

# ITER Test Program TBWG Meeting

*US Summary on:*

- 1) US Situation
- 2) US Evaluation of R&D Requirements
- 3) Suggestions for Coordination

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# Current Situation in the US Fusion Program as it Relates to Test Program and Blanket R&D

- The US Fusion Budget was severely cut to \$244.1M in FY 96 (compared to \$365M)
- Congress asked DOE to restructure the program and to develop a new strategy assuming no significant increase in budget for the next several years
- A new Draft Strategy for fusion was issued by DOE for comments in October 1995.
- The Draft Strategy defines 3 Fusion Technical Issues:
  - Confinement concept improvements (Tokamak Optimization and Alternates)
  - Physics of Burning Plasmas
  - Low Activation Materials
- Specifically Relevant in the Draft Strategy:
  - Fusion Nuclear Technology was removed from the list of fusion issues
  - The Draft says that “The issue of fusion power technology, including blankets and tritium handling, is also fundamental and must be addressed in the future as part of a fusion energy development program; this issue will not be addressed by the restructured Program except for small-scale efforts in selected key areas.”

## Current Situation in the US (cont'd)

- The base blanket (i.e. the breeding blanket) program budget for FY 96 was very severely cut (to \$1M).
- The subject of the US blanket test program on ITER has been under discussion (together with many issues) in DOE. There is no policy decision yet.
- DOE asked FEAC to review and make recommendations concerning Strategy and Budgets for various elements of the Fusion Program assuming annual fusion program budget 200, 225, 250 and 275 million dollars per year for the next several years.
  - This exercise has involved wide participation of the fusion community
  - Deliberations are continuing
- It is only after FEAC completes its Strategy/Budget Deliberations and approval/modifications by DOE that there will be a US official policy.

## Budget for ITER and Base Technology for FY 95 and FY 96

	FY 1995			FY 96 \$244M			
	ITER	Base	Total	ITER	Base	Closeout	Total
Technology	39.9		39.9	25.8			25.8
Design - JCT	13.4		13.4	13.5			13.5
Design - HT	8.7		8.7	9.0			9.0
HT Management	3.0		3.0	1.8			1.8
Co-Center	3.9		3.9	4.3			4.3
Joint Fund	.6		.6	.6			.6
<b>Total</b>	<b>69.3</b>		<b>69.3</b>	<b>55.0</b>			<b>55.0</b>
<b>Technology Areas</b>							
Magnets	14.1	1.6	15.7	14.6	.7		15.3
ECH	1.5	2.9	4.4	.2	.6	.4	1.2
Fueling	1.0	.3	1.3		1.1		1.1
PFC	8.7	1.5	10.2	5.5	1.4		6.9
ICH	1.8	.5	2.3	.4	.3	1.0	1.7
ITER Materials	1.9		1.9	.5			.5
Blanket	4.8	1.0	5.8	1.8	.8	.2	2.8
Remote Handling	1.0		1.0	.7			.7
Tritium	1.2	1.3	2.5		1.4		1.4
Environ/safety	2.1	1.1	3.2	1.2	.7		1.9
Vessel	1.0		1.0	.7			.7
Diagnostics	.7		.7	.2		.1	.3
<b>Total</b>	<b>39.9</b>	<b>10.0</b>	<b>49.9</b>	<b>25.8</b>	<b>7.0</b>	<b>1.7</b>	<b>34.5</b>
PFC + Other							
		<b>FY 95 Total</b>	<b>79.3</b>	<b>FY 96 Total</b>	<b>63.7</b>		
Tax					.8		.8
Gen Reduction							.0
<b>Total</b>					<b>.8</b>		<b>.8</b>
<b>Grand Total</b>	<b>69.3</b>	<b>10.0</b>	<b>79.3</b>	<b>55.0</b>	<b>7.8</b>	<b>1.7</b>	<b>64.5</b>

# Summary of US FY 96 Budget for areas relevant to ITER Testing

Blanket	\$ 1M
Materials (IFMIF, Low Activation Materials)	\$ 8M
Tritium	\$1.5M
Safety	\$0.8M
(Part of System Study)	~ \$0.5M ?

## Observations

- 1) The MAJOR Problem is that the budget for the Base Blanket R&D Program has been cut to a very low level (\$1M).
- 2) It is conceivable that the US can be a viable partner (but not a full partner) if the Base Blanket R&D Program Funding is corrected to be at the 3 to 5 million dollars per year level.

## US Position Concerning ITER Test Program

- The Fundamentals have not changed
  - The US remains a partner in ITER EDA
  - The US community has always had the view that Technology Testing is a critical objective of ITER
- There is no policy decision that affects US participation in ITER Test Program
- The US intends to remain a participant in the ITER Test Program
- The budget problems, however, are real. The level of US participation in the ITER test program will depend on how the blanket R&D budget problem is resolved.
- Given the current situation in the US, TBWG is advised to proceed with its work plan assuming the US to be a participant.

## Cost Estimate for Required Blanket R&D for ITER Test Modules

- The US has conducted several comprehensive studies on Blankets:
  - Design and Selection (e.g. BCSS)
  - Characterization of Technical Issues and R&D Planning (E.G. FINESSE)
- In 1992, the US developed a detailed plan (including specific technical tasks) and cost estimates specifically for the R&D of the ITER Test Module  
(A copy of a summary document that describes this work with a cover letter from M. Abdou to T. James (DOE) is provided as a separate hard copy)
- This 1992 document remains the US best cost estimate and definition of technical tasks required for the R&D of ITER Blanket Test Module.
- For the purpose of TBWG, we have updated these cost estimates and made a cost estimate for test module construction.

**R&D PLAN FOR ITER TEST MODULE**  
**(Draft prepared by UCLA, April 1992)**

**Executive Summary**

An ITER test module R&D plan has been developed for a 15-year period, from 1992 to 2007, the date at which ITER operation is scheduled to start. It is assumed that test modules will be inserted in ITER from the start of operation. The R&D plan encompasses all needed R&D irrespective of any ongoing or planned activities. The plan focuses on two kinds of breeders, solid breeders and liquid metals, which have been extensively considered worldwide in various reactor conceptual design studies and for which a relatively large number of potentially attractive power reactor blankets exist.

