Nuclear Testing Mission in ITER-

R&D Cost Estimates and Program Details for the ITER Blanket Test Program

- Highlights of the 2nd TBWG Meeting
- The European Blanket R&D Programme
- JA DEMO Blanket Development R&D Program
- US Situation and Role in the ITER Blanket Test Program

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Highlights of the Second Test Blanket Working Group (TBWG) Meeting and Nuclear Testing Mission in ITER

- The 2nd TBWG meeting was held at the San Diego ITER JWS on January 17-19, 1996.
- The test blanket program general design requirements document were developed and reviewed. The document will be incorporated into the ITER GDRD.
- Each Party was asked to present materials concerning the national test blanket development plans and proposal for coordination, with emphasis on:
  - cost estimate for the R&D program required to develop and qualify the considered test articles (including ideally the test article fabrication costs),
  - the national budget devoted to this program,
  - the main R&D lines of the program for the coming years.
- The Director stressed the need for the completion of ITER test blanket DDD and DDR by Oct., 1996.

Specific Actions Regarding ITER Test Blanket Interface

- The US [because the US has correctly addressed the integration issues] is asked to lead the test port integration design using EU He-cooled ceramic breeder blanket design as the reference blanket concept.
- No definite conclusion can be made with regard to the test port allocation:
  - design concept oriented test space requirement
  - R&D realism toward the qualification of ITER test modules [Will there be any Li/Vanadium test module for testing on the ITER time scale?]
  - Number of ITER test ports required to test one blanket concept
- It is agreed that each Party will provide the facilities [such as ancillary equipment, tritium processing system, special hot cell equipment, etc.] required for its proposed blanket test program[The parties are to provide the JCT with specific ancillary equipment layouts for the test concepts by the end of April.]
- As part of ITER DDR, a draft blanket test plan will be developed and circulated by JCT.

Summary of Key Points Concerning Test Blanket R&D

- All parties (except RF) agreed that the cost required for R&D and module construction per DEMO blanket concept over the 10 to 15 years is about 200 to 300 $M.
- The EU and Japan consider that ferritic steel is the only low activation material available for testing on ITER. [The TBWG concerned the consequences of the misinterpretation of the use of the word "low activation materials".] Japan believes the composition of this material is finalized and they need only modest investment to do irradiation testing. EU indicated the same.
- The Parties agreed on the need to consider Two Common Reference World Blankets which all parties would collaborate on [based on the US suggestion]. The US will adopt the EU helium-cooled ceramic pebble bed design as the reference SB blanket concept.
- The TBWG Chairman has agreed to request that the four Program Directors report on plans for blanket R&D coordination and resources to be allocated for the ITER test program.

Summary of EU Blanket R&D Programme

- The principal medium term goal is to develop and build DEMO-relevant test modules for testing in ITER (only 2 concepts):

  - a water-cooled lithium-lead concept (WCLL)
  - a helium-cooled ceramic breeder pebble bed concept (HCPB)
  - (Adopt Low Activation Martensitic 7-19% Cr Steels for blanket structural material; Eliminate Self-Cooled Liquid Metal Concepts)

- The EU blanket development programme combines blanket, related materials work and safety and reliability studies.

  There will be a management committee for the Blanket Program with one leader for the He-cooled ceramic breeder concept and one leader for the LiPb-water concept. (Materials will be part of the Blanket Program)

- The EU Blanket Program will proceed in 4 phases:

  Phase A: Technology oriented phase (1995-2000)
  Phase B: Test Blanket oriented phase (2001-2005)
  Phase C: Manufacturing R&D for ITER test blanket inc. mock-up (2006-2010)
  Phase D: Manufacturing costs for test modules & infrastructure (2006-2010)

Summary of Cost Estimation for the EU Blanket Development Programme

- The medium-term blanket R&D programme cost estimates up to module testing in ITER (1995-2010) are:

  - 205.4 MECU ($265M) for the He-cooled ceramic breeder concept
  - 162.7 MECU ($212M) for the water-cooled LiPb concept

- This corresponds to an average annual budget of about 23.06 MECU ($30M) over a sixteen year period 1995-2010.

