ITER TECHNOLOGY PHASE

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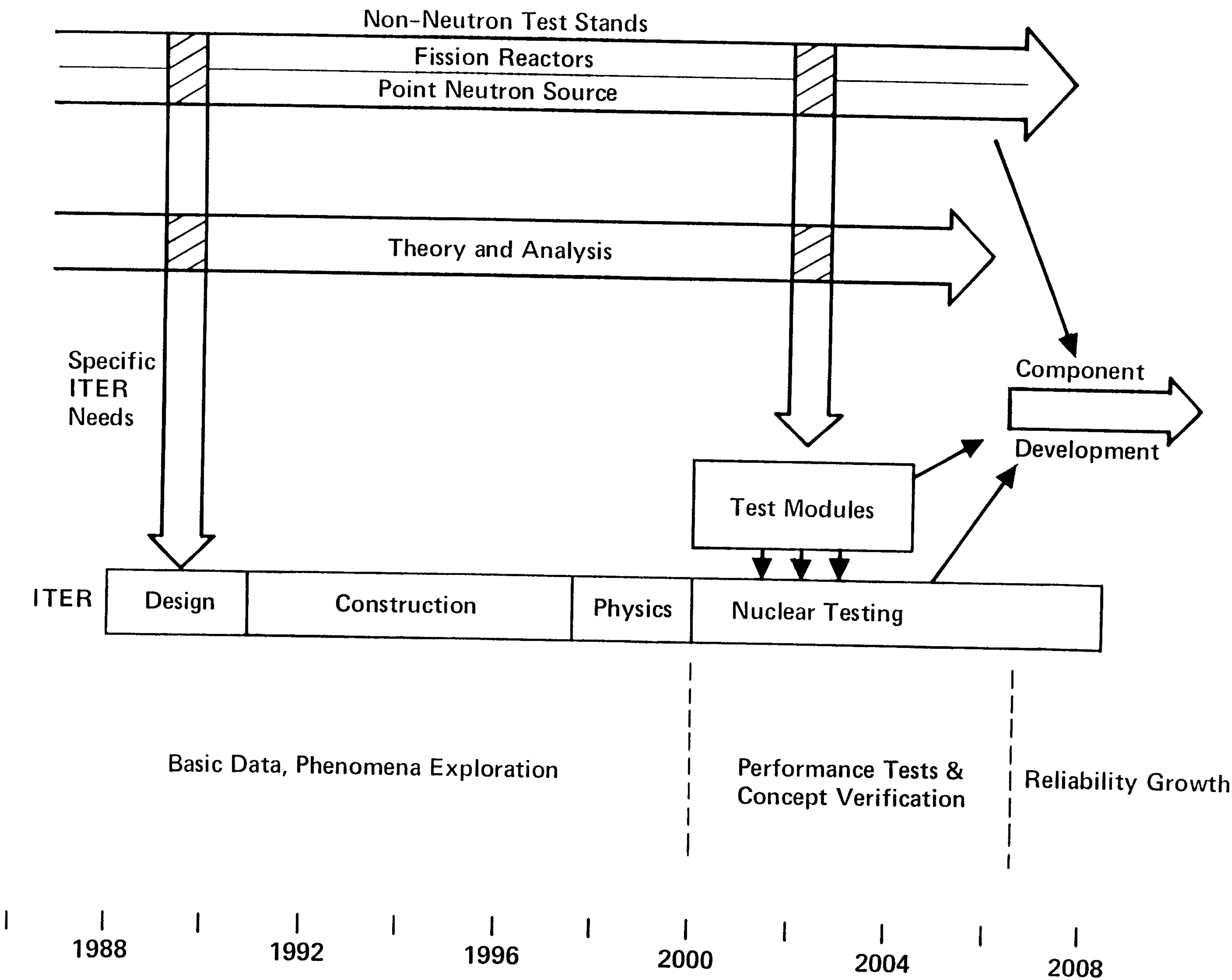
Framework For Fusion Nuclear Technology Development



Physics Phase		Pre-Technology Phase	Technology Phase	
OPERATIONAL CONDITIONS	PLASMA OPTIMIZATION	IGNITION AND DRIVEN OPERATION	CONCEPT PERFORMANCE TESTS	LONG-TERM AND CONCEPT VERIFICATION TESTS
6000 Shots	1500 Shots	7000 Shots		

|-Year 1--||-Year 2--||-Year 3--||-Year 4--||-Year 5--||-Year 6--||-Year 7--||-Year 8--||-Year 9--||-Year10--||-Year11--||--Year12--- *

H H H D/^{3}He D/T D/T D/T D/T D/T D/T D/T

Hands-on Maintenance		Remote Maintenance	Availability ≤10%	Availability ≥10%
Initial Ohmic Operation Full-Field and Heating System Tests	Physics Studies Wall Material Studies Steady-State Studies Ion Mass Effect He-Pumping	"Flash" Ignition Studies, Alpha Particle Studies; He-ash Removal 200 s Controlled Burn Demonstration Driven Operation Demonstration	Demonstrate Driver Blanket and Fuel Processing System Short-Term Blanket Module/Sector Tests on Several Options Includng T-Extraction Surveillance Tests of Machine Components Test Advanced Divertor Concepts	Blanket Module and Sector Concept Tests Blanket Reliability Data Fuel Processing Reliability Data Material Irradiation Experiments Transient Safety Tests Continued Surveillance Testing Test Additional Advanced Blanket Options
			During this period, individual experimental campaigns will usually last 0.5-l year	Experimental campaigns will include combinations of long-term tests (several years each) and short-term tests (-1 yr)

* This phase can continue further up to year 15-20

POSSIBLE OPERATING PHASES FOR ITER

<u>FNT Testing Requirements</u>

- *<u>Major Parameters of Device</u>*

  - Device Cost Drivers

  - Major Impact on Test Usefulness

- *<u>Engineering Design of Device</u>*

  e.g.,

  - Access to Place, Remove Test Elements

  - Provision for Ancillary Equipment

  - Accommodation of Failures in Test Elements

KEY ITER PARAMETERS OF PRIMARY IMPORTANCE FOR NUCLEAR TECHNOLOGY TESTING

- Wall Load
- Neutron Fluence
- Availability
- Steady State vs. Pulsed Length of Plasma Burn and Dwell Times
- Surface Area for Testing