In developing this R&D plan for blanket test modules, several assumptions are made covering the level of technology development prior to and during testing in ITER. First it is assumed that blanket technology will be aggressively developed in non-fusion facilities. This means that to the extent possible, all key issues will be resolved and engineering models and codes will be developed to the point where there is a high degree of confidence in the design and operation of the test modules. This degree of development is necessary to insure that no unexpected defects are present in the blanket modules which might jeopardize the operation of the entire ITER device. Second, it is assumed that the large number of blanket designs present today will be culled down to a relatively small number of candidates. During the course of non-fusion testing, some concepts will prove more attractive than others, and the tests in ITER will be focused on the most attractive designs. Finally, certain tests where there is high risk of failure will be performed outside ITER. Such tests include severe transients and test which will explore the ultimate performance limits of the blankets.

A number of major tasks have been identified in order to address issues associated with solid breeder and liquid metal blanket test modules. Figures 1 and 2 show test plans which have been developed for the ITER solid breeder and liquid metal test module respectively based on those generated as part of the FINESSE program and accounting for recent development. They show the major tasks and a time line of facilities and experiments required to accomplish these tasks. These test plan are also closely coupled to other R&D areas, such as structural material development and tritium processing. In all task areas, the test plan calls for a progression from smaller, simpler experiments to larger, more integrated ones requiring the construction of new facilities.

The total estimated R&D cost over 15 years for ITER test modules is shown below (excluding the costs for structural material and tritium processing R&D activities which are assumed to be carried out separately):

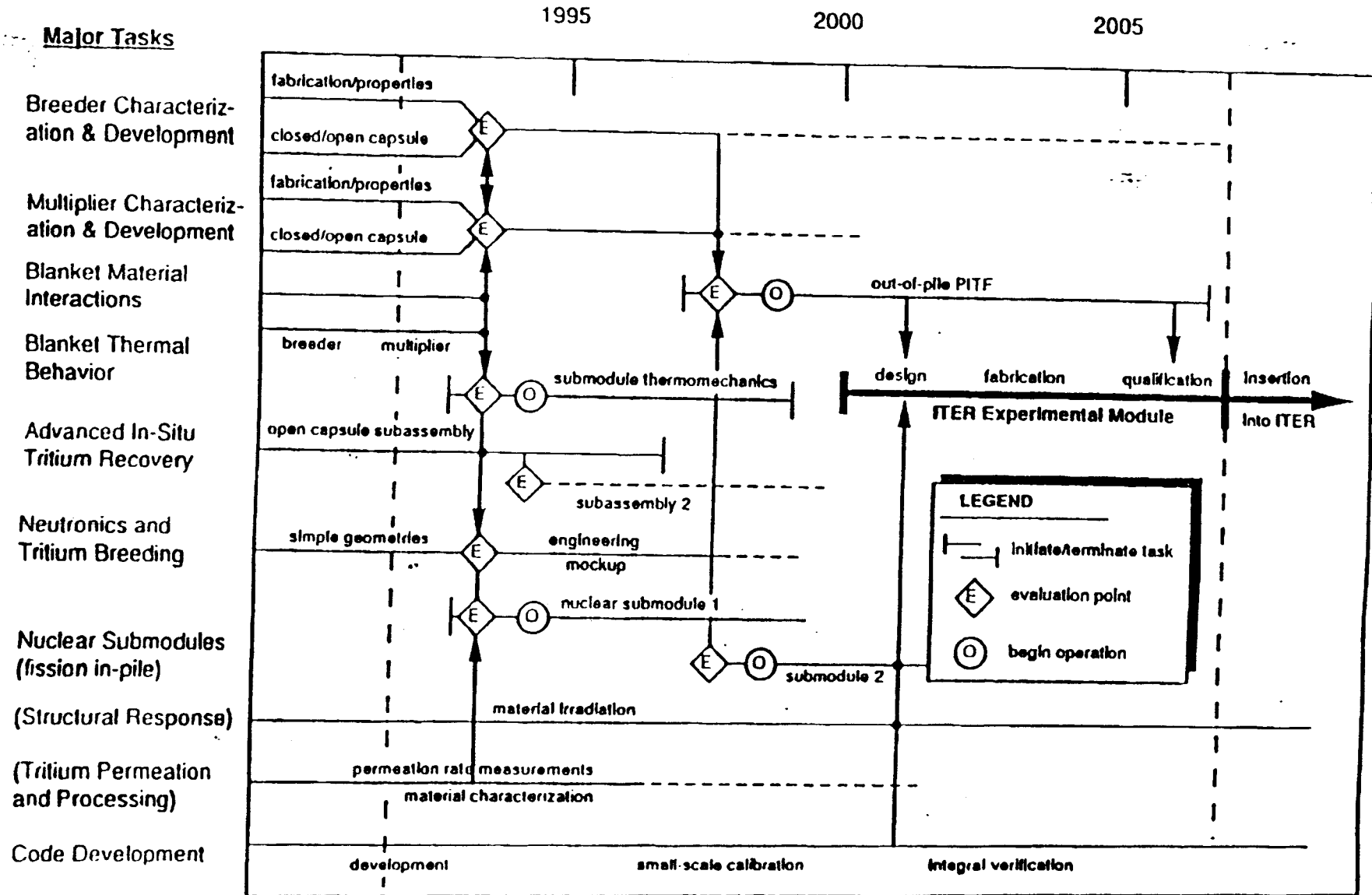
Solid breeder test module:	\$ 293M
Liquid metal test module:	\$ 180M
Neutronics:	\$ 94M
Test program interface:	\$ 40M
<b>TOTAL:</b>	<b>\$ 607M</b>

If a collaborative program between the four parties participating in ITER is assumed, the total annual R&D cost for ITER test module is about \$ 10M per party over the next 15 years.



