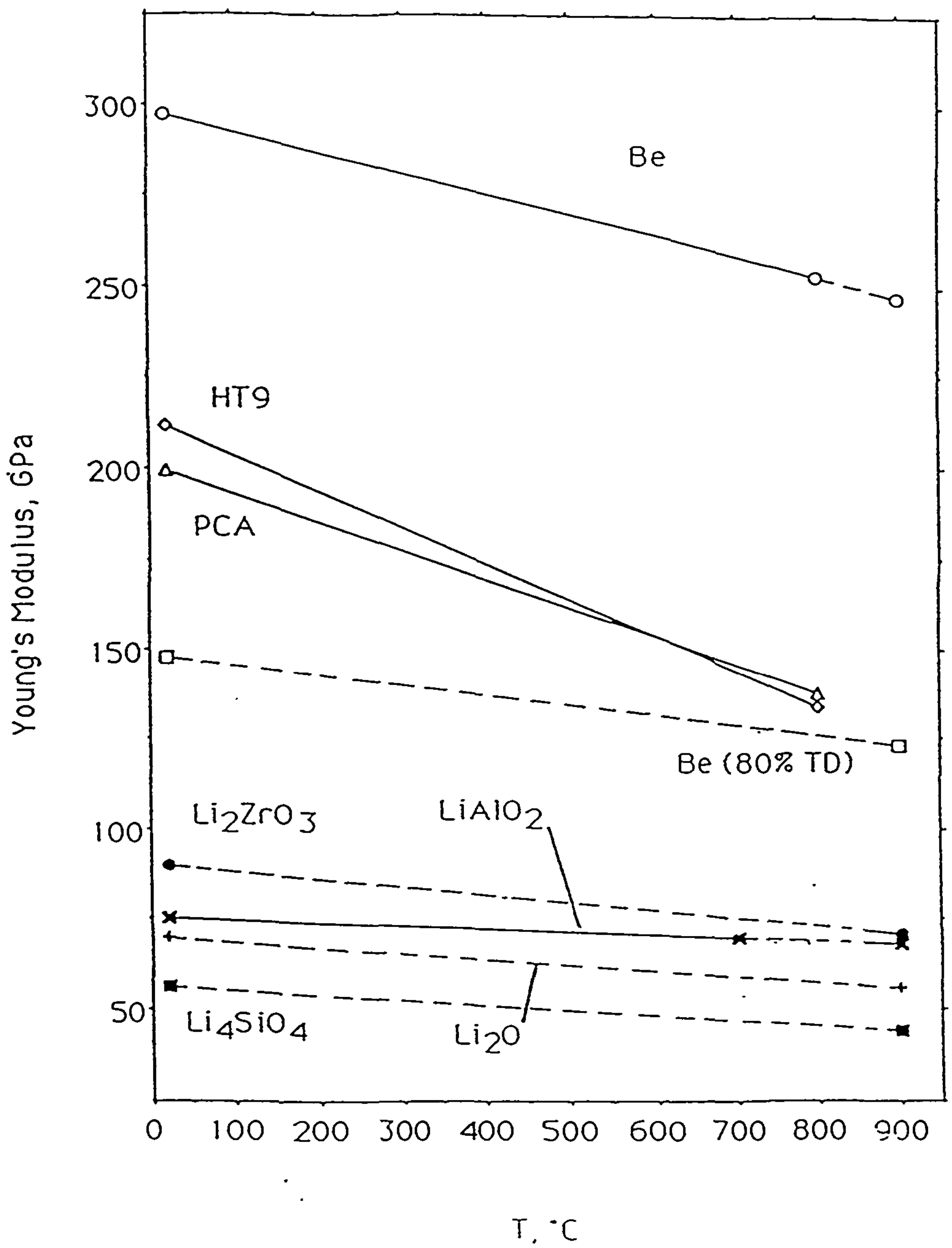




Laboratory annealing data for fractional tritium retention in dense and porous Be.



Swelling data for 100% dense hot-pressed beryllium.



