FUSION NUCLEAR TECHNOLOGY TESTING REQUIREMENTS

and

Possible Role in National and International Strategy Options

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FUSION NUCLEAR TECHNOLOGY

TESTING REQUIREMENTS

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Possible Role in National and International Strategy Remarks

Introductory Remarks

- FNT Testing Requirements have been derived from technical (e.g. FINESSE)
  - They are clear and fixed (to the extent we understand the technical issues now)
  - Differences among the parties can be resolved by technical studies and technical discussion.

- Strategy to perform FNT testing involves programmatic as well as technical considerations.
  - depends on views and vision of individuals, institutions, governments, etc.
  - Technical studies can and should provide (and have provided) partial input.

What is Needed?

Technology development to:

A) Provide the database for construction of DEMO

B) Show that fusion is viable and has potential attractiveness as ENERGY Source.

Technology Development Tasks

1. Performance verification and concept validation for components and systems
   - DT fuel cycle self sufficiency
   - Thermomechanics (efficient energy recovery)
   - Safety

2. Failure modes and effects

3. Availability/reliability growth

4. Remote maintenance demonstration

5. Component lifetime

6. System integration

Facilities need for FNT

1. Non-fusion facilities
   Fission Reactors, non-neutron test stands

2. Fusion Facilities

Conclusions of Technical Studies

A. Testing of Nuclear Components in Fusion Facilities is absolutely necessary (prior to DEMO)

B. The Fusion environment must satisfy specific technical requirements in order to validate concepts for DEMO nuclear components.

DEMO Characteristics

Neutron Wall Loading	2-3 MW/m^2
Availability*	> 50%
Fluence	5-10 $MW\text{-}yr/m^2$
Fuel Cycle	Self-sufficient, demonstrate doubling time requirements
Plasma Mode of Operation	Steady state (or very long burn, short dwell)

* To achieve machine availability of 50%, means the availability per blanket module needs to be > 99%

Remarks on Table of Nuclear Testing Requirements

- These requirements have been derived from several years of technical studies.

- The technical requirements for the end goal they are defined for (i.e. decision on DEMO) are not controversial.

  - All international workshops, including ITER-CDA Test Program workshops.

- But, because these requirements have major impact on device characteristics, they are often confused with the strategy debate.

NUCLEAR TESTING REQUIREMENTS

	Minimum	Highly Desirable
Neutron Wall Load (MW/m^2)	1	2
Plasma Burn Time	> 1000 s	steady state
Dwell Time	a	< 20 s
Continuous Test Duration (steady state or back-to-back cycle 100% availability	> 1 week	2 weeks
Average Availability	10 - 15 %	25 - 30 %
Total Neutron Fluence ($MW\text{-}a/m^2$)	1.5	4 - 6
<u>Test Port Size</u> ($m^2 x m$)		
Module	0.5 X 0.3	1 x 0.5
Outboard Sector	2 x 0.5	4 x 0.8
<u>Total Test Area</u> (m^2)		
Modules Only	5	10 - 20
Including Outboard Sectors	7	20 - 30

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Points of Discussion Raised by EC on FNT Testing Requirements

1) Steady State vs. Pulsing

2) Neutron Fluence

3) Availability

Key Point not previously included in ITER discussion. But, it should be brought up in order to clarify sources of difficulty.