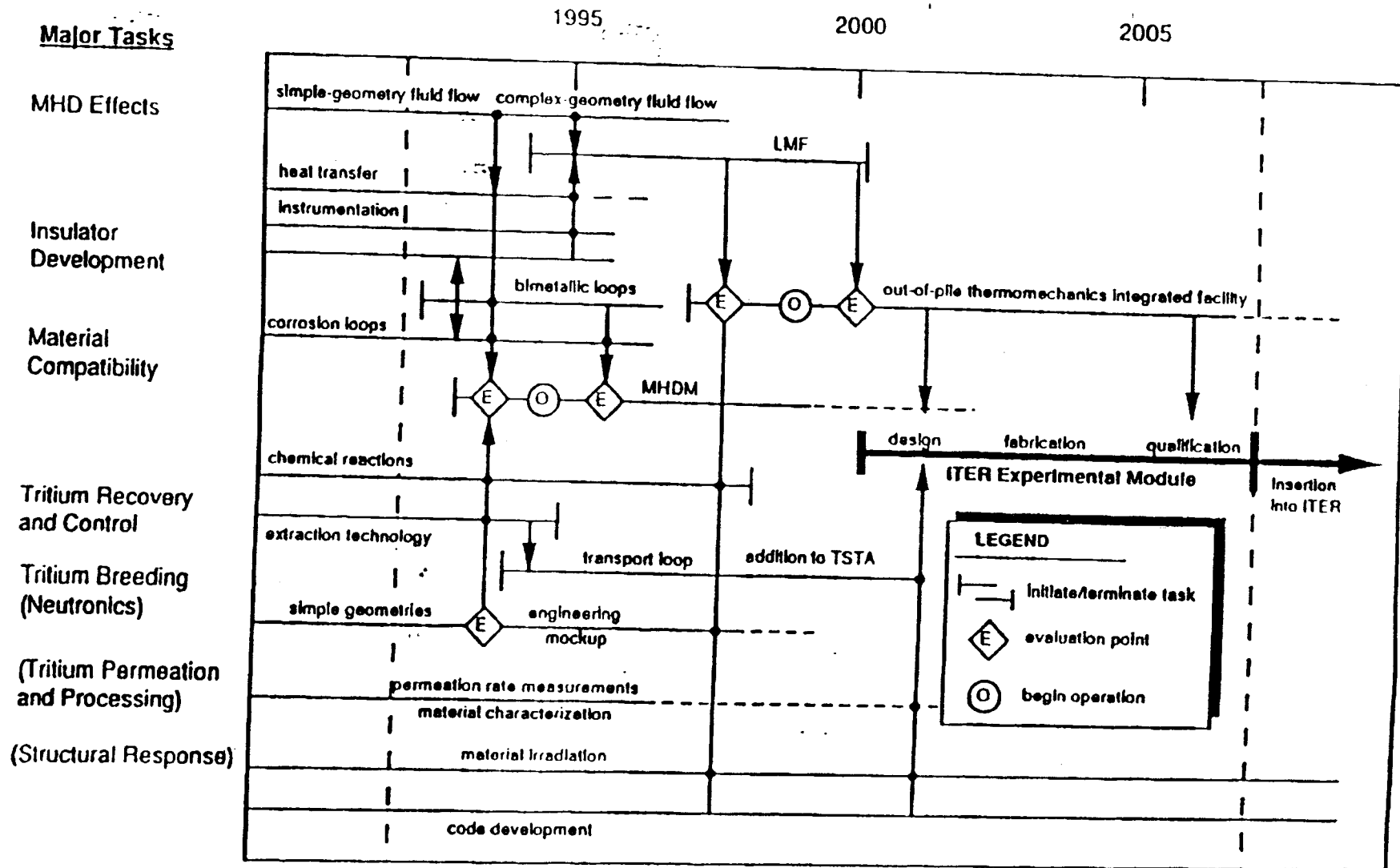
Figure 2 R&D Plan for Solid Breeder Blanket Test Module in ITER

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UCCLA

Figure 3 R&D Plan for Liquid Metal Blanket Test Module in ITER



# R&D For Test Program Interface

- Most of the R&D for nuclear testing in ITER is directly related to the R&D for the test modules
- However, a separate and important class of R&D issues is associated with the generic questions of
  - 1) how to do successful, safe and useful tests, and
  - 2) the impact of the test program on the ITER device
- Six tasks areas have been defined here (additional detailed write up is available)

## A. Test Program Validation

1. Demonstrate validity of Engineering Scaling
2. Demonstrate feasibility of data collection
3. Validate Safety Guidelines

## B. Engineering Design Issues

4. Interactions between test equipment and the base machine
5. Ancillary Equipment Systems Interfaces and Piping Issues
6. Removal and Replacement of Modules & Submodules

Table 1 Summary of R&D Cost Estimates for ITER Solid Breeder Test Modules

Tasks	Facilities	Capital Cost (\$M)	Average Operating Cost (\$M)	Years of Operation	Total Cost (\$M)
<b>SOLID BREEDER</b>					
Material Development & Characterization	Laboratory-scale & fission reactors		6	4	24
Blanket Thermal Behavior and Material Interaction	Laboratory-scale & fission reactors		6	5	30
	Submodule-size facility	4	3	6	22
	Out-of-pile facility	15 for facility 10 per blanket assembly	8	6	83 for 2 assemblies
Advanced In-Situ Recovery	fission reactor	10 per subassembly	2	6	32 for 2 sub-assemblies
Nuclear Submodules	fission reactor	12 per submodule	4	6	48 for 2 sub-modules
Code Development			1	15	15

**Total Cost for Solid Breed Test Modules**

- Assuming Only One Assembly and One Submodule 172
- Assuming Two Assemblies and Two Submodules 254

# Cost Estimate for ITER Blanket Test Program: Test Module R&D and Manufacturing

## A. R&D For Test Modules

- |  |          |
|--|----------|
| 1) R&D for Solid Breeder Test Modules<br>(Assuming Two Assemblies/Two Submodules)                | \$254M   |
| [This R&D Cost can be reduced to \$172M<br>If number of assemblies/submodules is reduced to one] | (\$172M) |
| 2) R&D for Self Cooled Liquid Metal Test Modules   | \$230M   |
| 3) Neutronics R&D and Verification [Per Blanket Concept]   | \$ 20M   |
| 4) R&D for Test Program Interface [Per Blanket Concept]  | \$ 20M   |