Neutron Wall Load

Desired Value Determined by

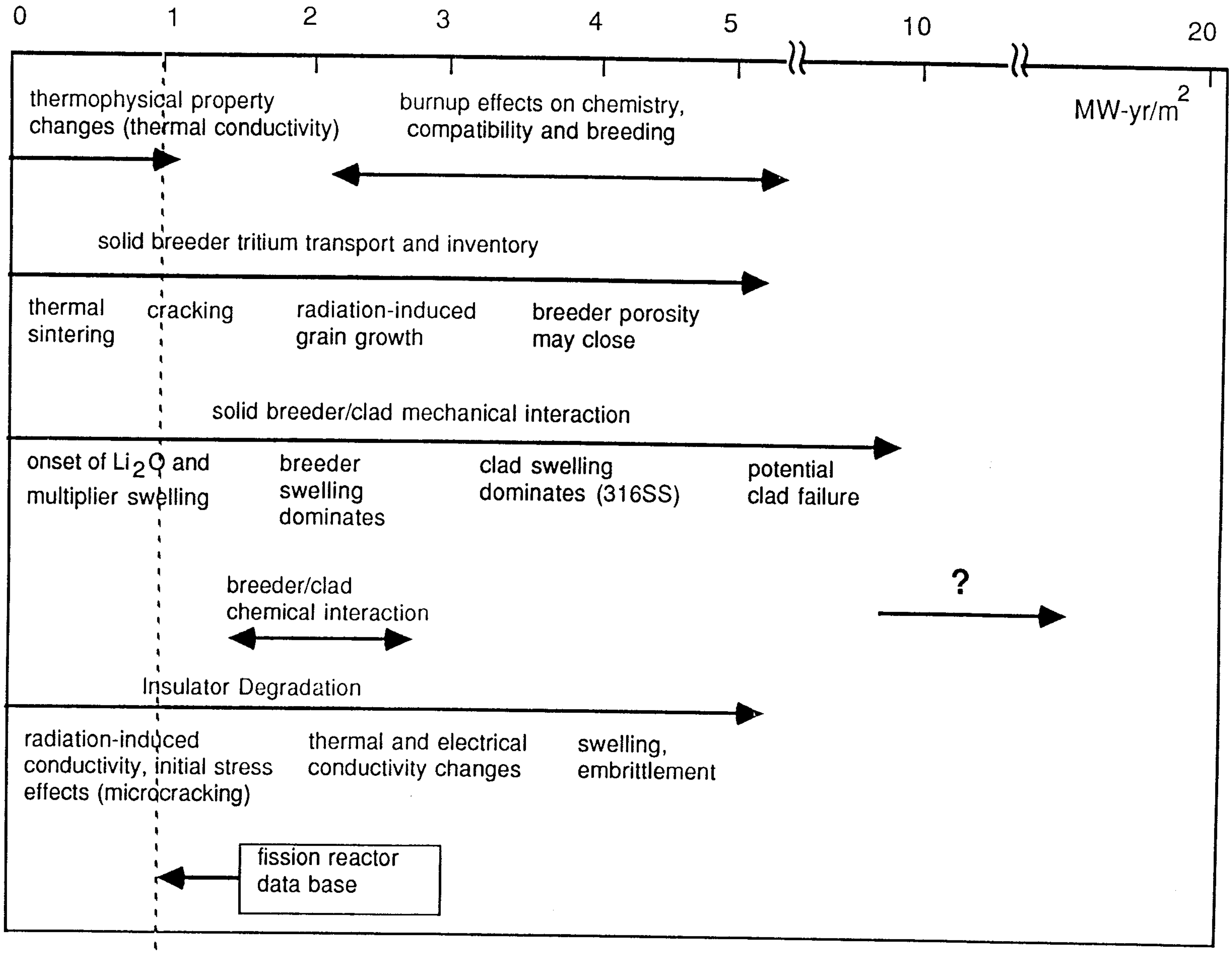
1) Engineering Scaling Requirements

2) Fluence Requirements

Device Availability (%)	Neutron Wall Load (MW/m^2) for 6 $MW{\cdot}y/m^2$ Fluence
60	1
40	1.5
30	2
24	2.5

Table 2 Contributors to the Required Fluence Lifetime of ITER

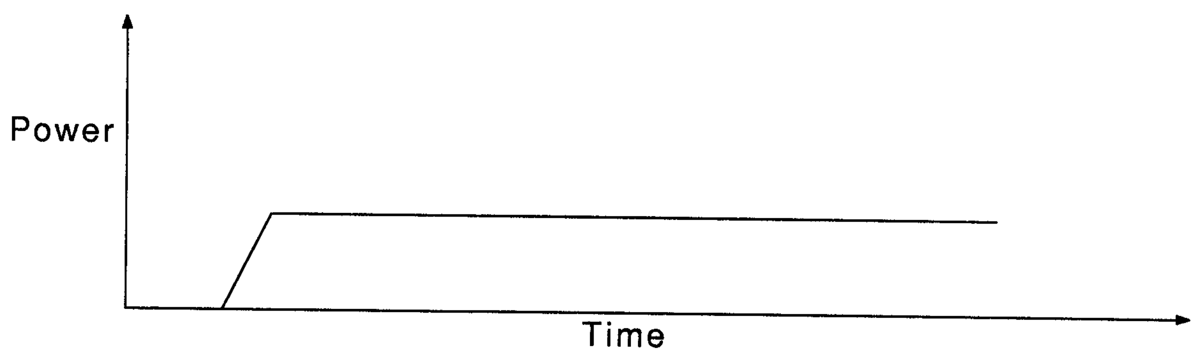
Contributor	Approximate Fluence ($MW \bullet yr/m^2$)
Checkout and physics testing	0.5
Nuclear Stage 1: scoping	1 - 2
Nuclear Stage 2: concept verification	3 - 4
Allowance for enclosure attenuation and test module replacement (25%)	1.0-1.5



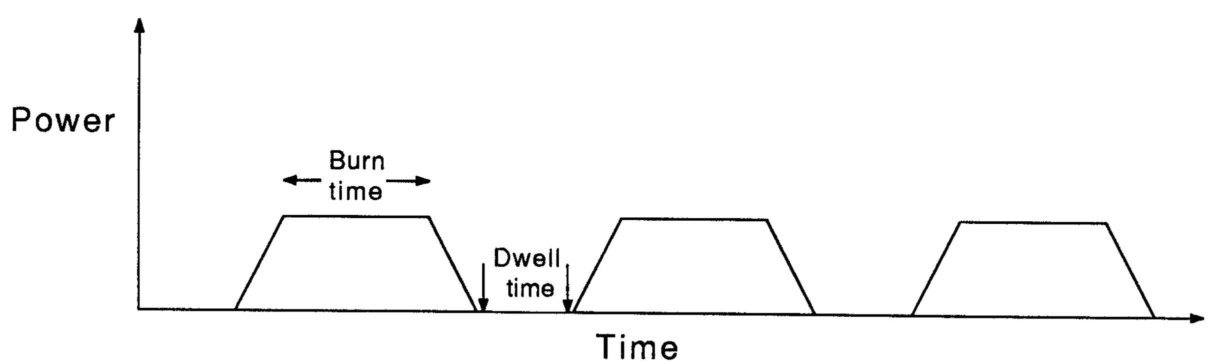
A2: Fluence-Related Effects in Solid Breeders and Insulators

Steady State Vs. Pulsed

Steady State



Pulsed



Motivation for Steady State Operation as Design Basis for ITER

1. To Explore Long Term Reactor Potential

2. To Reduce the Failure Rate and Improve the Reliability of Many of the Basic ITER Components

3. To Substantially Increase the Capability for Nuclear Technology Testing

Effects of Pulsed Plasma Operation on Nuclear Technology Testing

- Time-Dependent Changes in *Environmental Conditions* for Testing:

  - Nuclear (volumetric) heating

  - Surface heating

  - Poloidal magnetic field

  - Tritium production rate

- Result in Time-Dependent Changes and Effects in *Response* of Test Elements that:

  - Can be more dominant than the steady-state effects for which testing is desired

  - Can complicate tests and make results difficult to model and understand

Length of Burn Time?