Geometry/Power Requirements

Fusion Nuclear Testing Requires only 10-20 MW over a test area of 10-20m^2

TABLE VI

Fusion Nuclear Technology Tests Requiring Fusion Neutrons

Tests	Typical Test Article Size (cm)	Number of Test Articles[a]
Basic tests		
Structural material irradiated properties	1 × 1 × 2	20 000
Solid breeder irradiated properties	1 × 1 × 2	1 200
Plasma interactive materials irradiated properties	1 × 1 × 5	900
Radiation damage indicator cross sections	1 × 1 × 0.5	500
Long-lived isotope activation cross sections	1 × 1 × 0.1	200
Neutron sputtering rate cross sections	1 × 1 × 0.1	30
Single-effect tests		
Structure thermomechanical response experiments	10 × 10 × 10	50
Weld behavior experiments	10 × 10 × 5	50
Shield effectiveness in complex geometries	50 × 50 × 100	50
Optical component radiation effects	2 × 2 × 2	20
Multiple-effect/multiple interaction tests		
Submodule thermal and corrosion verification	LB[b]: 100 × 100 × 30	5
	SB[b]: 10 × 50 × 30	5
Partially integrated and integrated tests		
Verification of neutronic predictions		
Tritium breeding, nuclear heating during operation, and induced activation	50 × 50 × 100	4
Full module verification		
Thermal and corrosion	LB[c]: 100 × 100 × 50	5
Module thermochemical lifetime	SB: 100 × 100 × 50	5
Tritium recovery		
Instrumentation transducer lifetime	1 × 1 × 2	70
Insulator/substrate seal integrity	1 × 1 × 2	20
Biological dose rate profile verification	D-T device	1
Afterheat profile verification	D-T device	1
Component tests		
Blanket performance and lifetime verification	SB: 30 × 100 × 80	3
	LB: 900 × 300 × 80	3
Radiation effects on electronic components	1 × 1 × 1	20
Instrumentation performance and lifetime	5 × 5 × 5	100

[a]A test article is defined as one physical entity tested at one set of conditions. Duplication of tests for statistical purposes, off-normal conditions, data at several time intervals, for high fluence tests, etc., are *not* included in the number of test articles.

[b]LB = liquid breeder blankets; SB = solid breeder blankets.

[c]Some designs require a larger test volume.

defined test matrices that specify the number, type, conditions, and size of specimens needed for structural and breeder materials testing,[1,3,9,10] but the more complex tests also indicated in this survey were not quantified. Such tests are obviously important, and Sec. IV focuses on their requirements.

One preliminary requirement that can be estimated from the information in this survey is the overall irradiation testing area (first-wall area) and volume. Based on Table VI for tests requiring significant fusion (or at least high-energy) neutrons, the irradiation testing area and volume are listed in Table VII. The space requirements are not needed in a given reactor at a given time, but rather represent the overall space integrated over the test program duration. While tentative, these numbers point to the need for a considerable amount of irradiation testing space for fusion R&D.

IV. EXPERIMENT REQUIREMENTS

IV.A. Introduction

In Secs. II and III, the issues were identified and the testing needs to resolve these issues were surveyed.

Physics and Technology Requirements for Testing are very Dissimilar

	Fusion Power	integrated burn time	Tritium Consumption
Physics	1000 MW	15 days	0.7 kg
Technology (FNT)	20 MW	3 yr	1 kg

Combined e.g. ITER CDA	1000 MW	3 yr	50 kg

Higher TDF Availability Lead to More Test Time and Faster MTBF Growth

The ITER-CDA blanket is expected to have a minor impact on device availability (10–20% at best)

However, the low availability of the ITER device seriously limits blanket testing

