Tasks to be Accomplished Prior to Fusion DEMO

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Presented to FEAC Panel No. 1,
on November 18, 1991, in Dallas, Texas

Suggestion

To properly address the many questions in the charge to the panel:

1. We should consider

   - All Major Tasks Required For Fusion Power Demonstration

     - Identify the tasks (information available from previous studies; we need to organize the information in a useful format).

     - Indicate where (type of device) the task can be performed.

2. Consider and Compare Complete Scenarios (i.e. pathways) to DEMO

   - Each pathway should indicate how and where each of the major tasks is performed.

     (Each pathway should include major fusion devices and complimentary non-fusion facilities).

Observations

- A Fusion Power Demonstration is a fixed target. Only limited number of features and major parameters need to be stated in order to define the broad areas of R & D.
  [The objectives of any machine prior to DEMO can change. Objectives of DEMO will not change.]

- A cost/benefit analysis in which the objectives of the machine vary is meaningful only in the context of the overall scenario/pathway to DEMO.

- What is suggested here is not difficult to do. Extensive information exists on the R & D requirements and facilities.

Approach to Defining the R & D Prior to Fusion DEMO

Approach 1

Top level description of Objectives in major technical areas

For example

1. Reactor-Grade Plasma
2. Tritium self sufficiency
3. Engineering Feasibility
4. Reliability, Availability, Lifetime
5. Safety and Environmental impact

Approach 2

List components and state tasks to be accomplished (see separate page).

Approach 2

Components

Plasma	Tritium Systems
Blanket	Magnets
PFC	Plasma Heating
Shield	Diagnostics

R & D Tasks Prior to DEMO

1. Performance verification and concept validation
2. Failure modes and effects
3. Remote maintenance demonstration
4. System integration
5. Availability/reliability growth
6. Component lifetime

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%.

Example Only
Devices in Which Development Tasks Could be Accomplished

	Performance Verification	Failure Modes and Effects	Remote Maintenance	System Integration	Availability Growth	Component Lifetime
Blanket	$ITER_1$, TDF	$ITER_1$, TDF	$ITER_1$	$ITER_1$	$ITER_1$, TDF	$ITER_1$, TDF
PFC	$ITER_2$	$ITER_2$	*	*	$ITER_2$	$ITER_1$, TDF
Shield	*	*	*	*	*	*
Tritium Processing	*	*	*	*	*	*
Tritium Fuel Cycle	$ITER_1$	*	*	*	$ITER_1$	*
Magnets	*	*	*	*	*	*
Plasma	$ITER_2$	$ITER_2$	*	*	$ITER_2$	*

* any DT-burning tokamak

$ITER_1$ = CDA, $ITER_2$ = reduced mission

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.

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 (or long burn, hours)
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
Test Port Size ($m^2 x m$)		
Module	0.5 X 0.3	1 x 0.5
Outboard Sector	2 x 0.5	4 x 0.8
Total Test Area (m^2)		
Modules Only	5	10 - 20
Including Outboard Sectors	7	20 - 30

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 bought 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

Technology Development Facility

The option of a technology development facility (TDF) should be considered in some scenarios as complementary parallel facility to a reduced-mission ITER.