Length of Dwell Time?

Response (e.g., Temperature):

Burn: $F = F_o (1 - e^{-t/\tau})$

Dwell: $F = F_o e^{-t/\tau}$

τ = characteristic Time Constant

Allowable Variation (During a Specific Test)

- The goal is not just reaching equilibrium. It is to stay at equilibrium during test
- Small changes in some fundamental quantities result in large changes in key parameters

  e.g., 5% change in SB temperature results in a factor of 5 change in Tritium Diffusion Time Constant

Guidelines (95% Level)
burn time $> 3\ \tau$
dwell time $< 0.05\ \tau$

Note: Doubling or tripling the allowable variation will not significantly alter conclusions

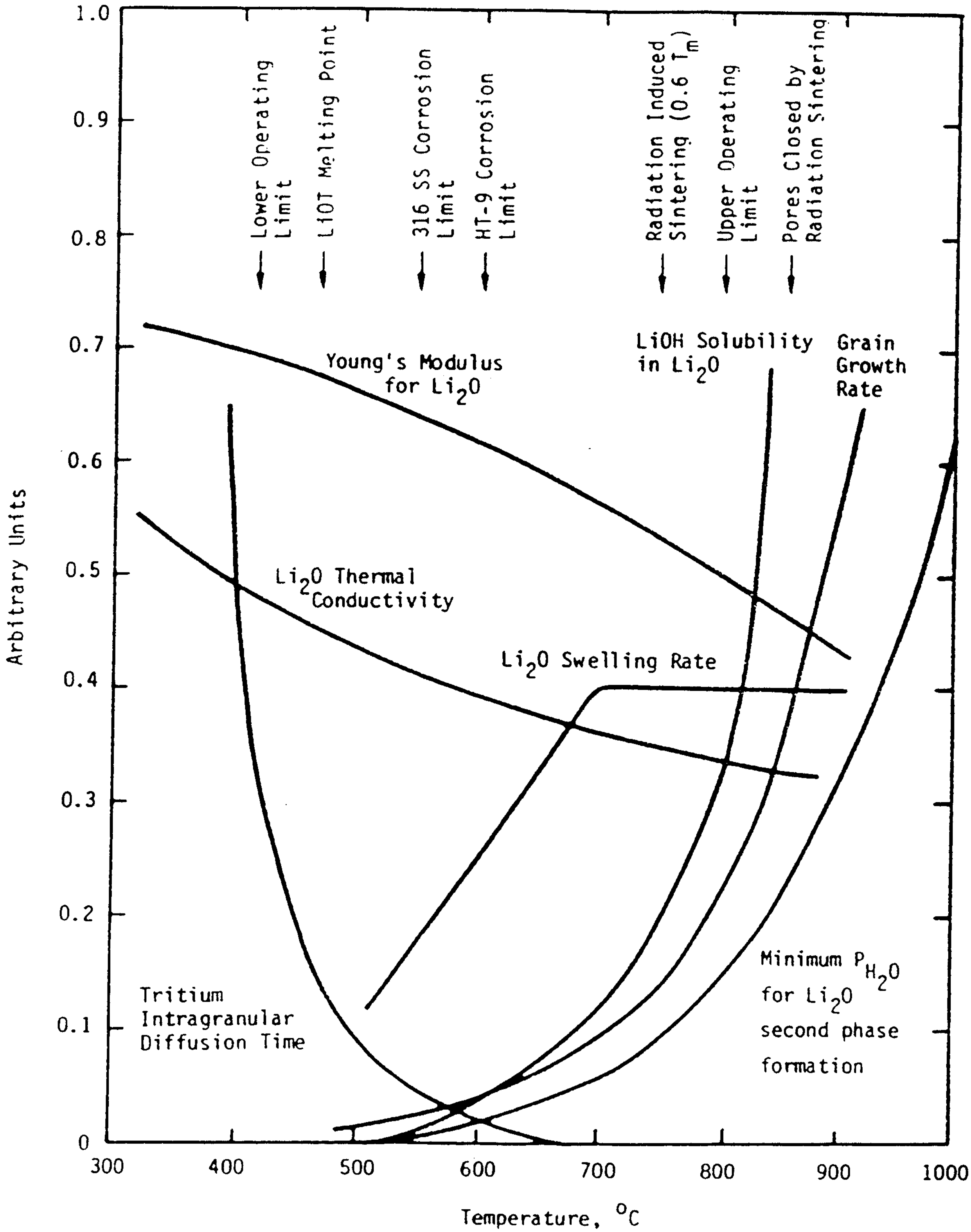
TIME CONSTANTS FOR KEY NUCLEAR PROCESSES RANGE FROM VERY FAST TO VERY SLOW

	Time Constants
	Fast
	Seconds
Heat Conduction	
Flow Processes	
	Minutes
Thermal Processes	
	Hours
Tritium Processes	
Material Interactions	
Other Important Processes	
	Days
Tritium Inventory	
	Slow