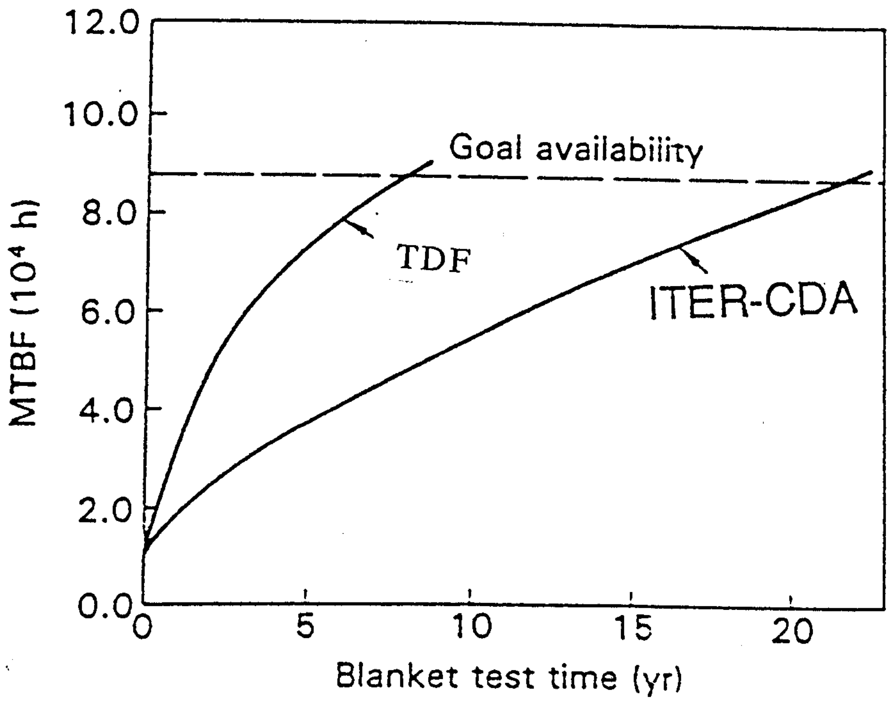
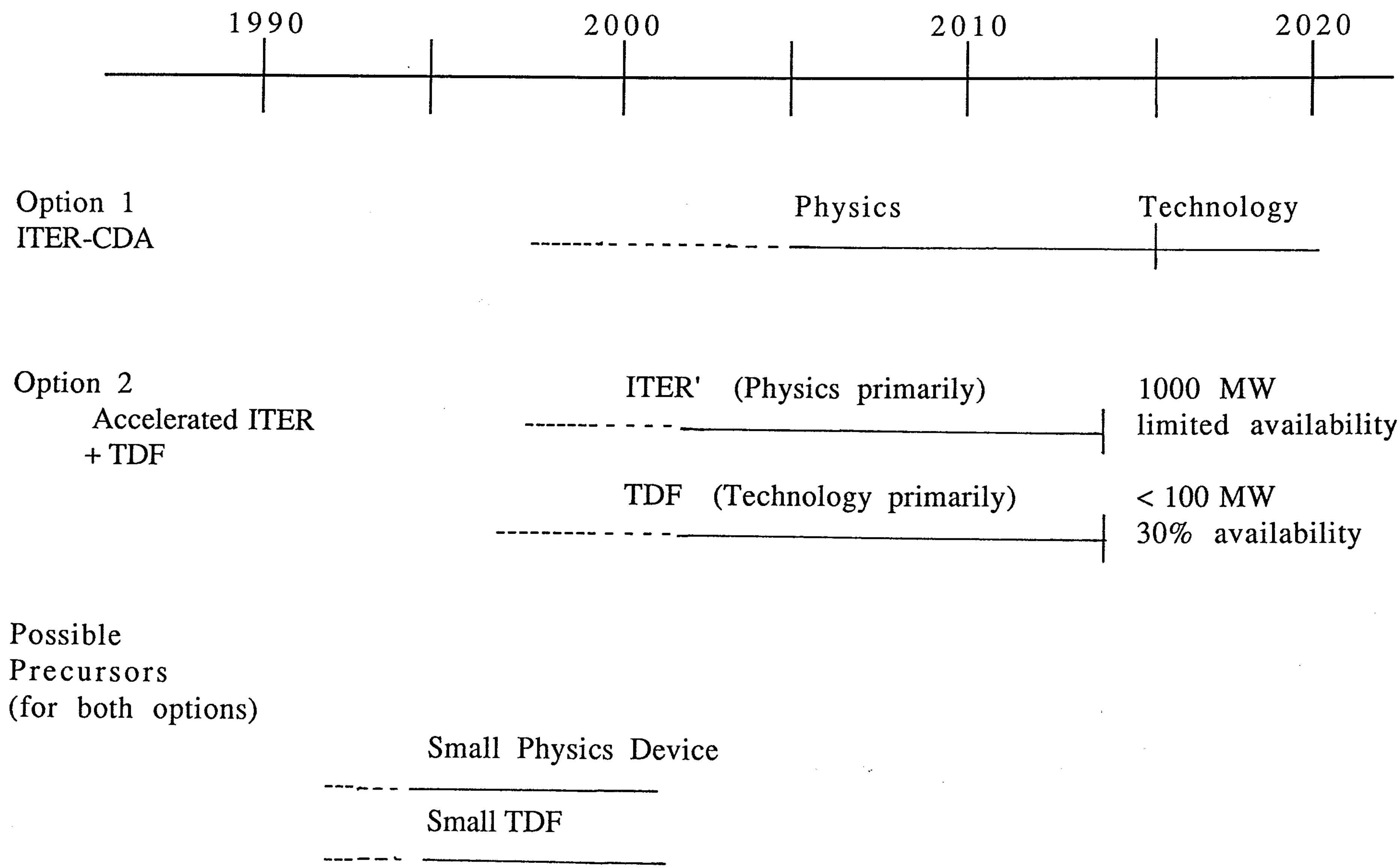


Fig. 25. Higher FERF availability leads to more test time and faster MTBF growth.

