# ITER Technology Testing
# Status and Performance Requirements

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# ITER Test Program

- Briefing on current activities
- Current ITER parameters versus requirements for FNT testing
- Identification of problems/issues

# TPWG

- Test Program Working Group (TPWG) for ITER was formed based on agreement between the Director and Home Team Leaders

- Current Members of TPWG (nominated by Home Teams and JCT)

  | | |
  |---|---|
  | M. Abdou* (US) | Y. Strebkov (RF) |
  | H. Takatsu (J) | M. Dalle Donne (EC) |
  | R. Raffray (JCT/G) | D. Lousteau (JCT/G) |

  (* asked by TPWG members to Chair)

- TPWG met at Garching December 15, 1993

  - consensus on approach and issue
  - developed detailed work plan for 1994
  - group will meet again in April and August 1994
  - reports from the group will be distributed to key persons in JCT and to Home Team Leaders. Special summaries will be prepared for TAC and MAC upon request.

## TPWG (cont'd)

- TPWG agreed that an early task for the group is to write a section on the overall requirements for development of fusion nuclear components for DEMO. Such requirements are relatively independent of the capabilities of any given test facility

  - As the work of TPWG proceeds, tests that can be performed on ITER will be identified according to ITER parameters and capabilities

- The Test Program is not limited to blankets. A serious attempt will be made to identify and include tests for all components (divertor, rf antennas, materials, etc.)

- Testing should start in ITER as early as possible, preferably <u>from Day One</u> of ITER operation in the Basic Performance Phase

## TPWG (cont'd)

### Technical Tasks

0. Requirements for development of FNT for DEMO

I. Test Program by Party

II. Integration of Parties' Test Program into ITER Test Program

III. Interface between the Test Program and the ITER Basic Device

### Schedule

- January - March, 1994
  - Work on Tasks O and I
  - Interim Report in April 1994

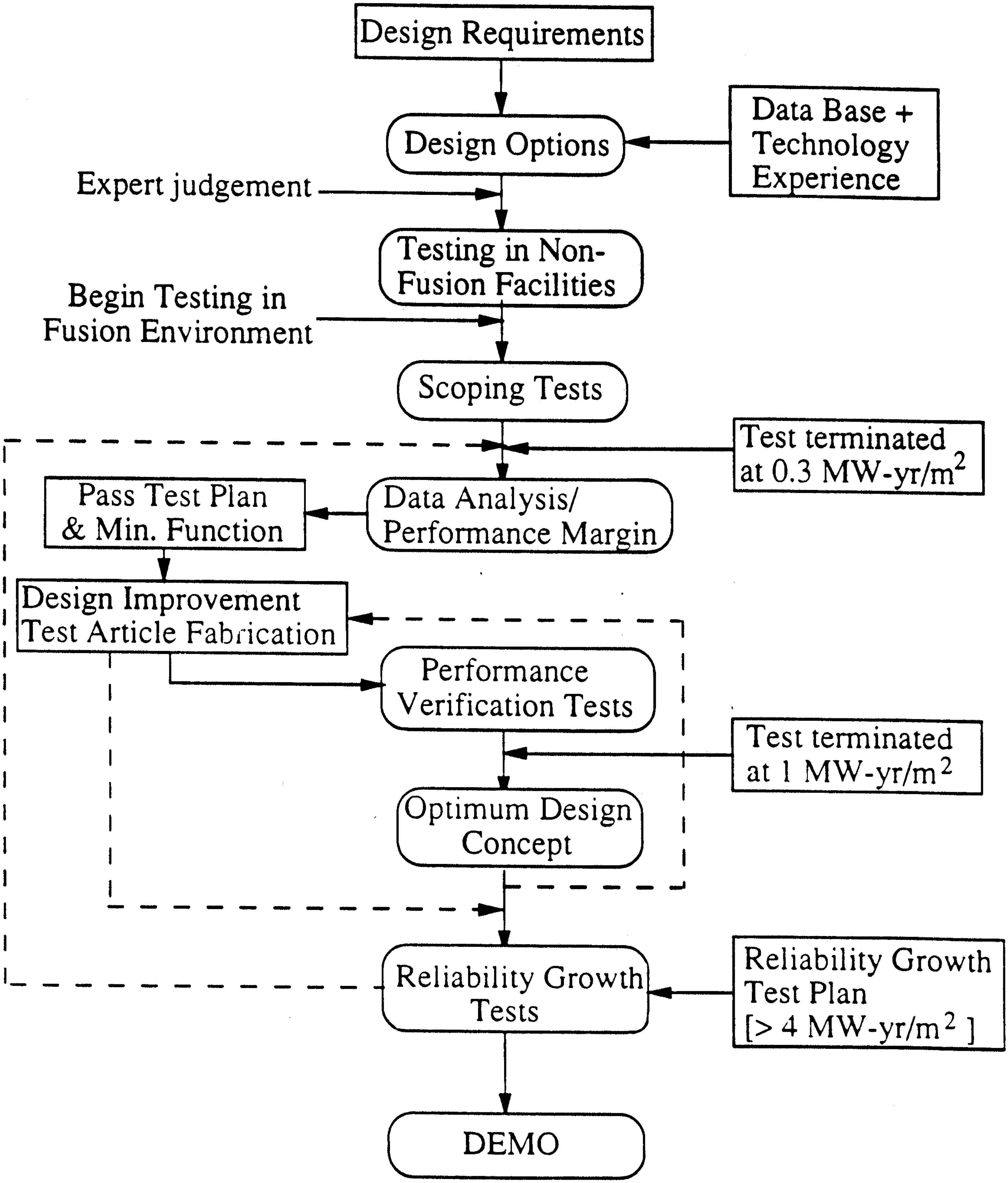
- April - December, 1994
  - Work on Tasks II and III
  - Prepare Report on All Tasks (December 94)