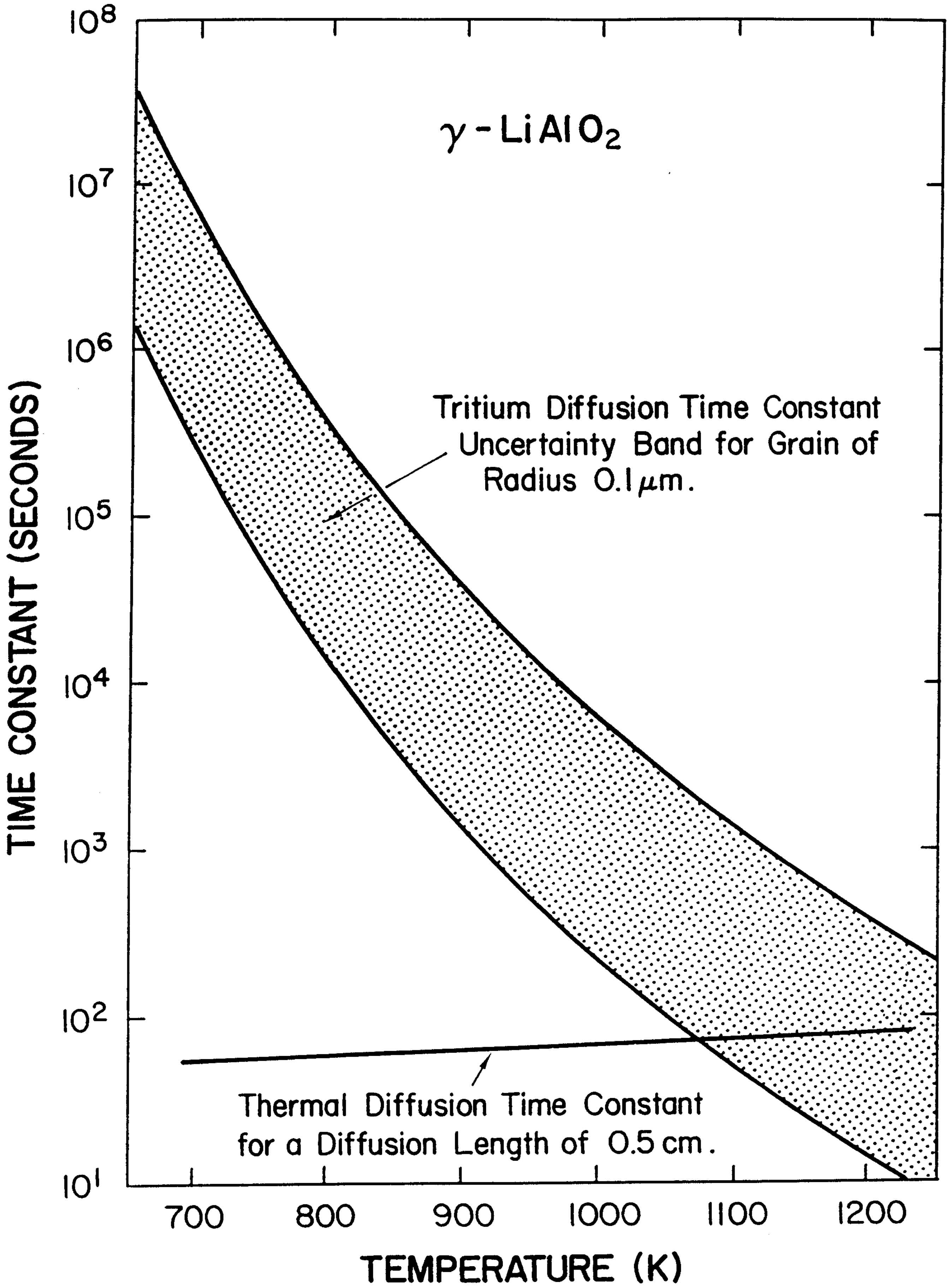
Most Critical Nuclear Issues for Testing in the Fusion Environment Have *Two* Characteristics:

1) Processes with long time constants
2) Crucial dependence on other processes with short time constants

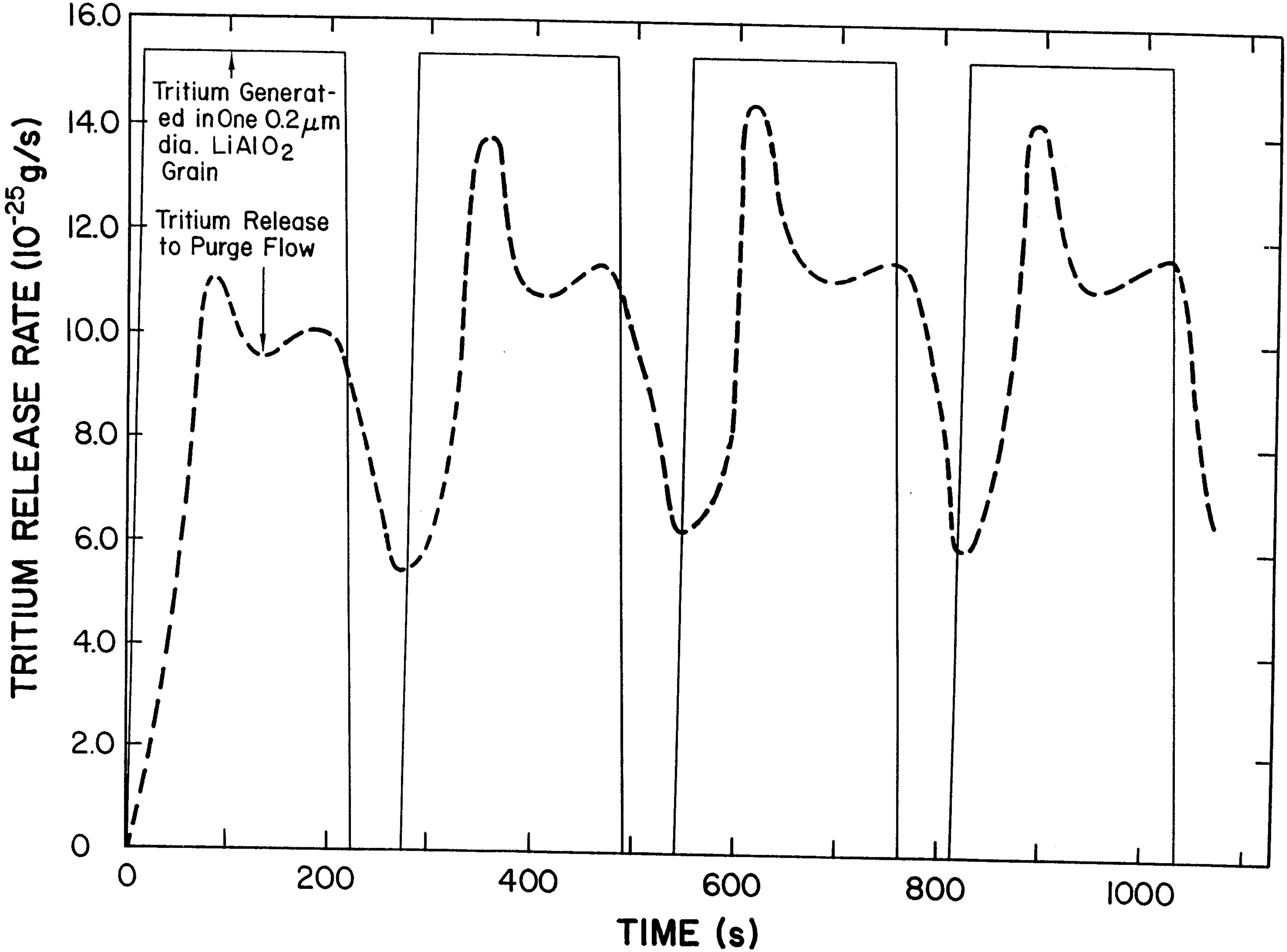
(It takes a long time to establish equilibrium; a short time to ruin it)



THE HEAT SOURCE (MAGNITUDE AND TIME DEPENDENCE) DETERMINES TEMPERATURES IN THE BLANKET, WHICH ACTIVATES MANY IMPORTANT ENGINEERING PROCESSES