Key Assumptions in the Availability Analysis

	Blanket Test Modules	Blanket Tritium Breeding Modules
Initial MTBF (yr)	1	2.9
Initial test experience (day)	31	99
MTTR (week)	2	4
Goal MTBF (yr)	10	10
Test improvement factor	0.50	0.10
Experience factor[a]	0.50	0.50


1990
2000
2010
2020
Option 1
ITER-CDA
Physics
Technology
Option 2
Accelerated ITER
+ TDF
ITER' (Physics primarily)
1000 MW
limited availability
TDF (Technology primarily)
< 100 MW
30% availability
Possible
Precursors
(for both options)
Small Physics Device
Small TDF

Fluence

Critical Distinction

Fluence accumulated at a given test module is much smaller than the device lifetime fluence.

Reasons

1. Attenuation through first wall and PFC

$$F_{module} < F_{wall} / 1.5$$

2) Time Sequence of Tests for a Practical Test Program

- Size sequence:
  --> unit cell --> submodule --> module --> sector

- Design Variations/Iterations

- Different Operating Conditions

Fluence
EC and USA

Primary Difference

EC recommends: ~0.3 $MW.y/m^2$

USA recommends: ~2-3 $MW.y/m^2$

Reasons for Difference

- Primarily different end goals for testing
- Some differences in technical calculations
  (There is now experimental data to support the US position)

Serious Concern

If one examines the US and EC work closely, one concludes that the required device fluence to get the data for the DEMO is probably greater than 6 $MW.y/m^2$

(From Nuclear Testing Standpoint)
What is the most important information
to get out of testing in a fusion device

<u>Answer</u>

Effect of 14 MeV neutrons (in a volume) on
component

<u>Stages of tests</u>

1) Instantaneous Performance
[Concept Screening]
T production, instantaneous tritium release
(needs ~0.3 $MW.y/m^2$ at test module)

2) Effect on <u>Performance of Components</u>
[Concept Selection]
(needs ~1-3 $MW.y/m^2$ at test module)

3) Effect on <u>Lifetime of Components</u>
[Concept Validation]
(needs ~10-20 $MW.y/m^2$)

Item 1: Requires low fluence but not worth much

Item 2: Most critical to Blanket Concept Selection
(as a minimum) and possibly validation

Item 3: Important but costs a lot

Fluence Effects

- **0-0.1 MW-yr/m^2** (at test module) Some changes in thermophysical properties of non-metals occur below 0.1 MW-yr/m^2

- **0.1-1 MW-yr/m2** (at test module) Several important effects become activated in the range of 0.1-1 MW-yr/m^2
  - 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/m^2** (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

Comments EC Report "Fluence"

EC Report Concludes (page 13)

"A total integral burntime of about 2500 hrs (including physics investigations) is therefore sufficient to assess the basic performance (e.g. thermal behavior and breeding capability) of all the blanket concepts."

How they derive 2500 Hr (i.e. < 0.3 MW.y/m2)

For each blanket concept

4 different operating conditions x 4 consecutive variants/iteratives x 40 hours per test ~ 700 hours

200% contingency → 1400 hr
(for checkout, repetition due to failure, etc.)