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

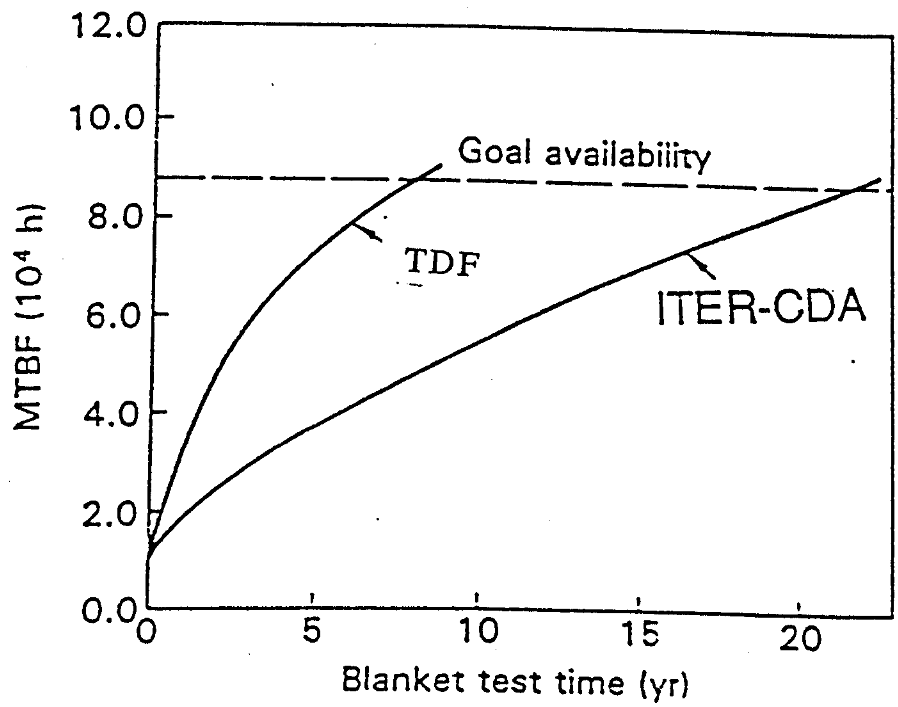


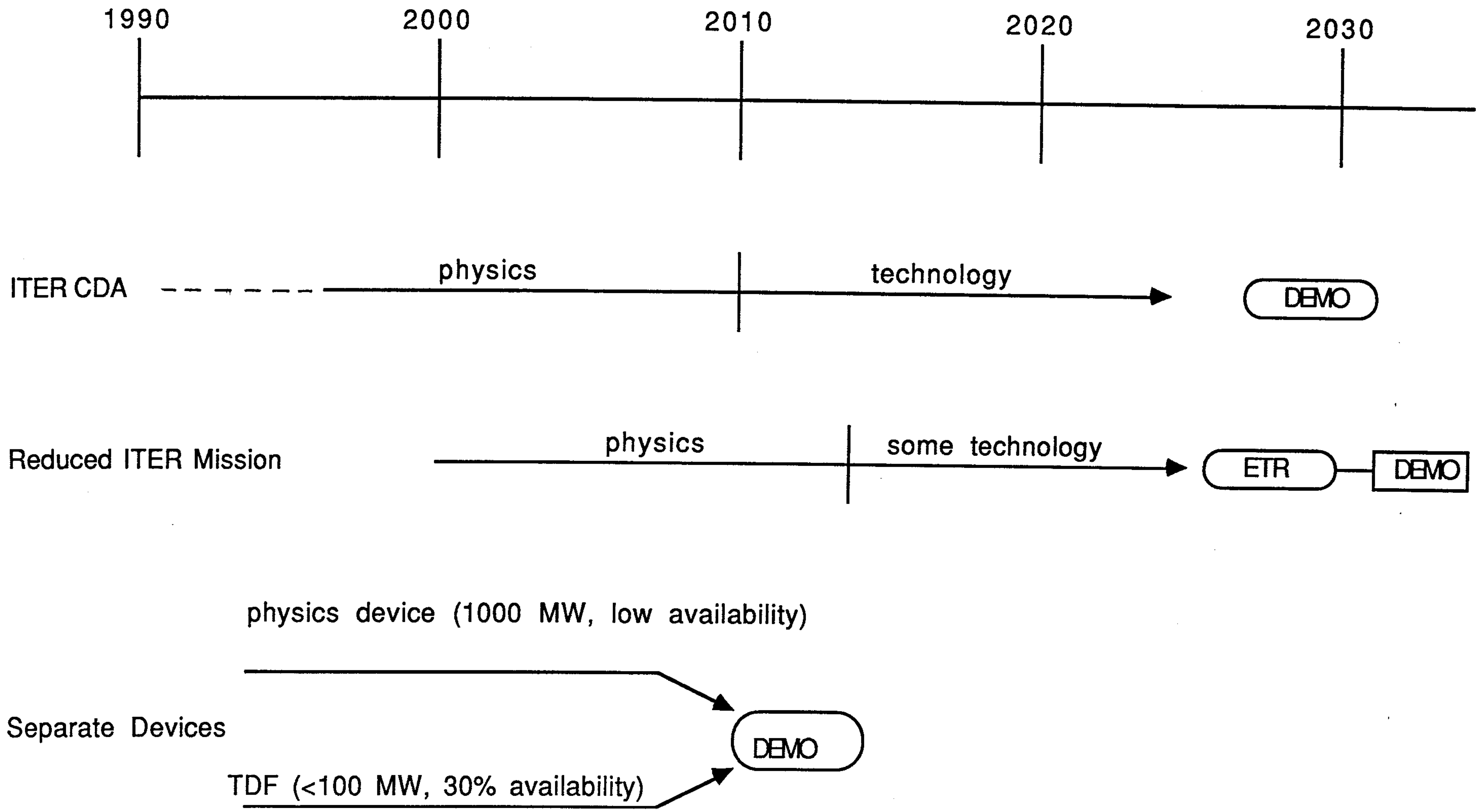
Fig. 25. Higher FERF availability leads to more test time and faster MTBF growth.