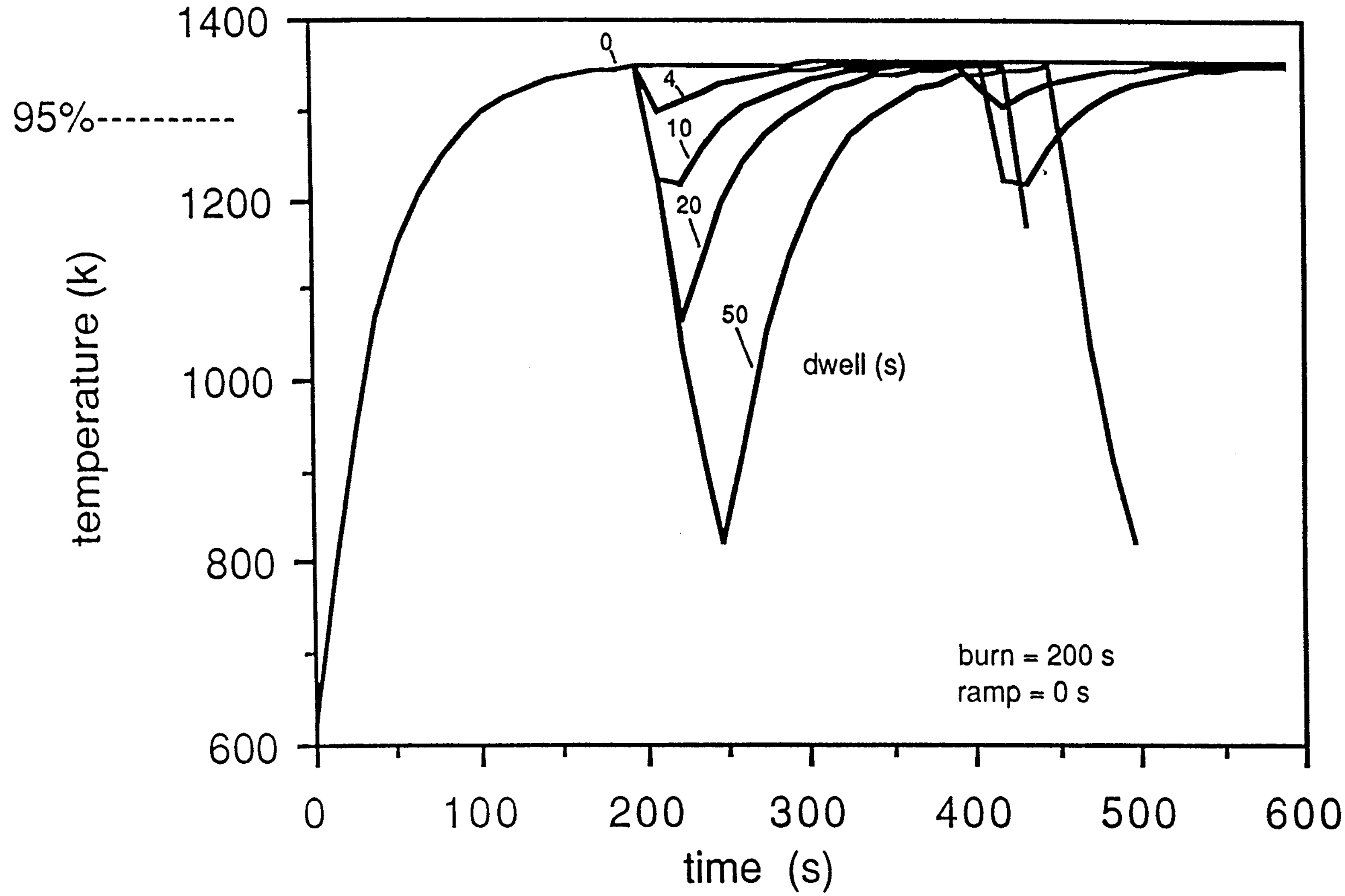


γ-$LiAlO_2$
Tritium Diffusion Time Constant Uncertainty Band for Grain of Radius 0.1 μm.
Thermal Diffusion Time Constant for a Diffusion Length of 0.5 cm.
TIME CONSTANT (SECONDS)
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
700
800
900
1000
1100
1200
TEMPERATURE (K)

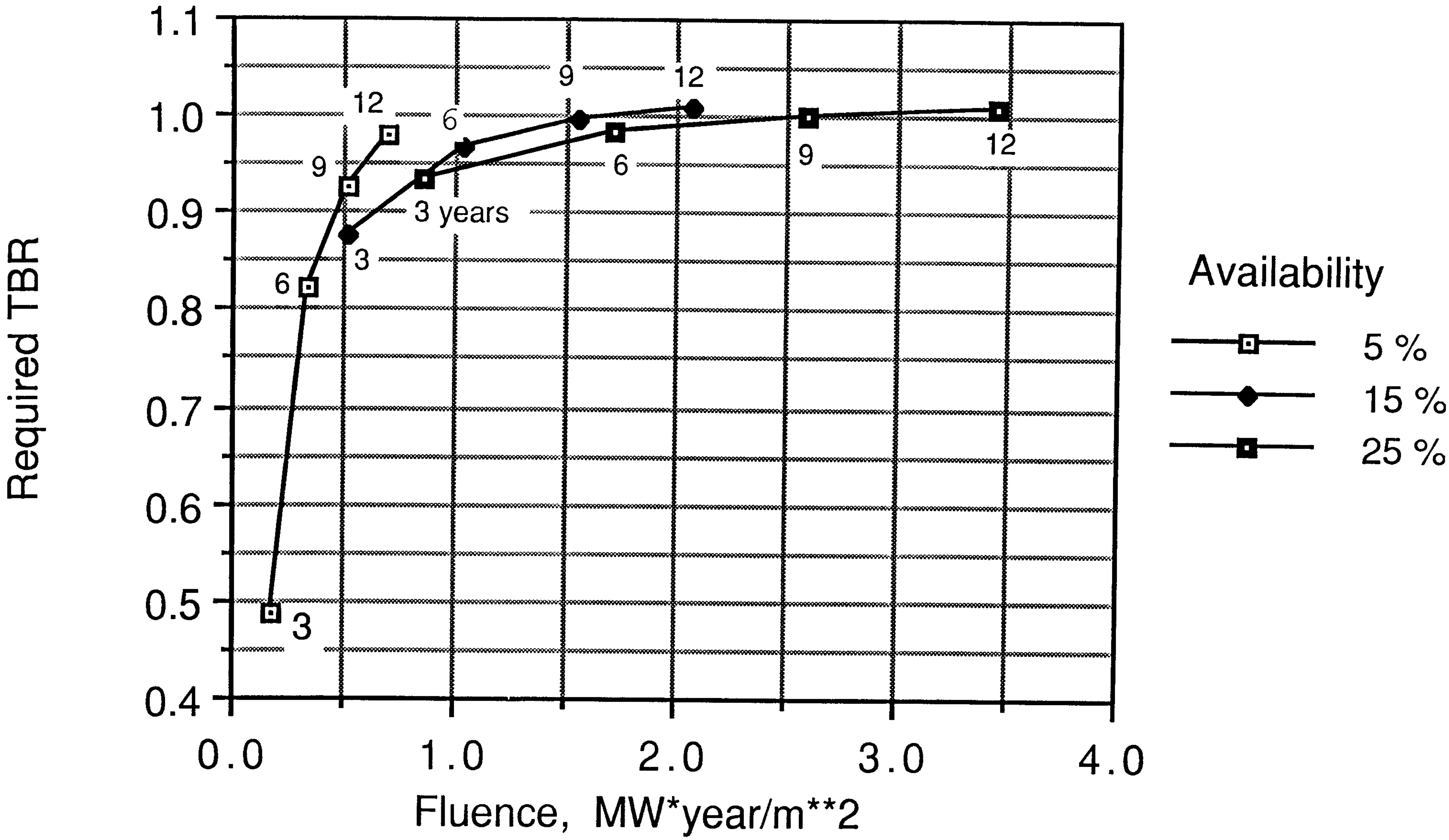


Tritium Generated in One 0.2 μm dia. LiAlO2 Grain
Tritium Release to Purge Flow
TRITIUM RELEASE RATE (10-25 g/s)
TIME (s)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
0
200
400
600
800
1000