Plasma Physics tests → 1000 hr

Total burntime → 2500 hr

Key Problem: 40 hours to do the test

EC Basis For 40 Hr Testing Time

EC

Derived based only on Tritium Release of $LiAlO_2$ at 550° C to 650° C

USA

1) Tritium Inventory (not release) is what is important Inventory time constant is much longer

2) Low Temperature Testing is more critical (Largest effect on inventory)

3) Tritium Inventory may be affected much by radiation effects

4) ITER testing is not only for Tritium Release from solid breeder

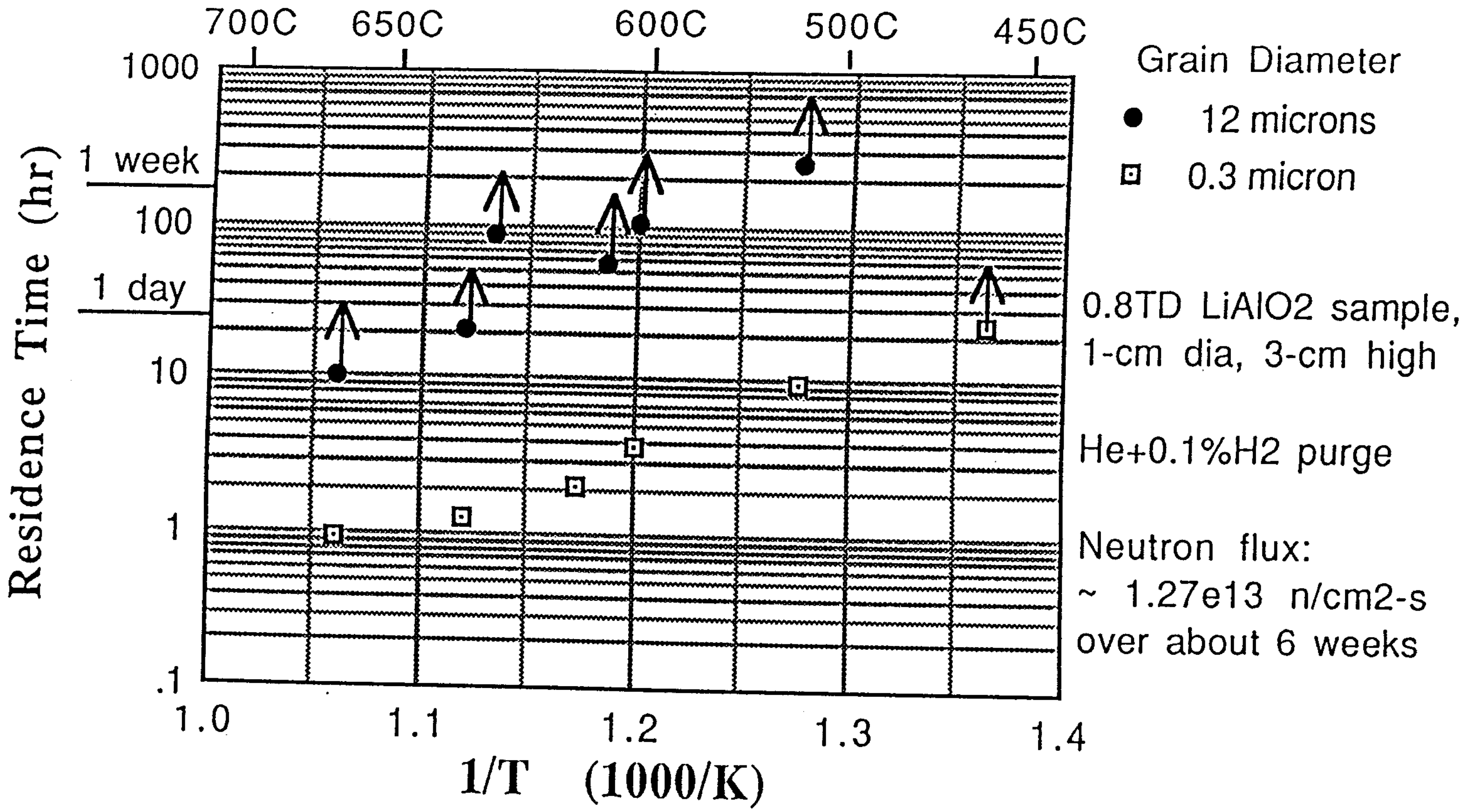
New Experimental Results from Europe

Residence time in $LiAlO_2$ at 400° C
(2 week) (330 hours)