## DEMO Characteristics

A DEMO Plant is one that demonstrates dependability and reliability. The size, operation and performance of DEMO must be sufficient to demonstrate that there are no open questions about the economics of prototype/first commercial reactor.

| | |
|---|---|
| Neutron Wall Loading | 2 - 3 $MW/m^2$ |
| Fluence | 5 - 20 $MW.y/m^2$ |
| Fuel Cycle | Self sufficient |
| Plasma Mode of Operation | Steady state or very long burn, short dwell |
| Net Plan Availability | > 50% (demonstrate reliability and maintainability) |
| Thermal Conversion Efficiency (Gross electric/thermal power) | > 30% |
| Disruption Resistance | One major disruption during lifetime |

# Fusion Nuclear Technology Development Approach



# Nuclear Testing Requirements

| | Minimum (To Be Useful) | Required (Prior to DEMO) | ITER (EDA) |
|---|---|---|---|
| Average Neutron Wall Load, $MW/m^2$ | 1 | > 1 | 1 |
| Plasma Burn Time<br><br><br>Dwell Time (maximum)<br>(time between successive pulses) | > 1000 s<br><br><br>< 200 s | Steady state (or long burn, hours)<br>20 s | 1000 s<br><br><br>≥ 1200 s |
| Continuous Test Duration, weeks<br>(with 100% availability) | > 1 | >2 | 1 - 2 |
| Neutron Fluence, $MW.a/m^2$ | >2 | 4-6 | 0.3 BPP<br>1-3 EPP |
| Test Port Size ($m^2$ x m)<br>Total Test Area ($m^2$) | 1 x 0.3<br>10 | 2 x 0.5<br>20 | 4<br>15-25 |

# Problems Requiring Attention in ITER EDA (from Nuclear Technology Testing Viewpoint)

1. Fluence

    - Only 0.3 MW.a/m2 in 12 years (BPP)

    - Assuming ITER operation by year 2006 and 2-yr between phases, serious testing will not begin until year 2020

    - Two issues arise:

        a) to achieve EPP goal of 3 MW.y/m2 in 10 years requires device availability of 66% (if plasma duty cycle remains 45%), which is almost impossible
        b) DEMO operation theoretically is after year 2045 even if these impossible assumptions (i.e. 66% ITER availability and 3 MW.a/m2 sufficient) are made

2. Plasma Burn/Dwell Cycle

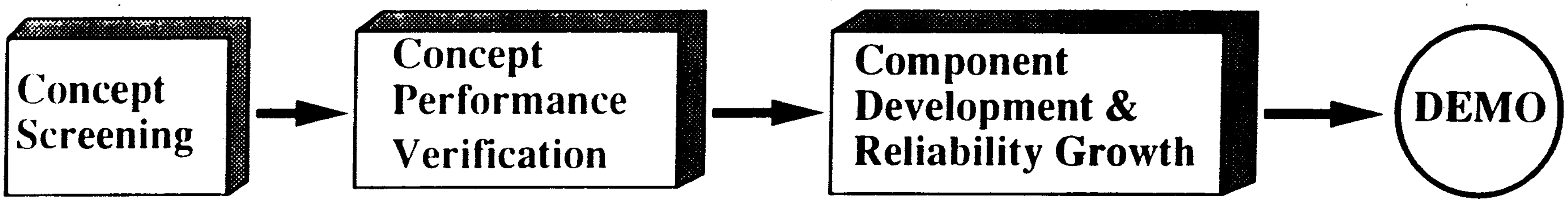
    - 1000 s burn

    - 1200 s dwell

- Such a plasma burn/dwell cycle is likely to make nuclear testing on ITER not useful (for DEMO/ Reactors as presently defined)