VARIATION OF TEMPERATURE WITH TIME FOR DIFFERENT DWELL TIMES (LIALO2 BREEDER)

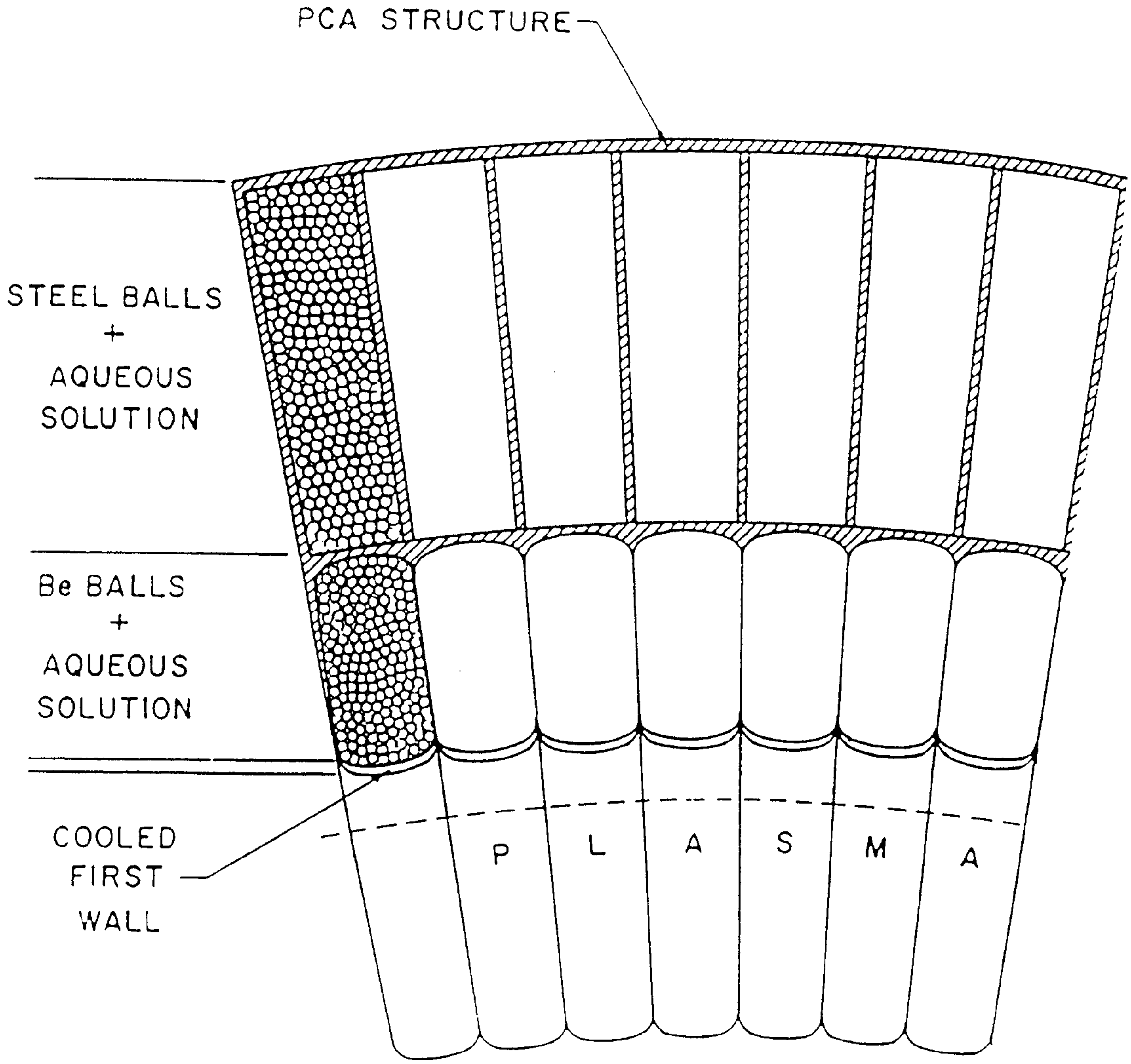


ITER Requires Basic Tritium-Producing Blanket
REQUIRED TBR VS. NEUTRON FLUENCE

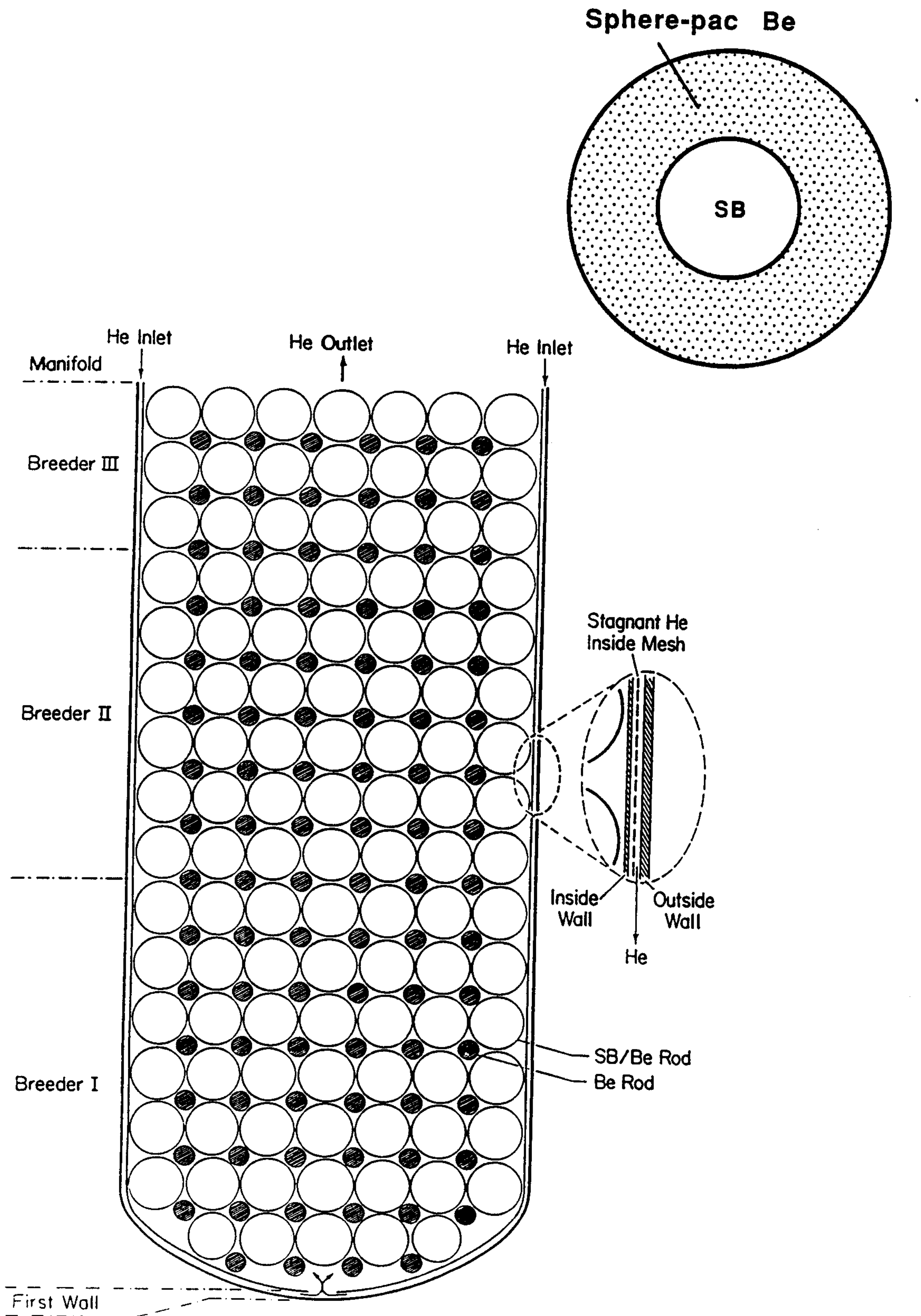


Blanket Material Options Considered For ITER