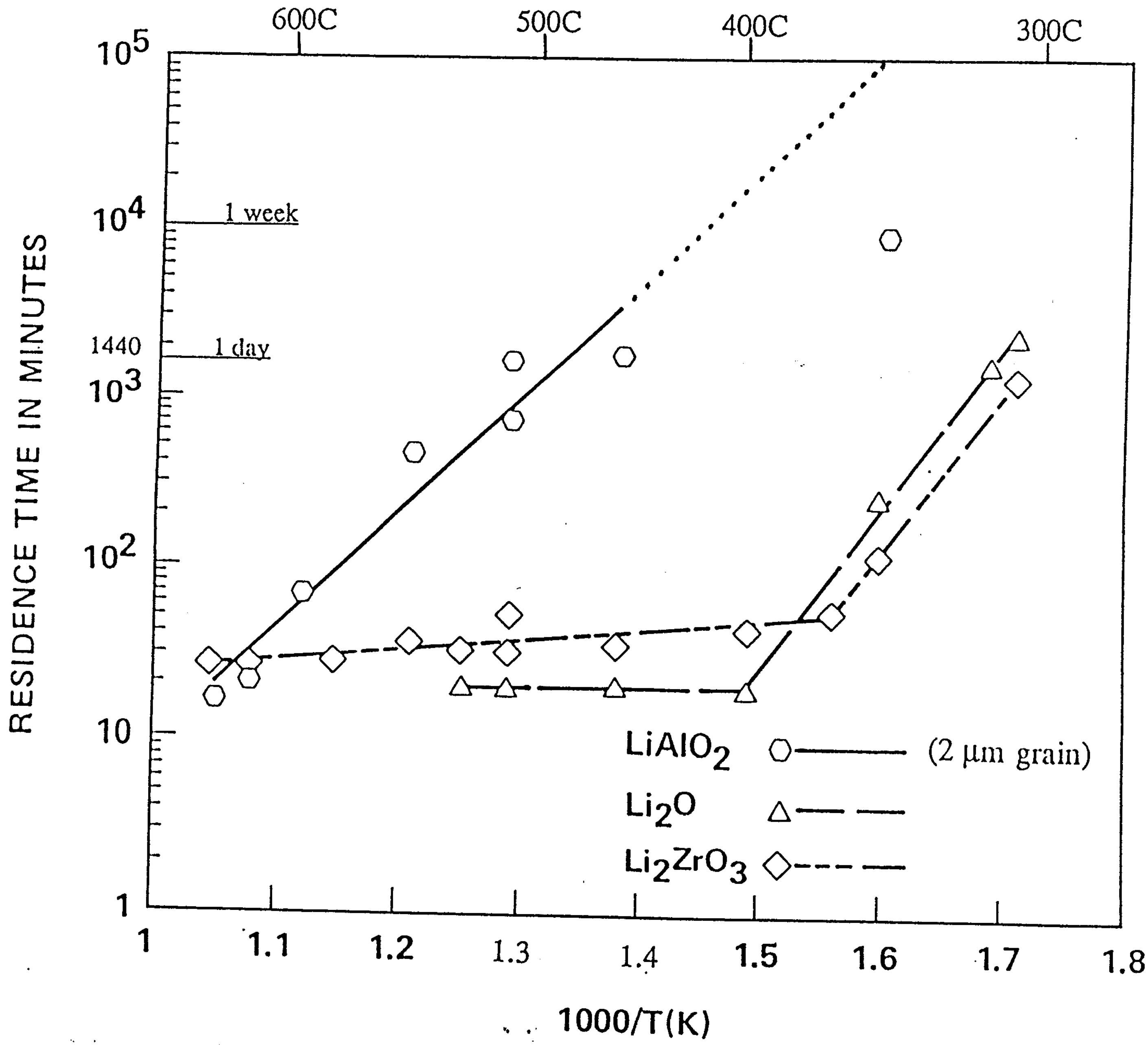
Using 2 week in EC calculations yield testing time requirement of:

20600 Hr ~ 2.3 $MW.y/m^2$

Tritium Residence Time for LiAlO2 from TEQUILA Experiment



Tritium Residence Time in Solid Breeders as a Funcion of Temperature Based on Mozart Experimental Results



Time Constants for Tritium and Thermal Diffusion in Li ALO_2 as a Function of Temperature