## B. Manufacturing R&D

Manufacturing R&D and Test Module Mockup [Per Blanket Concept] \$ 30M

## C. Manufacturing Costs for Test Modules

- |                               |        |
|-------------------------------|--------|
| 1) Solid Breeder Test Modules | \$ 20M |
| 2) Liquid Metal Test Modules  | \$ 20M |

Estimated Total Cost for ITER Test Program R&D and Construction:  
About \$300M per Blanket Concept

## Cost of ITER Blanket Test Program R&D and Construction: \$600M for TWO Blanket Concepts

- This cost does not include the cost of operation and associated Research Program during Testing Blanket Modules in ITER.
- This R&D cost for test modules assumes aggressive R&D in non-fusion facilities prior to testing in ITER. This means that to the extent possible, all key issues will be resolved and engineering models and codes will be developed to the point where there is a high degree of confidence in the design and operation of the test modules.
  - This is a prudent approach:
    - 1) to insure that no unexpected defects are present in the blanket modules which might jeopardize the operation of the entire device,
    - 2) testing time on ITER is too short to allow many iterations, and
    - 3) cost of testing on ITER (i.e. cost of ITER operation) is more expensive than non-fusion facilities

### Can the Test Blanket R&D Be Reduced?

- Yes: By doing less tests in non-fusion facilities.  
But this increases the RISK to BOTH ITER and Blanket Development
- Even if we are to take high risks, the best that can be done is to reduce the R&D cost by a factor of 2

# How Many Blanket Concepts Can One Party Develop for Testing on ITER?

Cost per year per Blanket Concept:

- At \$300M per concept (High Confidence Approach)

Cost per year per concept = \$30M for 10 years  
= \$20M for 15 years

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- At \$180M per concept (High Risk Approach)

Cost per year per concept = \$12M for 15 years

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- US Situation

- Given the current budget situation, the US can not afford to do the complete test module R&D even for one concept
- The best the US can probably do (assuming \$5M per year for US Base Blanket Program) is:

25% of R&D for one concept with the High Confidence Approach  
or  
40% of R&D for one concept with High Risk Approach  
[Both Cases are with the 15-year stretched out program]

Thoughts on  
IDEAL Cooperation  
On ITER Blanket Test Program

- \* Select TWO Reference DEMO Blankets as Common Concepts for Collaborative Development by All Parties
- \* One of the Reference Blankets can be led by Europe.  
The Other can be led by Japan.
  - The US can support one (or both of reference concepts)
  - Russia can also support one or both reference concepts
- \* Each party would be free to test other concepts beside the two common concepts (but perhaps at smaller scale and lower priority).
- \* The ITER Basic Breeding Blanket Concept need to be developed and tested in addition to the TWO MAIN Reference Concepts.



# Division of Responsibilities Among the Parties on ITER Blanket Test Program

## Steps to Arrive at a Practical Division

- 1) **Agree on TWO Reference Blanket Concepts** [The idea of only ONE Reference Blanket should also be discussed]  
  
(This does not preclude an individual party from pursuing additional blanket concepts if they have enough resources)
- 2) **Assign One Lead Party for Each Reference Concept**
  - Other parties serve in a support role
- 3) **Agree on a Matrix that has two dimensions**
  - A) **Test Articles** (e.g. One look-alike, two act-alike, and six submodules)
  - B) **R&D Tasks: Definition and Work Breakdown Structure**
- 4) **Divide the Work Among the Parties by Test Article and R&D task** (Based on resources, capabilities, and interests of each party)

## How Many Modules/Submodules Need to Be Tested in ITER For Any Given One Blanket Concept?

- Never assume one module because engineering science for testing shows the need to account for:
  1. Engineering Scaling
  2. Statistics
  3. Variations required to test operational limits and design/configuration/material options
- The US detailed analysis in this area indicates that a prudent medium risk approach is to test the following test articles for any given One Blanket Concept:
  - One Look-Alike Test Module
  - Two Act-Alike Test Modules  
(Engineering Scaling laws show that at least two modules are required, with each module simulating a group of phenomena)
  - Four supporting submodules (two supporting submodules for each act-alike module to help understand/analyze test results)
  - Two variation submodules (material/configuration/design variations and operation limits)

## R&D Tasks For Solid Breeder Test Module

1. Design & Analysis
2. Breeder Characterization & Development
3. Multiplier Characterization & Development
4. Tritium Control Including Permeation Barrier Development
5. Breeder/Multiplier Thermomechanics (Out-of-Pile)
  - Unit Cells
  - Submodules
6. Safety Related Tests & Analysis
7. Tritium Extraction from Purge Streams
8. Fission Related Tests  
[advanced in-situ tritium release, material interactions, and synergistic effects]
  - 2 Submodules

# How Many ITER Test Ports Are Required to Test ONE Blanket Concept?

At least two ports, each port is  $3\text{m}^2$  at the first wall,  
for testing one blanket concept

- One Look-Alike Module:  $> 1 \text{ m}^2$
- Two Act-Alike Modules:  $> 2 \text{ m}^2$   
(2 modules x  $1 \text{ m}^2/\text{module}$ )
- Six Submodules:  $\sim 3 \text{ m}^2$   
(6 submodules x  $0.5 \text{ m}^2/\text{module}$ )

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Total  $> 6 \text{ m}^2$   
(i.e. at least two ports)

# ITER TEST PORT ALLOCATION

- One port for testing basic breeding blanket during BPP
  - The Same Port can be used for Material Testing During EPP
- Two Ports for Reference Blanket 1
- Two Ports for Reference Blanket 2  
(or for alternate concepts individual parties may wish to pursue if only one reference concept is selected)

# Summary of R&D Estimates and Test Port Allocation

- Realistic evaluation shows:

- 1) The total cost for R&D and construction of test modules for one blanket concept is about \$300M (i.e. \$20M per year over 15-yr. period)  
[The recent European Cost Estimates are consistent with the US estimates]
- 2) A minimum of two ports are required to test one blanket concept.
- 3) Given only 5 test ports in ITER, they should be assigned as follows:
  - One for ITER base breeding blanket during BPP, and for material testing during EPP
  - Two ports for a world reference concept
  - Two ports for a second world concept (or alternative concepts for individual parties)