- Something major needs to change

# Testing in Fusion Devices For Fusion Nuclear Development Can Be Classified Into a Number of Stages




| | | | |
|---|---|---|---|
| Required Fluence MW.Y/m$^2$ | 0.3 | > 1.0 | > 4 - 6 |
| Size of Test Article | Submodules | Modules | Modules/Sectors |

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- Reliability Growth Testing is Most Demanding
  - Requires testing of components in real operating environment (n, $\gamma$,B,T,V)
  - Requires an aggressive design/test/fix iterative program
  - Requires many test modules and high fluence

## Summary and Recommendations

- ITER satisfies fusion nuclear technology (FNT) testing requirements in a number of areas (test area, power density)

- Two major problems threaten to render ITER unsuitable for FNT testing:

  1) Fluence in 12 yr BPP is ~ 0.3 MW.y/m$^2$
  2) Plasma duty cycle:
     1000 s burn
     1200 s dwell

- Options for fluence issue resolution

  1) increase fluence during BPP
  or 2) change world time schedule for fusion (DEMO by year 2050)
  or 3) build another facility parallel to ITER and dedicated to nuclear testing

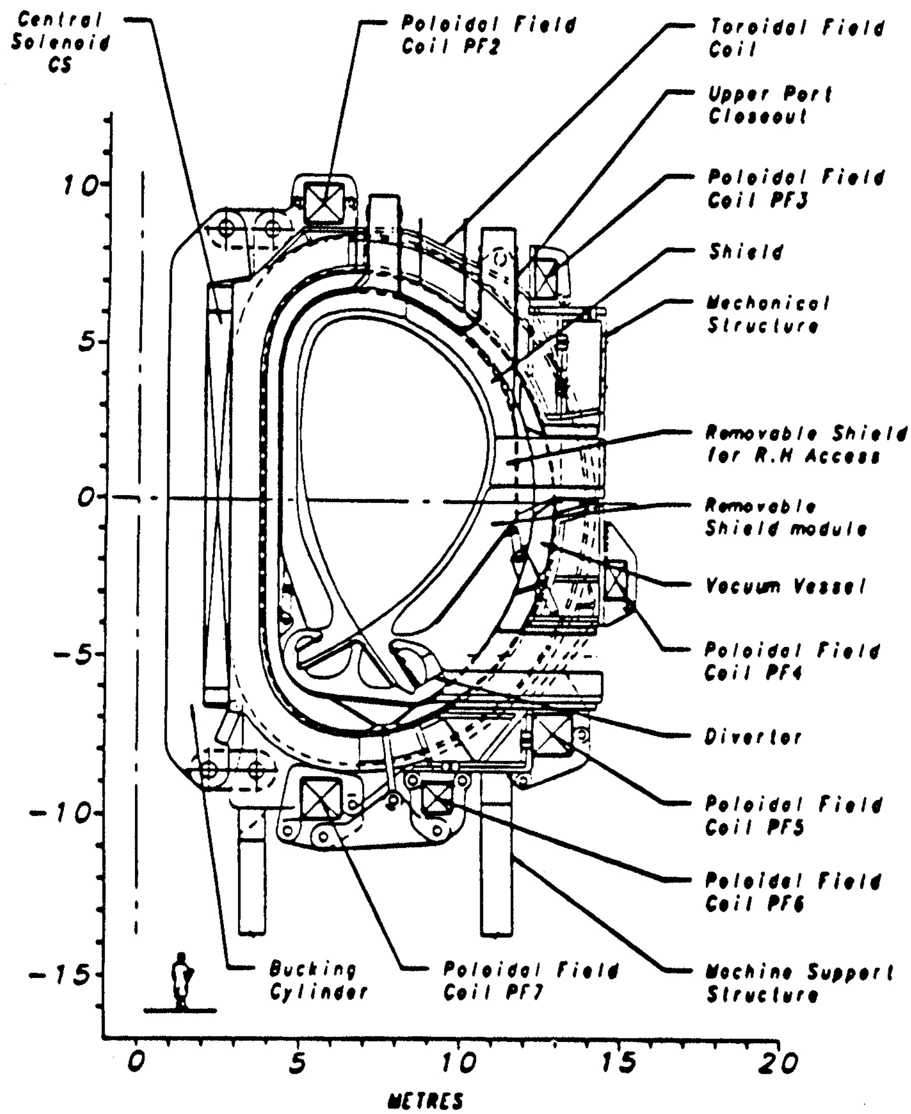
- The relatively short burn (1000 s) and the unusually very long dwell time (> 1200 s) make it impossible to do good FNT testing for DEMO/Reactors as presently envisioned.
  This is a very serious issue that requires:

  A. Urgent extensive study to see if (genius) methods exist to make FNT testing with such a cycle possible
  B. Study to understand the limitations on burn cycle in ITER. In particular: Why such a long dwell time in ITER? Is this inherent to tokamaks?
  C. Implications to DEMO/Reactors of long dwell time

# Appendix

# ITER Test Program Allocation

- 4 to 6 ports
- Each port: half a segment 6 m long,
  0.7 m wide, 0.6 m deep



# FNT Testing Requirements

- Major Parameters of Device
  - Device cost drivers
  - Major impact on test usefulness

- Engineering Design of Device e.g.,
  - Access to place, remove test elements
  - Provision for ancillary equipment
  - Accommodation of failures in test elements

# Fluence Requirements for Testing

- Major changes in the mechanical properties occur in the range of 0.1 to 1 $MW.y/m^2$

- Mechanical property changes will affect the response of test components

- The integrated response of test components need to be evaluated to at least the level where property changes saturate (1-3 $MW.y/m^2$)

- Failure mechanisms and damage accumulation continue to be a concern after properties saturate

  - Fatigue damage
  - Crack growth

# Fluence Effects

- **0-0.1 MW-yr/m2** (at test module) Some changes in thermophysical properties of non-metals occur below 0.1 MW-yr/m2

- **0.1-1 MW-yr/m2** (at test module) Several important effects become activated in the range of 0.1-1 MW-yr/m2
  - Major changes in mechanical properties
  - Radiation creep will change stress distribution (integrated response)
  - Solid breeder sintering and cracking
  - Possible onset of breeder/multiplier swelling
  - He embrittlement

  Correlation of materials data with fission reactors and 14 MeV sources can be done with 1 MW-yr/m2

- **1-3 MW-yr/m2** (at test module)
  - Property changes begin to saturate
    * Evaluate integrated response of test component
    * Begin to observe life-limiting effects
  - Numerous individual effects and component (element) interactions occur here:
    * Burnup effects in solid breeders
    * Swelling in solid breeders
    * Breeder/clad interactions
    * Changes in DBTT
    * Changes in fracture toughness
    * He embrittlement
    * Creep-swelling interactions

- Unpredictable Events
  - Failure modes
  - Changes in weld properties
  - Changes in braze properties
  - Evolution of solid breeder microstructure and effects on tritium release and inventory

## Length of Burn Time?

## Length of Dwell Time?

Response (e.g., Temperature):

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

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

$\tau$ = 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

Table 3-5 Approximate Characteristic Time Constants in Representative Blankets

| | |
|---|---|
| **Flow** | |
| Solid Breeder Purge Residence | 6 s |
| Liquid Breeder Coolant Residence | 30 s |
| Liquid Breeder Cooling Circuit Transit | 60 s |
| **Thermal** | |
| Structure Conduction | 4 s |
| Structure Bulk Temperature Rise | 20 s |
| Liquid Breeder Conduction (Li) | 30 s |
| Solid Breeder Conduction (½-cm plate) | 50-100 s |
| (1-cm plate) | 200-400 s |
| Coolant Bulk Temperature Rise (200 K at 4000 $MW_t$) | |
| Li | 100 s |
| LiPb | 1500 s |
| Solid Breeder Bulk Temperature Rise ($LiAlO_2$, 300-1000°C) | |
| Front (Near Plasma) | 120 s |
| Back (Away from Plasma) | 1800 s |
| **Material Interactions** | |
| Dissolution of Fe in Li (500°C) | 40 days |
| **Tritium** | |
| Diffusion Through Solid Breeder ($LiAlO_2$, 0.2 μm grains) | |
| 1250 K | 8-200 s |
| 750 K | 13-300 hours |
| Surface Adsorption ($LiAlO_2$) | 3-10 hours |
| Diffusion Through SS316 | |
| 800 K | 10 days |
| 600 K | 150 days |
| Inventory in Solid Breeder (Water-Cooled $LiAlO_2$, 0.2 μm grains) | |
| 67% of equilibrium | 6 months |
| 99% of equilibrium | 4 years |
| Inventory in Liquid Breeder | |
| LiPb | 30 minutes |
| Li | 30 days |