Young's modulus of 80%-dense solid breeder materials

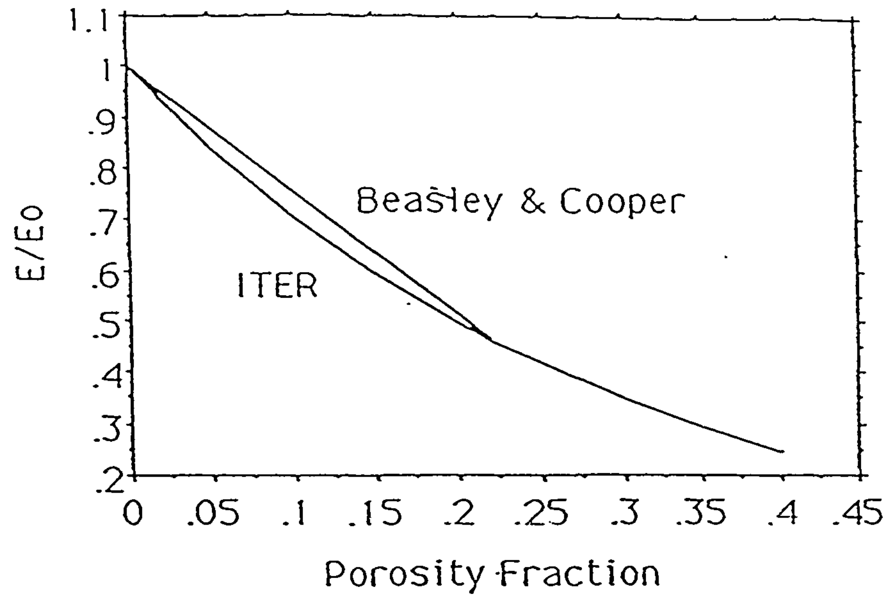
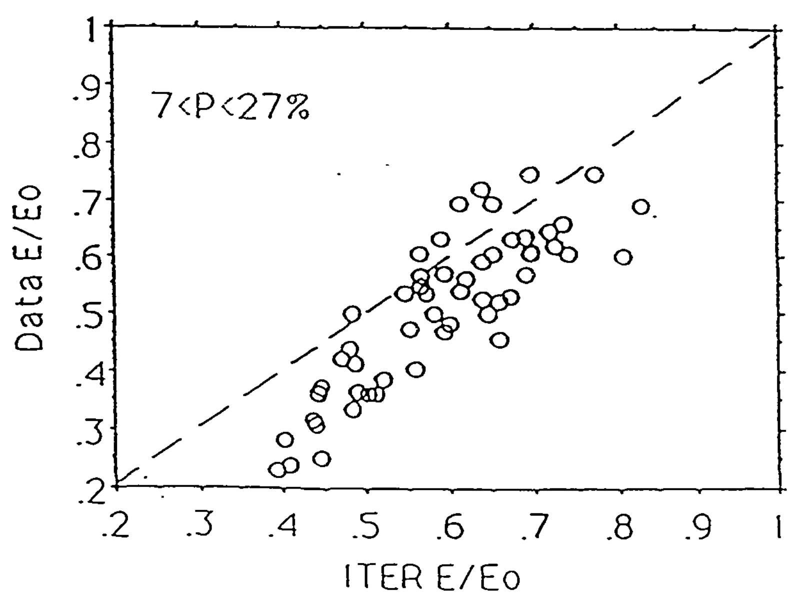
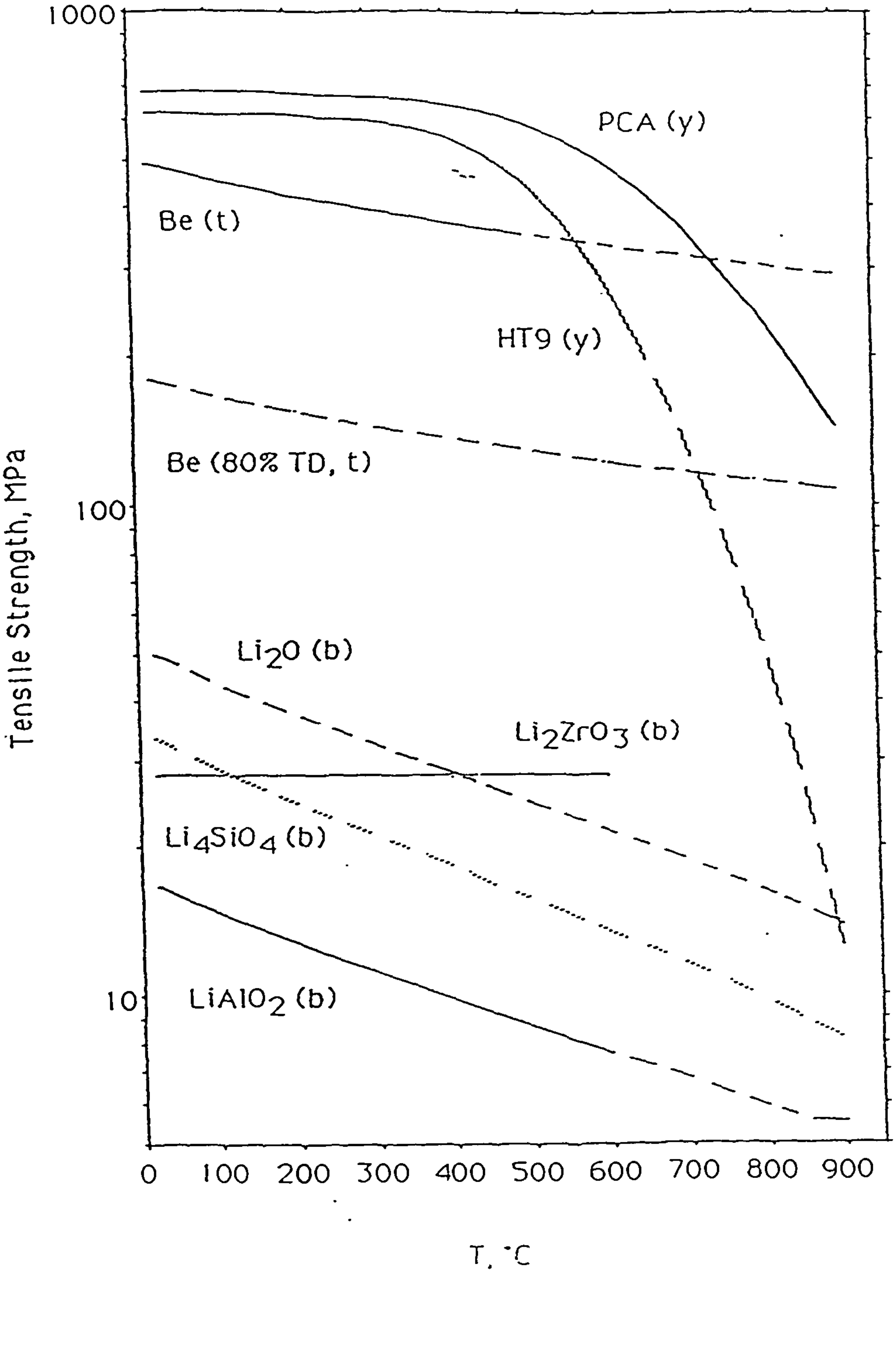