- The US Task Area Leader for the ITER Test Program has made suggestions for a true collaborative world program on blankets:

- All parties would collaborate on only TWO Reference Blanket Concepts
- These concepts would receive the highest priority in ITER Testing
- Each concept would be led by one party. Other parties would play a support role

# SUMMARY of US Situation

- The US community considers the Technology Test Program a very important part of ITER.
- The US ITER Home Team is prepared to fully contribute to the ITER Test Program issues related to EDA:
  - Test Port Design
  - Test Program Requirements, Definition, and Interface
  - Example Test Article Design
- The US Fusion Program has budget problems. FEAC is evaluating priorities.
- The US Base Blanket Program has been severely cut (to \$1M/year):
  - At this level, it is impossible for the technical experts to do any reasonable planning concerning R&D for test modules.
- The Technical Community in the US is eager to participate in the World Blanket R&D and ITER Testing. However, programmatic decisions need to be made by the US.
- Since TBWG reports to the Program Directors in the Four Parties on the Blanket R&D Tasks, TBWG Chairman may wish to submit a report to the Program Directors advising them of the implications of the current situation in the US blanket program.

Design Specifications and Interface  
Requirements of US Solid Breeder Blanket  
Test Program in ITER

Presented by  
Alice Ying

UCLA

Second Meeting of the ITER Test Blanket  
Working Group

San Diego JWS  
Jan. 17-19, 1996



## Test Objectives

The main objectives of solid breeder testing in ITER BPP include:

- investigating DEMO relevant blanket integrated performances in a fusion environment
- testing and developing experimental techniques and instrumentation
- observing effects of rapid changes in properties in early life
- calibrating non-fusion tests against performance in the fusion environment
- evaluating material combinations and design concepts
- validating code/model predictions

# Test Types

- Large scale module integrated tests
- Supporting submodule tests
- Variation submodule tests (advanced and high performance concept explorations)

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- *Reference DEMO blanket concept to be tested:*

*He-cooled/Be/Li<sub>2</sub>TiO<sub>3</sub>(Li<sub>2</sub>O)/FS*

- *SiC/SiC composite and vanadium are the two candidate low activation structural materials and would be tested in the submodule configurations.*

- *To maximize the test benefits and to obtain DEMO relevant data, the test modules are designed based on engineering scaling rules.*