# 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<br>Material Interactions<br>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)

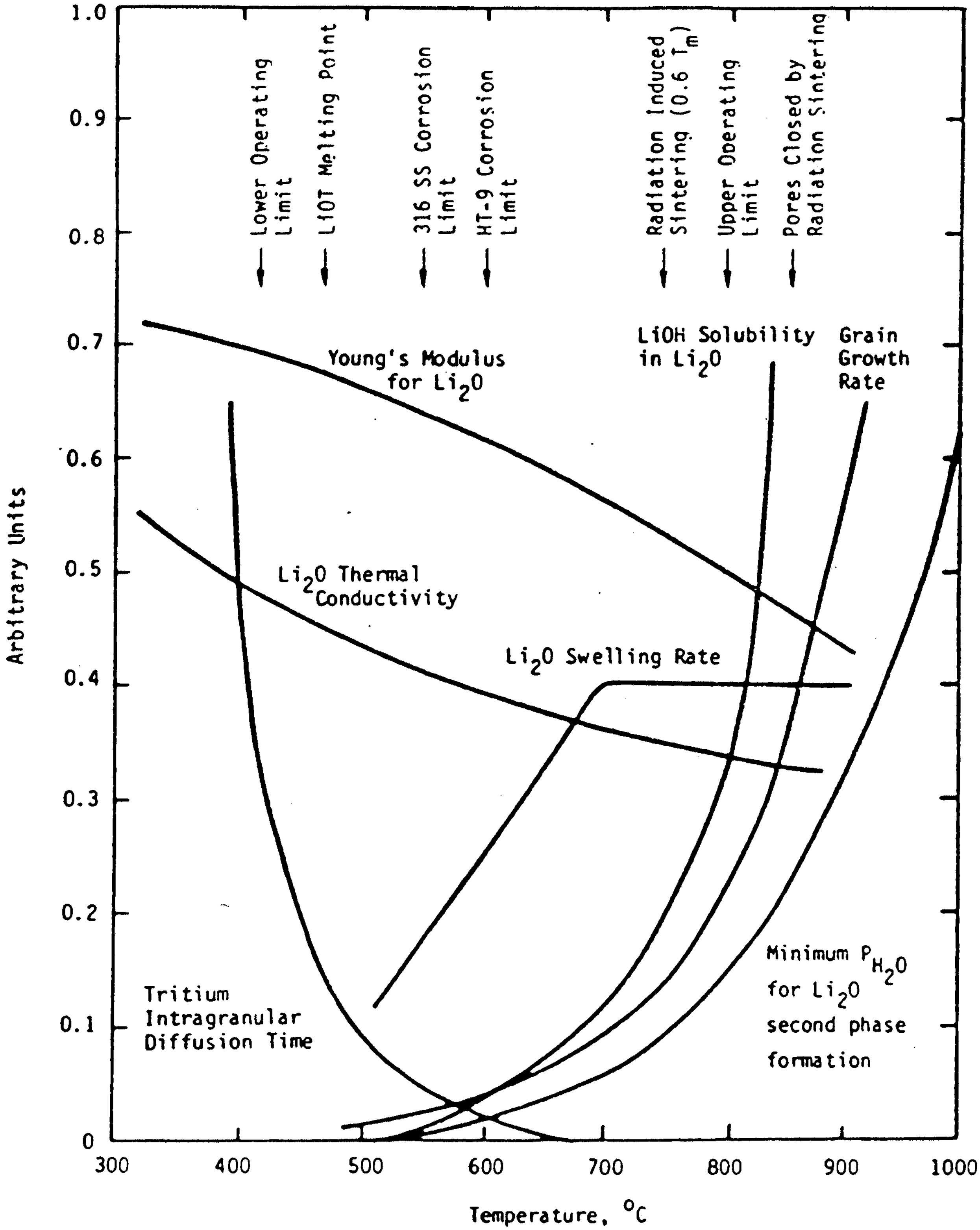
# Significant Plasma Dwell Time Impacts Many Critical Nuclear Tests