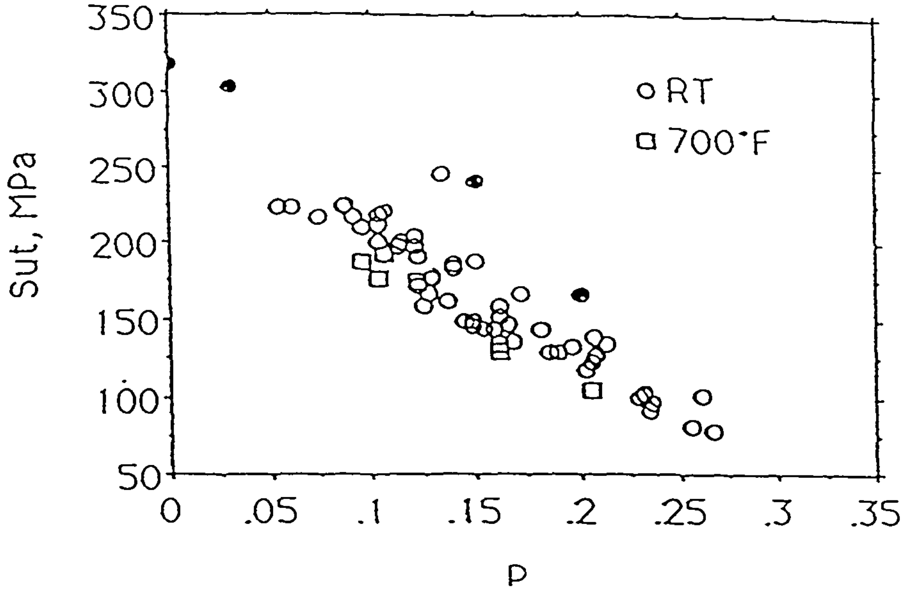
Figure 41a. Porosity dependence of Young's modulus for Be at room temperature.



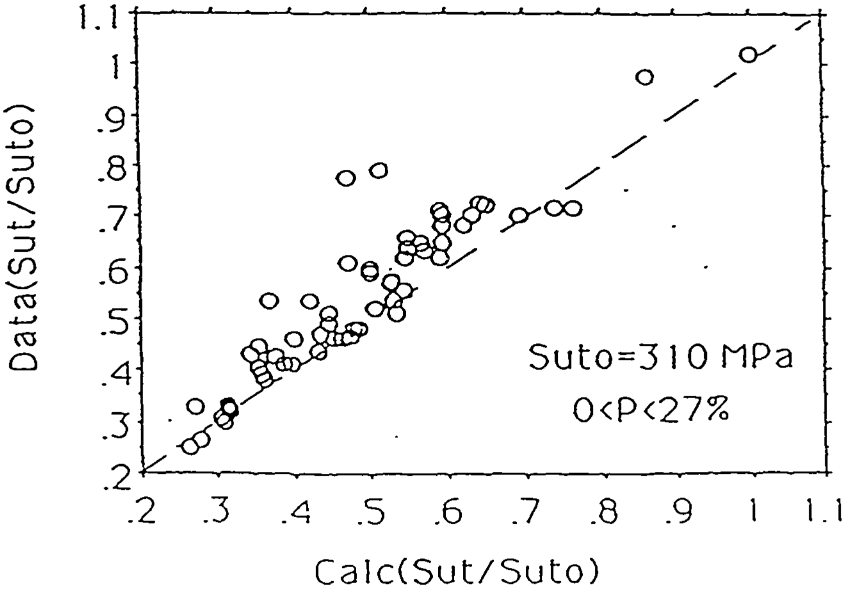
Comparison of ITER correlation to data for E/Eo for 0.07<P<0.27.