# Test Article Design Approach

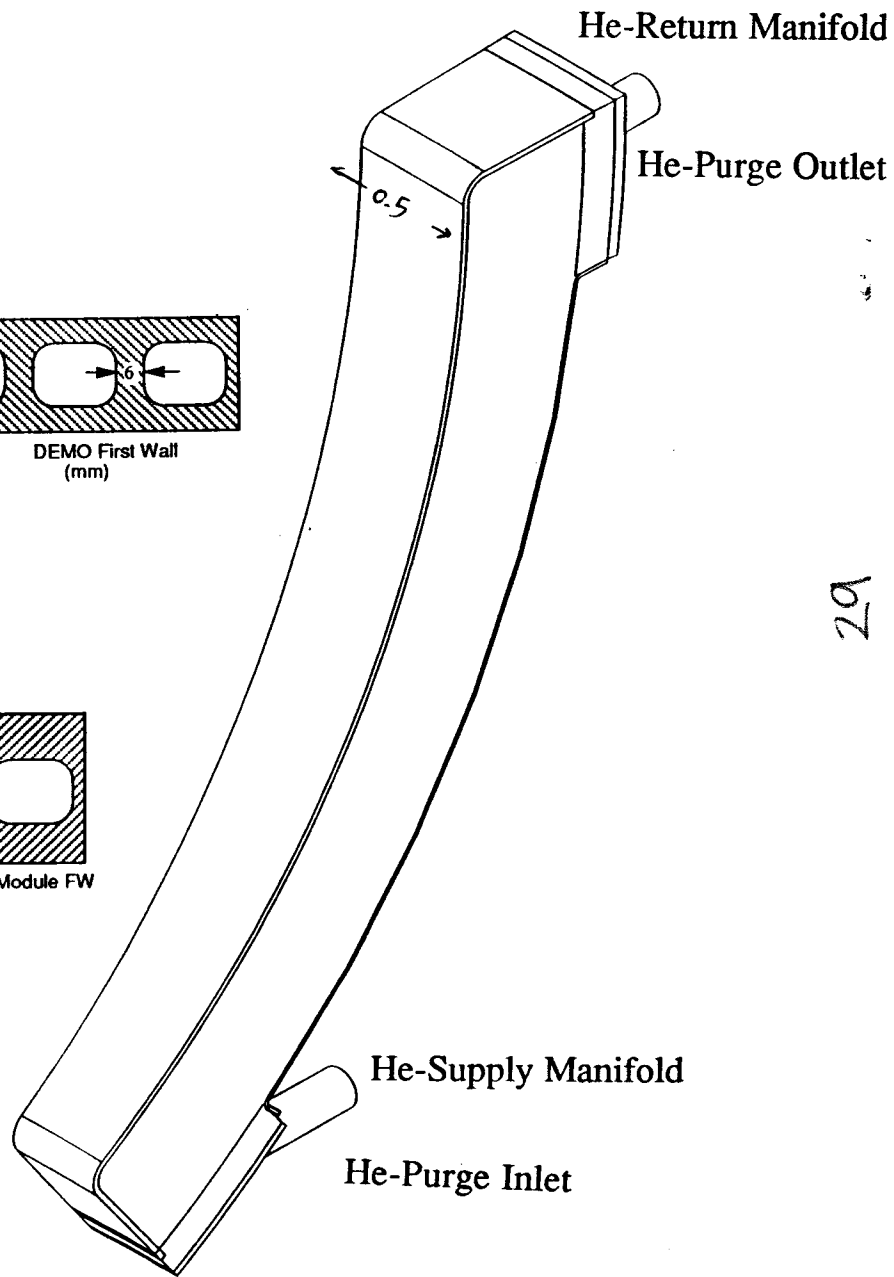
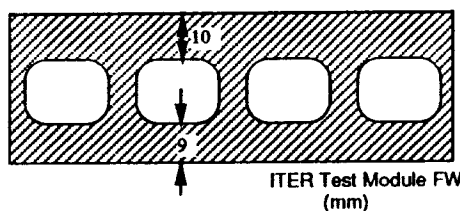
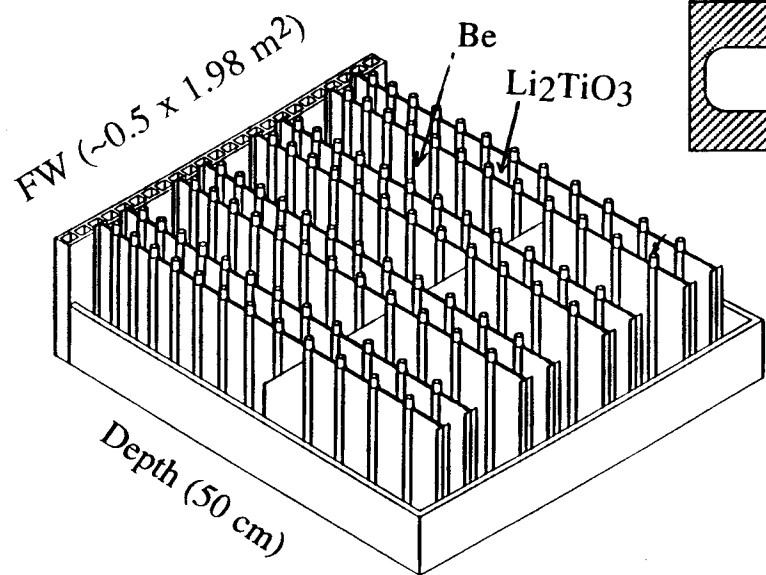
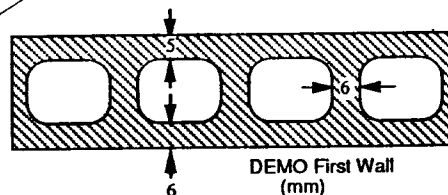
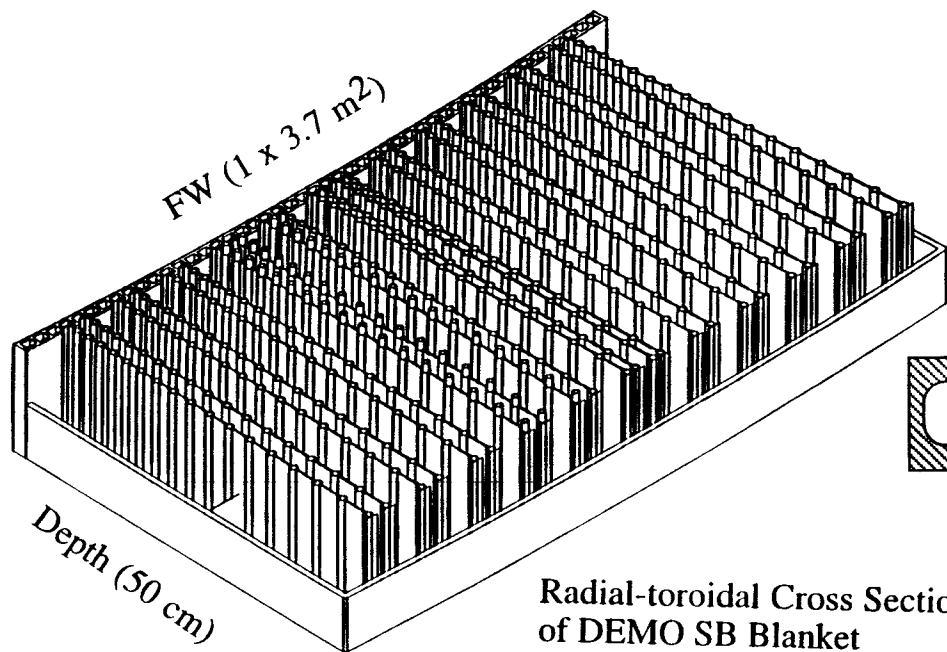
*Include essential features of the DEMO solid breeder blanket design- containing breeder, neutron multiplier, structure, and coolant in a subscale configuration prototypical to that of the reference blanket concept*

- **DEMO Act-alike**
  - It is impossible to address all the issues within a subscale module under scaled-down environmental conditions, the functions of integrated testing has to be distributed over several act-alike test modules, with each test article emphasizing a group of issues/phenomena
  - Multiple test articles are generally needed to distinguish any statistical variation
- **Factors determining the size of the test article:**
  - DEMO design feature(e.g., poloidally cooled vs toroidally cooled)
  - Boundary effects (e.g., sensitivity of performance parameter response to the surrounding environment/materials)
  - Test data resolution (e.g., uncertainty associated with the measuring quantity such as tritium concentration in the purge stream )

## Design Features of Large Scale Solid Breeder Test Article

- Breeder-Out-of-Tube (BOT) Concept
- Both the solid breeder and the Be are in the form of sphere-packed beds
- First wall and blanket are all poloidally cooled
- Solid breeder and Be regions are separated by coolant-panels
- The first wall is an integral part of the blanket module
- The shield is separate from the blanket (but can be incorporated readily as an integral part of the blanket module)
- The first wall and the blanket coolant panels use one manifold