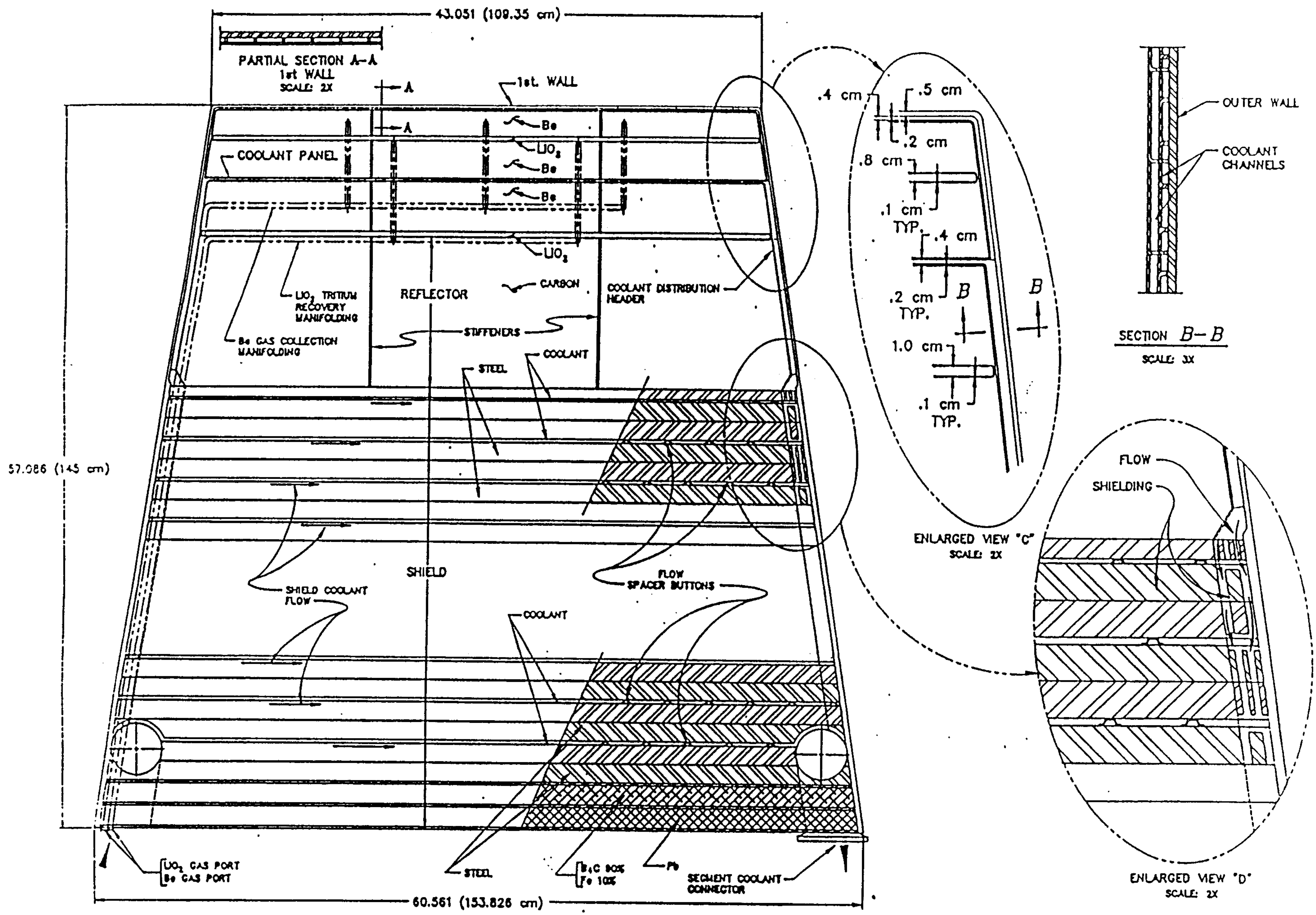
	Reactor Relevant		Non Reactor Relevant	
Breeder	Solid Breeder	Li Pb	Li OH $LiNO_3$	^3He
Coolant	H_2O, He	H_20	H_20	He, H_20
Structure	Austenitic Steel		Austenitic Steel	
Multiplier	Beryllium		Beryllium	