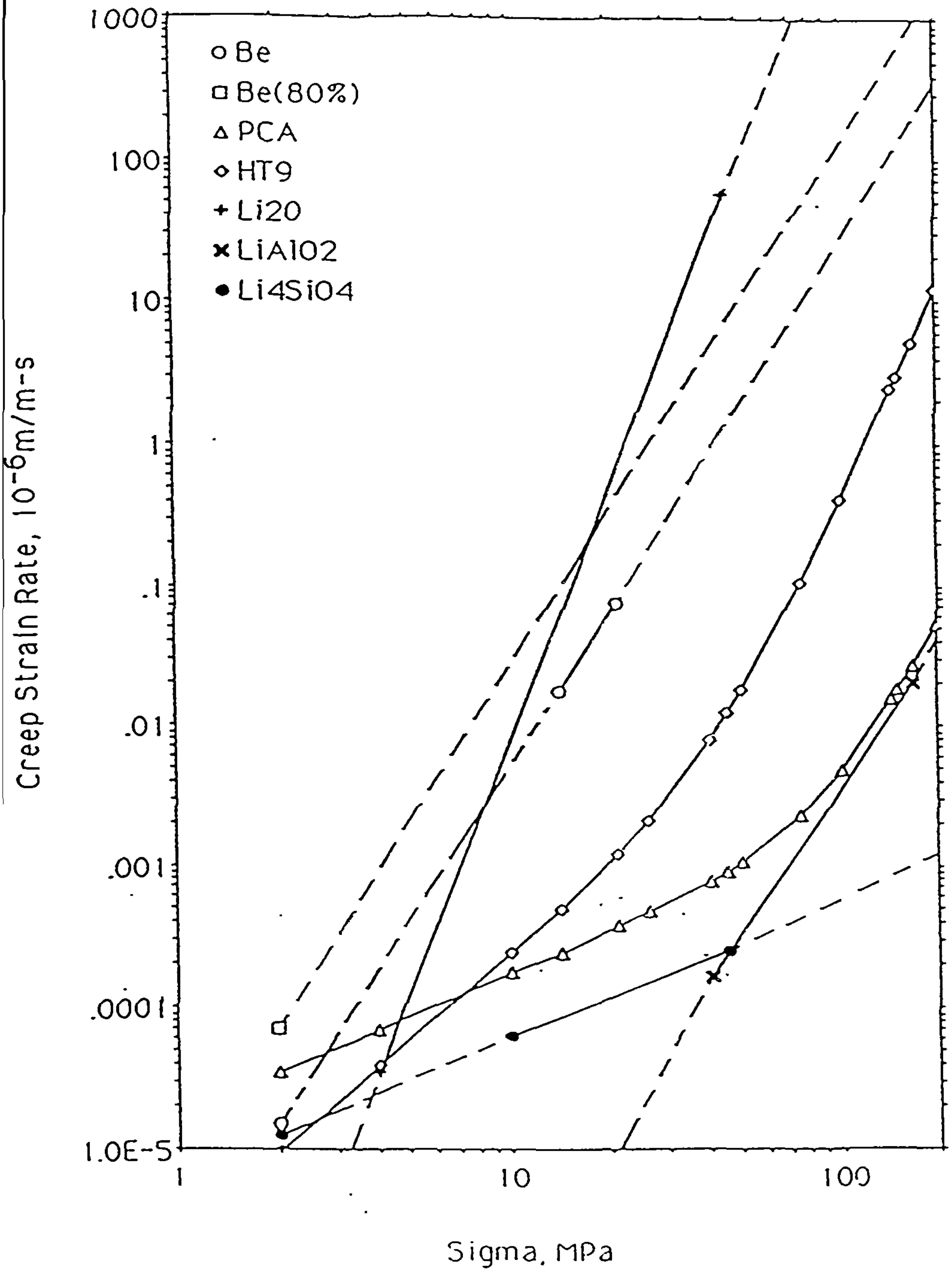
Bending (b) strength of 80%-dense, 10-micron grain size breeder materials.