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

Alternative Pathways to DEMO

(Schematic for illustration purposes only; need to check time schedule, add other fusion and non-fusion devices including devices in the 1990's)



ITER R&D TASKS

(cost over 5 years in $M shown in parentheses)

TASKS		BREEDING BLANKET YES	BREEDING BLANKET NO	TEST PROGRAM
BLANKET				
BKT-1	**Ceramic Breeder Driver Blanket Development**			
BKT-1.1	Blanket materials development (19)			
BKT-1.1.1	Ceramic breeder performance	x		x
BKT-1.1.2	Beryllium multiplier performance	x		x
BKT-1.1.3	Insulator performance	x	x	
BKT-1.2	Fabrication and Scale Model Testing (57)			
BKT-1.2.1	Fabrication capability of materials	x		x
BKT-1.2.2	Fabrication of blanket modules	x	x	
BKT-1.2.3	Integrated out-of-reactor performance	x	x	
BKT-1.2.4	Integrated in-reactor performance	x		x
BKT-2	**Alternate Driver Blanket Development (25)**			
BKT-2.1	Lithium-lead performance and materials study	x		x
BKT-2.2	Blanket channel fabrication and testing	x		x
BKT-2.3	Near full-scale segment fabrication and testing	x		x

BKT-3	**Blanket/shield neutronics (10)**			
BKT-3.1	Bulk shielding performance	x	x	
BKT-3.2	Shielding performance with discontinuities and penetrations	x	x	
BKT-3.3	Biological shield performance	x	x	
BKT-3.4	Buildup of radioactivity and afterheat	x	x	
BKT-3.5	Tritium breeding	x		x
BKT-4	**Blanket test program (10)**			
BKT-4.1	Liquid metal blanket performance in ITER			x
BKT-4.2	Solid breeder blanket performance in ITER			x
BKT-4.3	Integrated performance of test modules			x

FUEL CYCLE

FCY-1	Fuelling (14)	x	x	
FCY-2	Vacuum Pumping (18.8)	x	x	
FCY-3	Fuel Processing (8)	x	x	
FCY-4	BLanket Tritium Recovery (8.5)	x		x
FCY-5	Common Processes (9)	x	x	

STRUCTURAL MATERIALS

STM-1	Stainless steel structural development (25)	x	x	
STM-2	Divertor structure and blanket stabilizer development (25)	x	x	
STM-3	Advanced first wall and blanket structural materials (10)	x	x	x