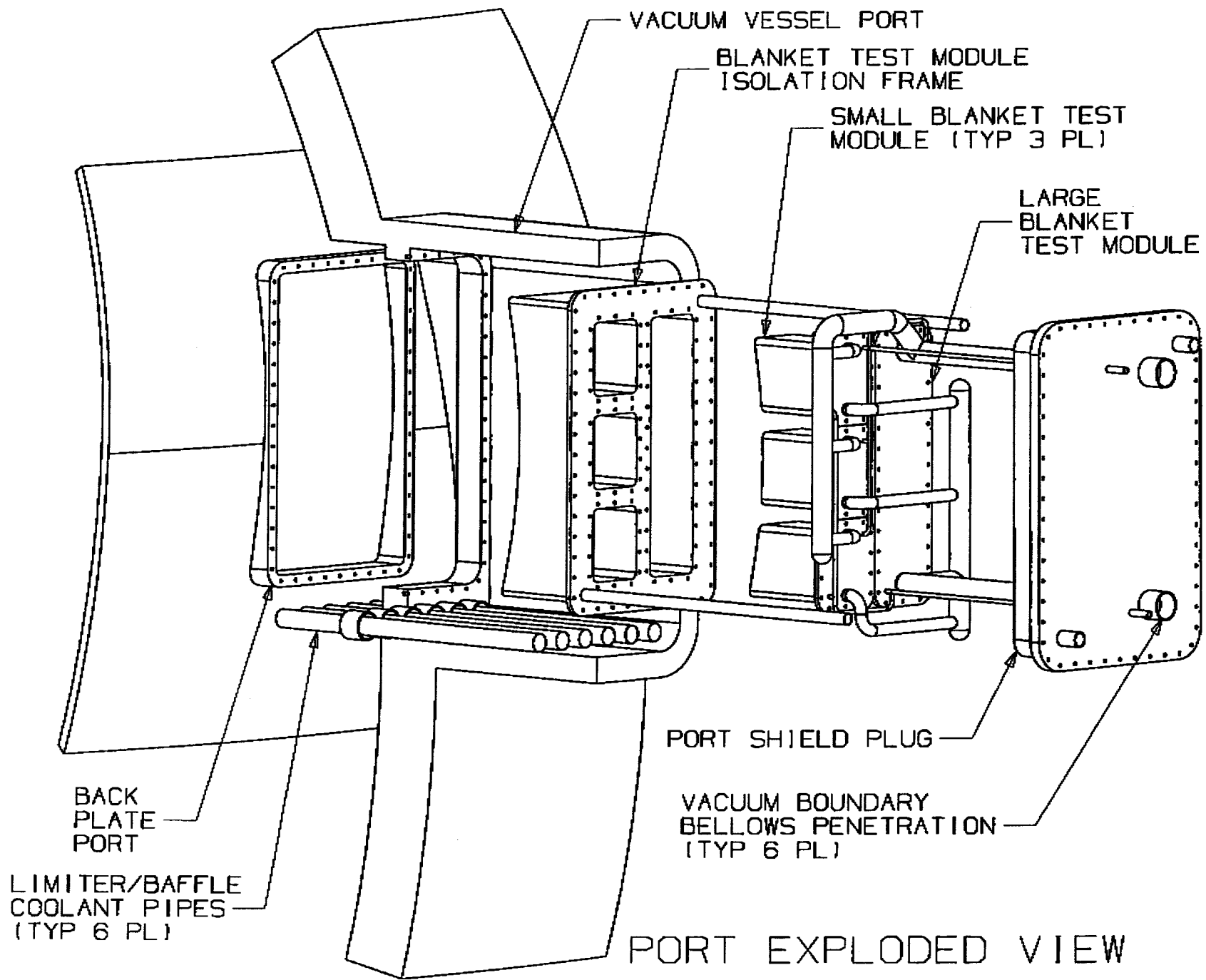
# Schematic View of the ITER Test Module Design for Reference DEMO SB Blanket



## Test Article Specifications

Parameter	Large Scale DEMO Test Article	Supporting Submodule Tests	Advanced Concept Exploration	High Performance Exploration
Dimensions, m <sup>3</sup> (WxHxD)	0.5 x 1.982 x 0.6	0.5 x 0.5 x 0.6	0.5 x 0.5 x 0.6	0.5 x 0.5 x 0.6
FW Exposure/Fluence*	Yes/0.3	Yes/0.3	Yes/0.3	Yes/0.3
No. of Test Articles	1	1-2	1	1
Materials				
PFC	Be	Be	Be	Be
First wall	Ferritic steel	Ferritic steel	Vanadium	SiC/SiC
Structure	Ferritic steel	Ferritic steel	Vanadium	SiC/SiC
Breeder	Li <sub>2</sub> TiO <sub>3</sub>	Li <sub>2</sub> TiO <sub>3</sub>	TBD	TBD
Multiplier	Be	Be	TBD	TBD
Coolant	He	He	He	He
Shield	SS	SS	SS	SS
Coolant Conditions				
Inlet Pressure, MPa	10	10	10	10
Inlet/Outlet Temp.	350/450	350/450	350/450 <sup>+</sup>	350/450 <sup>+</sup>
Flow Rate, kg/s	3.7	1.0	1.0 <sup>+</sup>	1.0 <sup>+</sup>
Maxi. Structure Temp.	550 °C	550 °C	650 °C	1000 °C
Weight				
Blanket, total	1200 kg	400 kg	TBD	TBD
Shield	TBD	TBD	TBD	TBD

\* MWy/m<sup>2</sup> ;+ Higher temperature is preferred.



SOLID BREEDER TEST MODULES

# Heat Removal System Descriptions

- Primary Helium Coolant Loop

## A. Operating Parameters

<i>Parameter</i>	<i>Values (desirable)</i>
Total thermal power/port	~ 6.2 MW
Inlet temperature	300 - 350 °C
Outlet temperature	450 (- 650) °C
Inlet pressure	10 (5-20) MPa
Fractional pressure drop	5 %
Flow rate (total)	12 kg/s
Coolant volume in loop	TBD
Total coolant volume in test articles	0.265 m <sup>3</sup>

## B. Components

Recirculators, piping and valves, makeup and surge tanks, a pressurizing system, a purification system, a heat exchanger system, and instrument sensors.

- Secondary Cooling Loop

- *Design Approach (to be discussed)*

An intermediate closed water heat transport loop will be employed for the helium-cooled Test Blanket Modules/Articles to reduce the temperature to a level compatible with the plant secondary loop defined in GDRD Section 5.12.3.2.