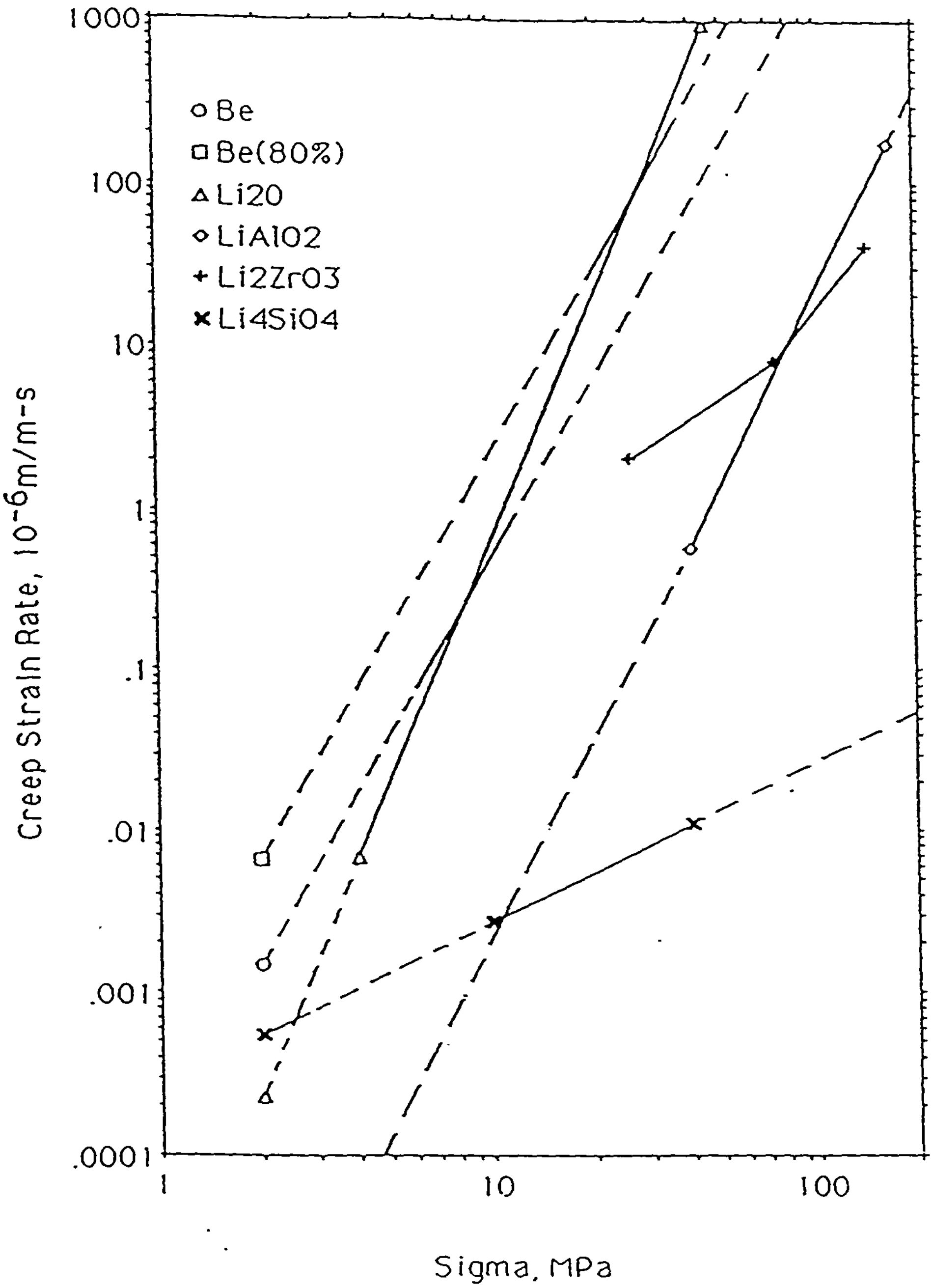
Ultimate tensile strength data for CIP/S Be vs. porosity (P).



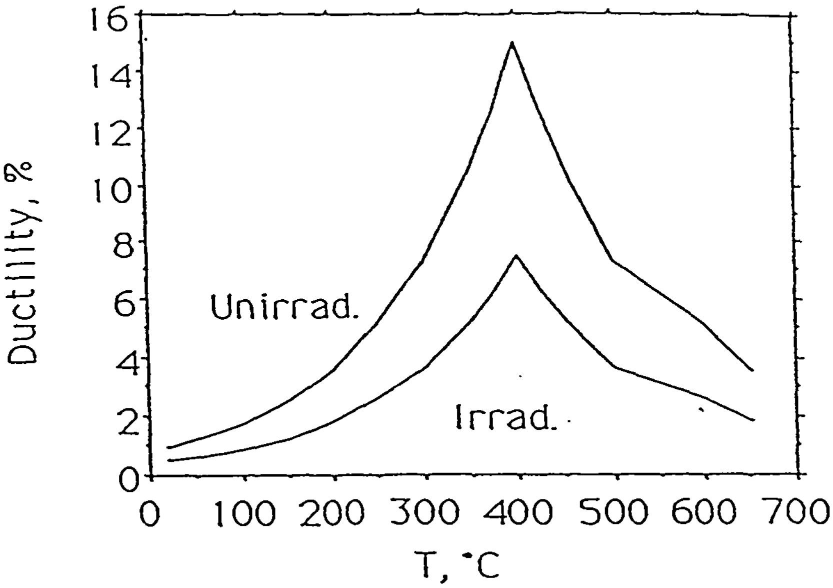
Comparison of ITER correlation to data for RT tensile strength.



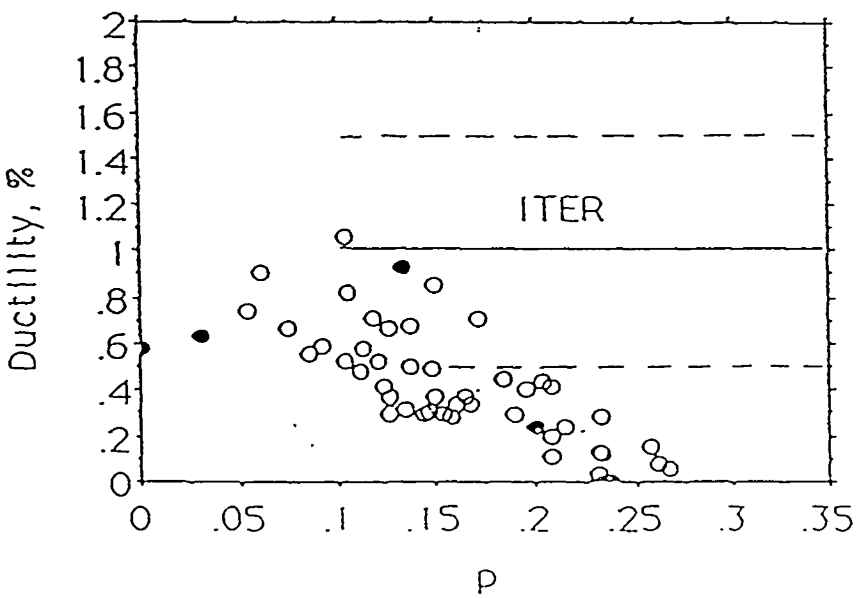
Thermal creep strain rate of 80%-dense breeder materials (700°C).