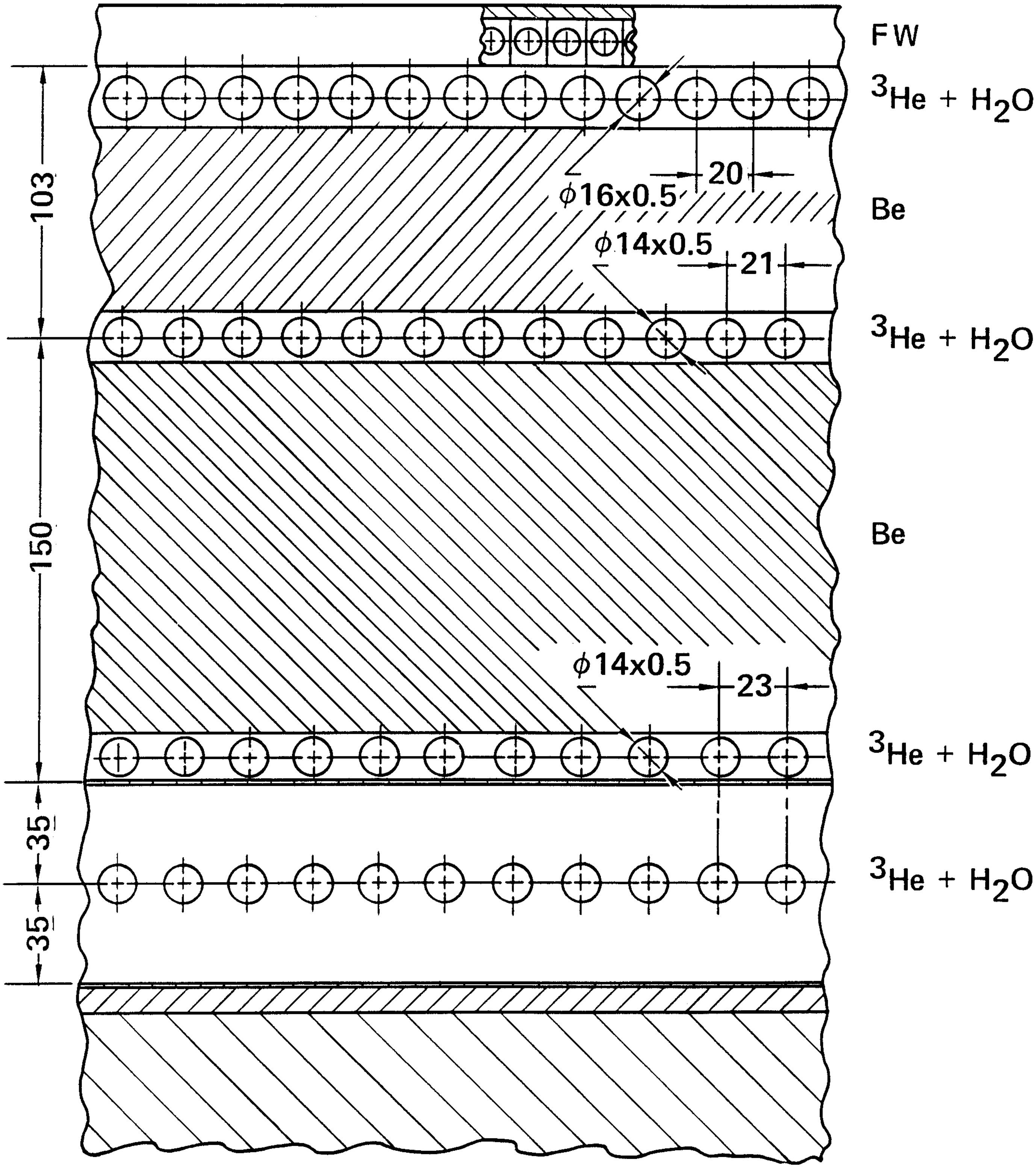
AQUEOUS LITHIUM SALT BLANKET DESIGN FOR ITER



He-Cooled Solid Breeder Blanket Design for ITER



43.051 (109.35 cm)
PARTIAL SECTION A-A
1st WALL
SCALE: 2X
1st. WALL
A
A
Be
LiO_2
Be
Be
COOLANT PANEL
LiO_2
LiO_2 TRITIUM RECOVERY MANIFOLDING
REFLECTOR
CARBON
COOLANT DISTRIBUTION HEADER
Be GAS COLLECTION MANIFOLDING
STIFFENERS
STEEL
COOLANT
57.086 (145 cm)
SHIELD
SHIELD COOLANT FLOW
FLOW SPACER BUTTONS
COOLANT
LiO_2 GAS PORT
Be GAS PORT
STEEL
B_4C 90%
Fe 10%
Pb
SEGMENT COOLANT CONNECTOR
60.561 (153.826 cm)
.4 cm
.5 cm
.2 cm
.8 cm
.1 cm
TYP.
.4 cm
.2 cm
TYP.
B
B
1.0 cm
.1 cm
TYP.
ENLARGED VIEW "C"
SCALE: 2X
OUTER WALL
COOLANT CHANNELS
SECTION B-B
SCALE: 3X
FLOW
SHIELDING
ENLARGED VIEW "D"
SCALE: 2X



^{3}He Blanket for ITER (USSR)

Observations on Concepts Proposed for ITER Basic Blanket by All Countries

- No Lithium

- Water-cooled LiPb only Proposed by USSR

- Aqueous Blanket Proposed as an Option by EC, USA
    - Simple design, fabrication
    - Not reactor relevant
    - Has most safety/environmental concerns

- Solid Breeder Blankets Proposed by All Countries
    - Water-cooled: at low temperature
    - Helium -cooled:
      Most reactor relevant
      Most safety advantages

- The Most Innovative Idea is ^{3}He Proposed by USSR, USA

  Primary concern: Helium supply

  ^{3}He Burnup: 8-10 kg/yr (25% availability)

  Supply

  1 kg/yr in US market from US
  1 kg/yr in US market from USSR

Table 1-3. Preliminary ITER Blanket & Shield Evaluation

Blanket/Shield Option	Aqueous Salt	H_2O/SB	He/SB	Li Particulate	^{3}He
1. Overall Reactor Cost	□	□	□	□	□
2. R&D Requirement	⬓	⬓	⬓	⬓	⬓
3. Design and Fabrication Complexity	□	⬓	⬓	⬓	⬓
4. Accidental Tritium Release	■	◲	◲	◲	◲
5. Accidental Activated Product Release	◲	◲	◲	◲	◲
6. Routine Tritium Release	◲	□	□	□	□
7. Compatibility with Phased Operation	□	▙	▙	□	□
8. Maintenance	⬓	⬓	⬓	⬓	⬓
9. Tritium Breeding	□	□	□	□	□
10. Chemical & Thermal Reaction Potential	▙	▙	□	□	□
11. Decay Heat Response	⬓	⬓	⬓	⬓	⬓
12. Tritium Extraction Technology	◲	⬓	⬓	⬓	⬓
13. Waste Disposal Rating	⬓	⬓	⬓	⬓	⬓
14. Power Reactor Relevance	■	▙	⬓	▙	■

□ = best, ■ = worst, ⬓ = intermediate

SOME KEY PARTICULAR ISSUES FOR ITER BLANKET/SHIELD OPTIONS

- Self Cooled Aqueous/Salt
  - stress corrosion cracking of austenitic steel by aqueous/salt mixture
  - cost effective tritium recovery from water
  - flow control in large tank configuration

- Water-Cooled Solid Breeder
  - aqueous stress corrosion cracking of austenitic steel
  - predictable gap conductance between breeder and clad, including irradiation effects
  - irradiation effects on solid breeder materials
  - ability to accommodate first wall neutron power loading variations

- Helium-Cooled Solid Breeder
  - predictable gap conductance between clad and breeder, including irradiation effects
  - irradiation effects on solid breeder materials
  - helium containment and manifolding

SUMMARY OBSERVATIONS

- A key part of the ITER mission is technology testing

- Fusion nuclear technology testing imposes important requirements on ITER parameters and design

    - Wall Load: > 1 MW/m^2

    - Neutron Fluence: ~ 3 $MW.\ y/m^2$

    - Steady State Operation

    - Reasonable Availability: ~ 25%

- ITER test program raises issues on international collaboration that are different from those for the basic machine

- ITER needs a basic blanket to provide its' own tritium

- Solid breeder and aqueous salt blankets are the key options being considered