# Tritium Processing Requirements

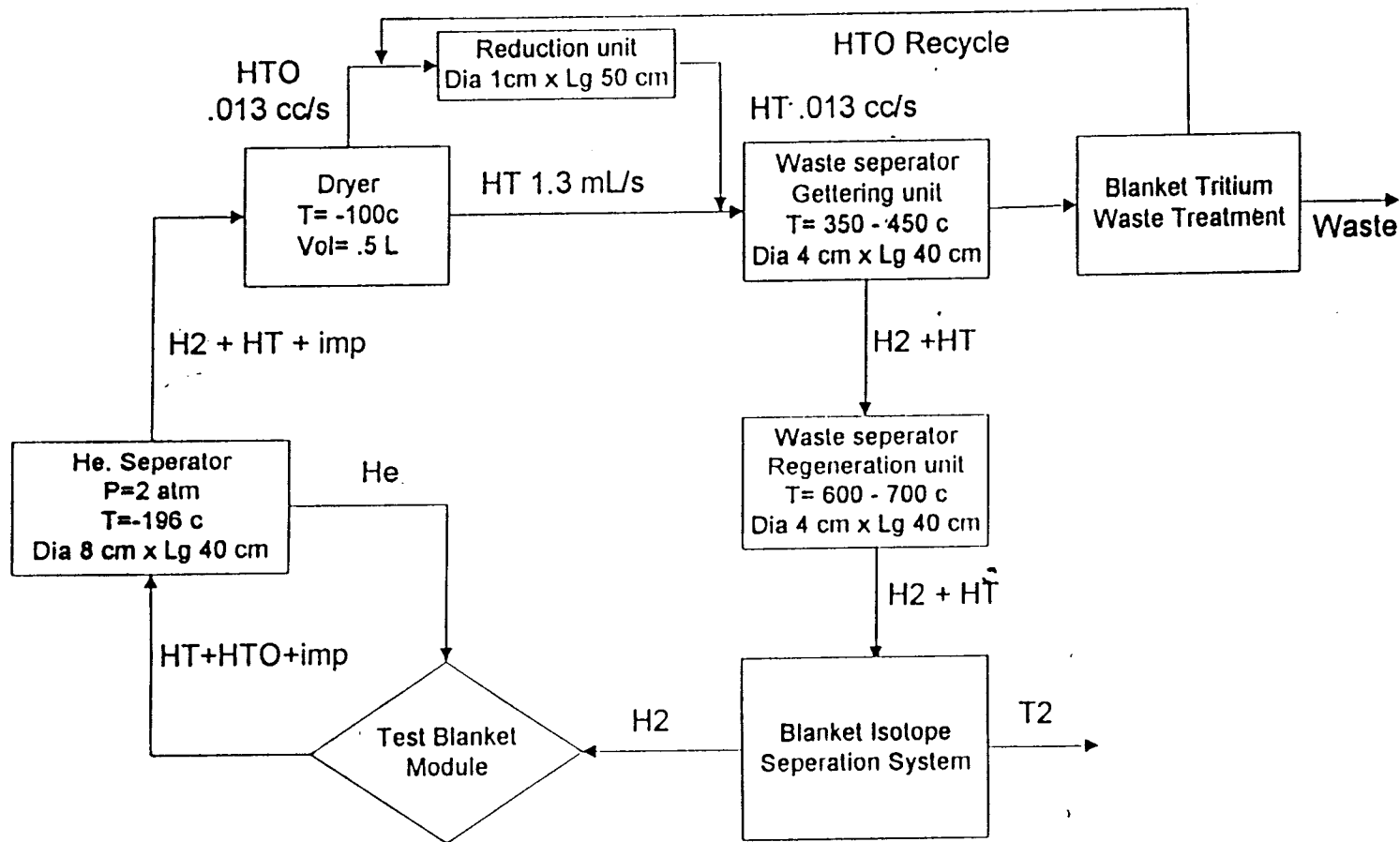
## Purge Gas Parameters

Tritium production rate	0.0115 g per 1000 s burn
Purge gas stream	He + (0.2-1 %) H <sub>2</sub>
Purge gas pressure	0.1 - 0.2 MPa
Purge gas inlet/outlet temperature	25/450 °C
Purge gas flow rate	2.15x10 <sup>-3</sup> m <sup>3</sup> /s
Tritiated species partial pressure	5 Pa
Tritium form	HTO, HT

## Tritium Processing System

- *Functionality*
  - The tritium processing system is to recover tritium from the solid breeder test modules to within an allowable tritium inventory in the testing modules.
  - The tritium recovered is to be processed to a purity required by the plant ISS.

# Tritium Recovery System for Solid Breeder Blanket Concept



## Interface Description and Main Parameters

- The test blanket modules will be attached to the Shielding Blanket Backplate to minimize the electro-mechanical loads transferred to the Vacuum Vessel(VV).
- The test blanket modules will be operated at higher temperatures, therefore thermal isolation is needed between the test modules and backplate.
- The weight of the test blanket modules will be transmitted to the VV through the standard shield blanket structural support.
- The main parameters include temperature, temperature gradient and loads [TBD].

## Abnormal Condition Descriptions

- Possible abnormal conditions for helium-cooled solid breeder test modules include:
  - overpressure due to loss of flow transient
  - melting due to loss of coolant accident
  - catastrophic failure due to disruption loads
- Provisions such as a pressure suppression system shall be incorporated in the design of the test modules to mitigate these consequences.
- All Test Blanket Modules/Articles attached to the Shielding Blanket Backplate will minimize the electro-mechanical loads transferred to the Vacuum Vessel. Consequently, the Backplate in the test port area shall be reinforced to accommodate the transmission of these loads.

## Diagnostic Requirements

- The test pieces will be instrumented to measure temperatures, coolant pressures, strains, deflections and leaks.
- Tritium concentration in the purge stream and coolant flow will be monitored and evaluated in terms of operational parameters (such as temperature, operating scenario, purge gas flow characteristics and permeation loss).
- Instrument sensors for measuring flow rates, temperatures and pressures will be installed in the coolant flow loops.
- Radioactive mass transfer in the coolant system will also be monitored.
- The conditions experienced by the test article in each burn-dwell cycle must be measured: surface heat flux, neutron flux, spectrum and forces (In addition, bulk heating measurements are necessary to interpret the data of temperature and thermal stress).