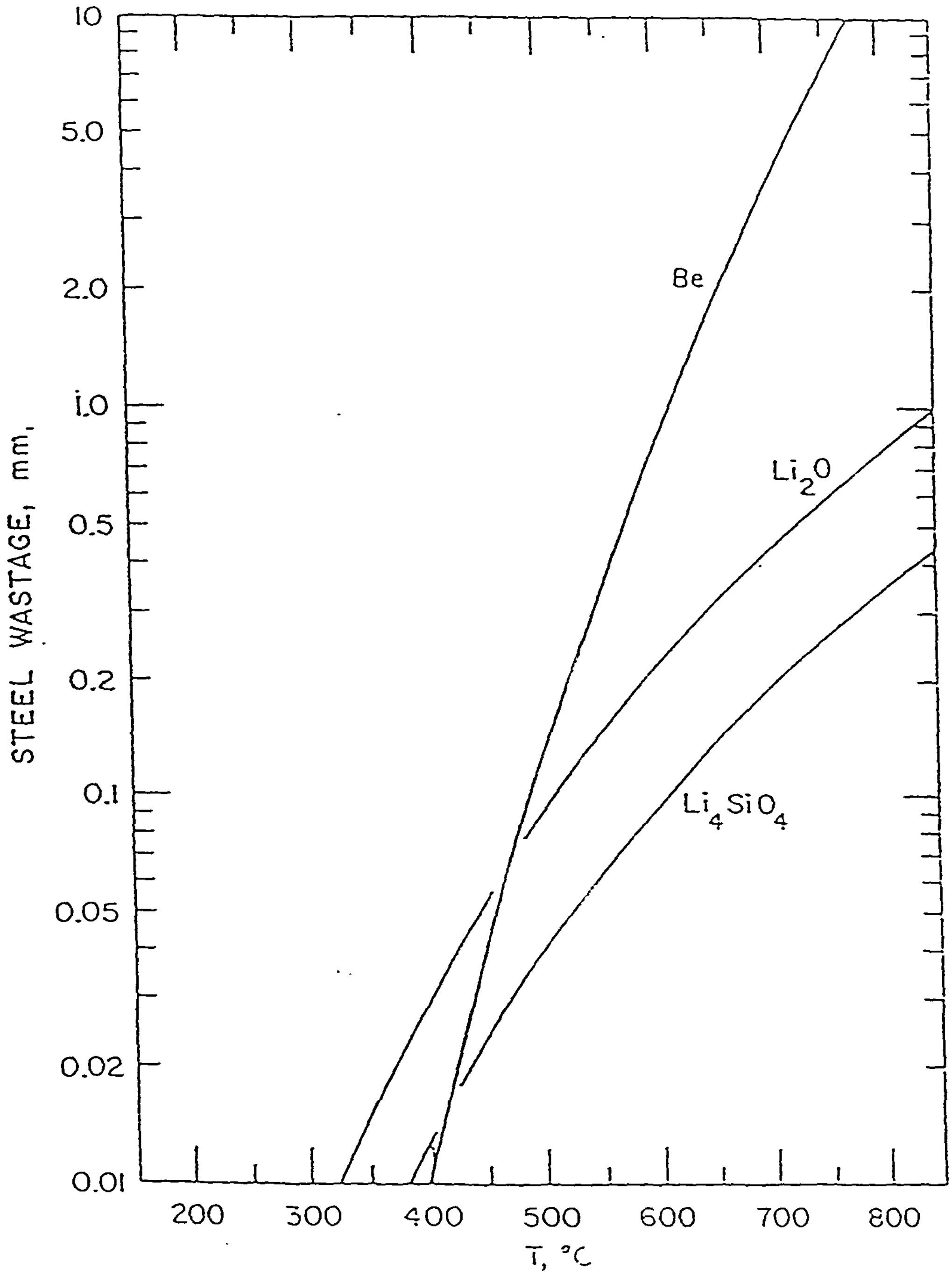
Thermal creep strain rate of 80%-dense breeder materials (900°C).



ITER correlation for Be ductility with porosity > 10%.