*Fast Changes (e.g.)*

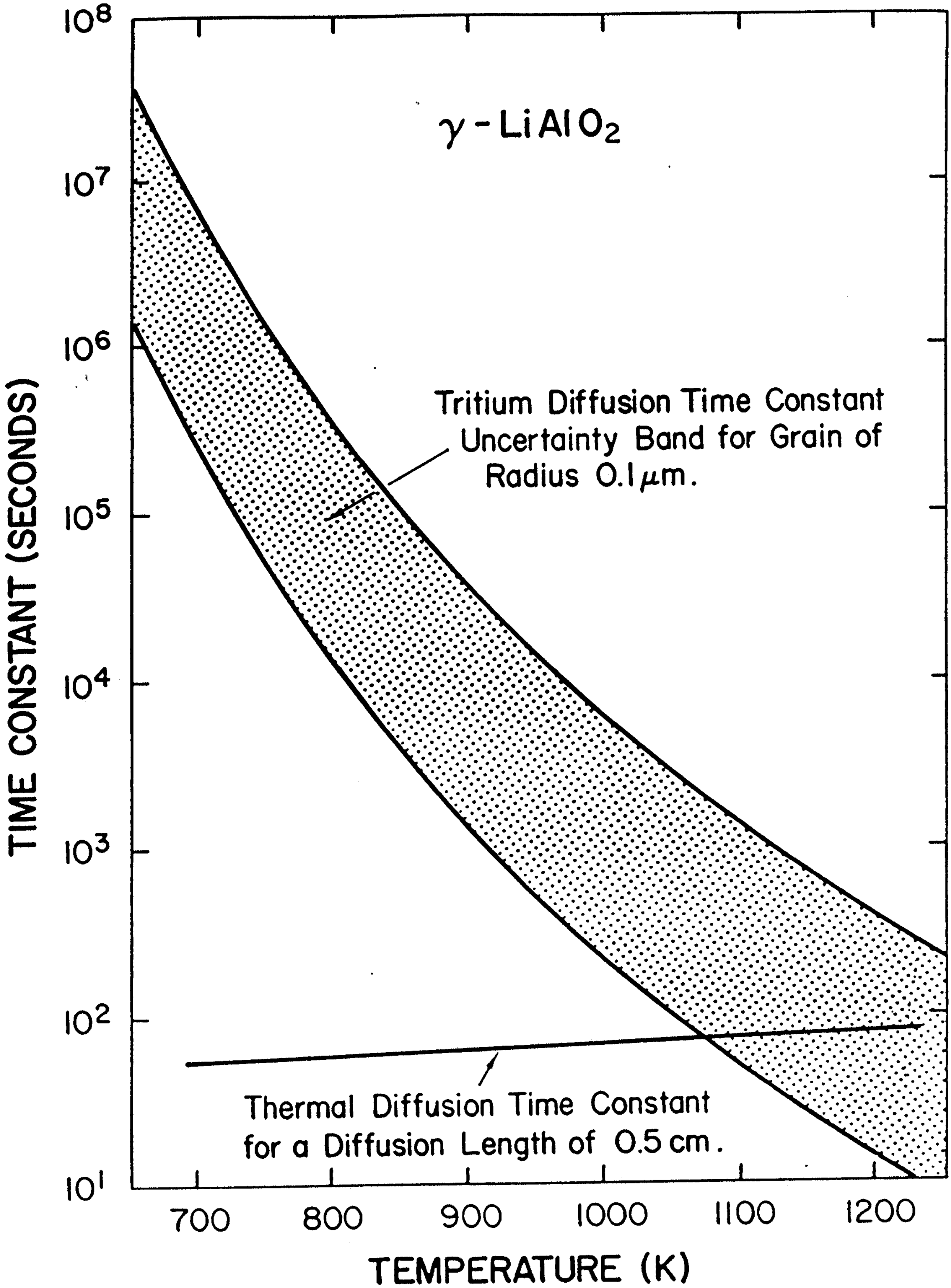
- Nuclear Heating
- Temperature
- Temperature Gradients
- Stresses
- Tritium Production
- Tritium Concentration Profiles

*Impact on Processes with Long Time Constants (e.g.)*

- Tritium Processes
  - Slow
  - Strong Dependence on Temperature, Fluid Flow and Tritium Production
- Corrosion and Redeposition Processes
  - Slow
  - Strong Dependence on Temperature and Fluid Flow
- Ferritic DBTT




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



γ - LiAlO2
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)
TEMPERATURE (K)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
700
800
900
1000
1100
1200

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