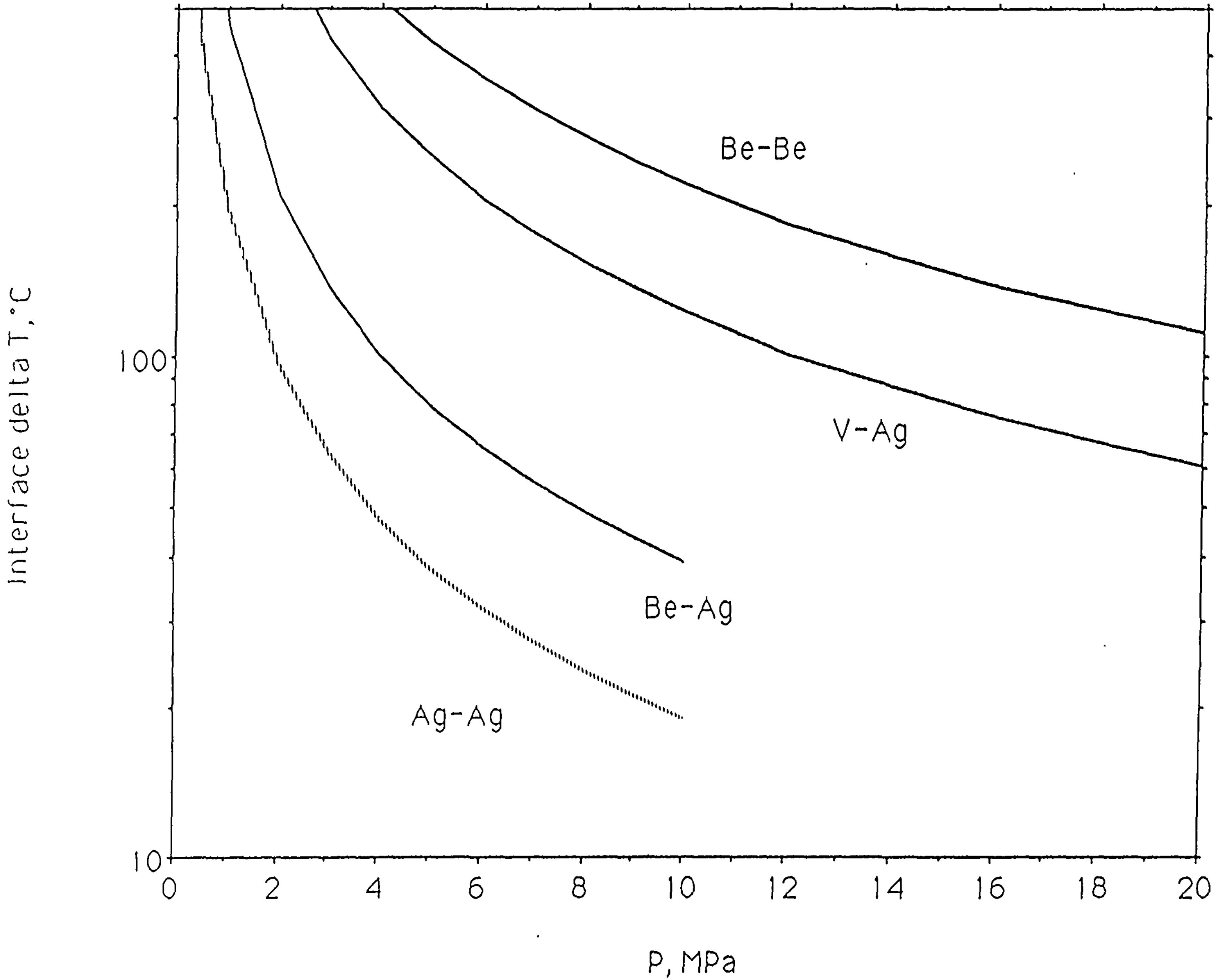


Room temperature ductility for CIP/S Be.



. Extrapolation of wastage correlations to an ITER lifetime of 3 MW-y/m^2 (3.792 full power years).

Temperature drop across interfaces with 1 micron roughness, 0.5 MW/m2, and 300°C sink temperature.



SAMPLE DESIGN CALCULATIONS

- **Thermal Performance**

  Be/metal contact in vacuum

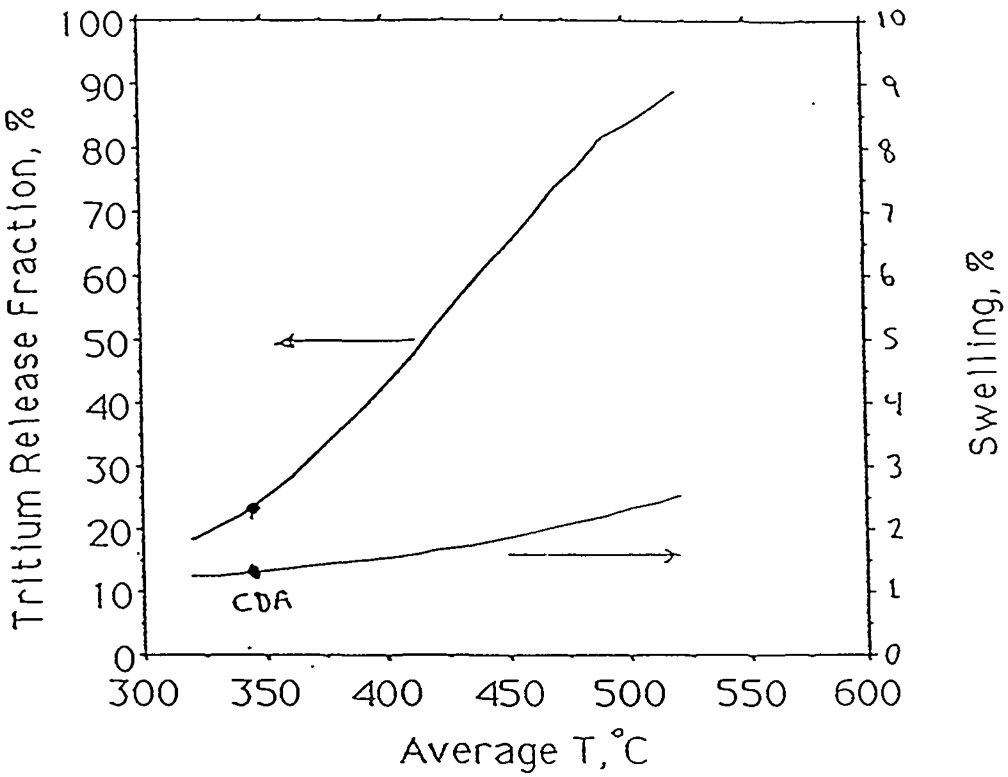
- **Tritium and Helium**

  Tritium release and swelling vs. temperature for porous Be

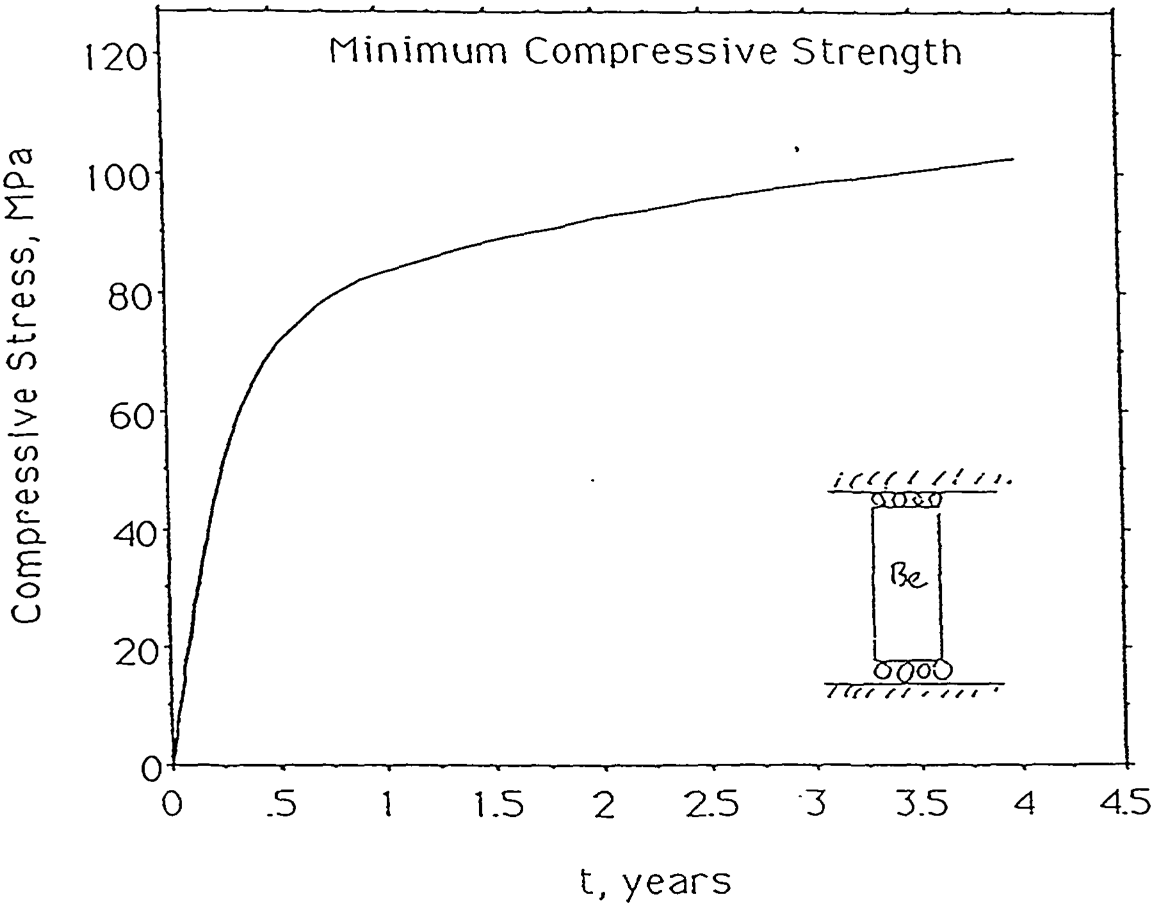
- **Swelling and Creep of Constrained Be**

  Increase in stress with time vs. strength

Sensitivity of tritium release fraction and swelling in Be to temperature.



Swelling-induced stress in constrained Be near the first wall.



OPTIMIZATION

Increasing Temperature

Good for tritium release

Poor for thermal performance; swelling, and compatibility

- **Increasing Porosity**

  Good for tritium release

  May be good for swelling

  Good for Be/structural–material mechanical interaction

  Poor for thermal performance and ductility

- **Decreasing BeO Content**

  Good for ductility

  Good for tritium release???

  Good for swelling???

- **Decreasing Grain Size and Texture**

  Good for ductility

  Good for tritium release???

  Good for swelling???