- The average annual costs for the first two phases have been estimated as follows:

  - Phase A: Technology oriented phase (1995-2000): 25.8 MECU/year
  - Phase B: Test Blanket oriented phase (2001-2005): 22.9 MECU/year

- The annual budget for blanket related work in the EU long-term technology programme, approved up to the end of 1998 is 21.1 MECU/year (12.5 MECU/year for blanket alone).

Summary of Japan DEMO Blanket Development R&D Program

- Near-term R&D plan is to develop DEMO modules for testing in ITER. Two DEMO blanket concepts are selected:
  - A water-cooled solid breeder blanket
  - A helium-cooled solid breeder blanket

  Both blankets use low activation ferritic steel (F82H) as structural material [material composition is finalized; yet irradiation testing in HFIR will continue to establish operating limits]

- JAERI submitted officially a plan to STA to have test blanket R&D and construction as a project starting April 1996 with $120M cost for 10 years for equipment and facilities.
  (The personnel budget is additional and it is covered under JAERI's base budget.)

- The DEMO test module R&D plan includes 4 categories:
  - Materials Irradiation Test (1996-2001)
  - Technology Development (1996-2001)
  - In-pile & Out-of-pile Module Testing (1999-2005)
  - Facility Upgrade (1997-2000)

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.

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)
SOLID BREEDER					
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 (Assuming Two Assemblies/Two Submodules)	$254M
	[This R&D Cost can be reduced to $172M 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

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

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

- <u>US Situation</u>
  - Given the current budget situation, the US can <u>not</u> 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.

Appropriate Budget Allocation for US ITER Test Program

- Without the nuclear testing mission, the benefits of ITER may be viewed as insufficient to justify a large expense of ITER (It was the US that fought so hard for ITER's nuclear testing mission).

- At the $1M/yr budget level for FY 96 we can do very little.

  - inadequate human resources
  - questions concerning international collaboration

- At 3 to 5 million dollar per year in the base blanket program, the US can be a strong player.

  - do enough R&D to be a viable international partner
  - have enough human resource skill base
  - allow exploration of blanket constraints and options that lead to attractive fusion systems

- The priorities in the US's base blanket/material/tritium processing/safety program need to be re-examined.

Appendix

TBWG-2

ITER-San Diego Joint Work Site
January 17-19, 1996

The European Blanket R & D Programme

- Cost Estimates and Programme Details -

The EU tritium breeding blanket R & D programme has the principal medium term goal of developing and building DEMO-relevant test modules for testing in ITER. The programme includes two blanket concepts; a water-cooled lithium-lead concept (WCLL) and a helium-cooled pebble bed concept (HCPB).

An overview of the cost estimates for the EU blanket development programme for the period 1995-2010, up to testing blanket modules in ITER, is given in the attached table 1. The figures include both blanket; related materials work and safety and reliability studies.

The average annual costs for the first two phases have been estimated as follows:

- Phase A: Technology oriented phase (1995-2000): 25.8 MECU/year

- Phase B: Test Blanket oriented phase (2001-2005): 22.9 MECU/year

Manufacturing R & D and the test module specific work, including mock-ups together with manufacturing costs, would come mainly in the later part of the programme. Adding the cost of this phase C & D work to Phases A and B would give an average cost/year of 23.06 MECU over the sixteen year period 1995-2010.

Budget figures for blanket related work in the EU long-term technology programme, approved up to the end of 1998 are given in Table 2. The current average annual budget figure from the long-term technology programme for 1995-1998 is 21.1 MECU/year (23 MECU/year including work on the neutron source IFMIF). The cost estimates given above should, however, be regarded as first estimates. They have been derived for new facilities and for the two concepts separately. It may be possible to use or adapt some of the existing facilities, which would result in cost savings. In the detailed integrated programme for the two concepts, to be finalised during 1996, further rationalisation is necessary. Additional cost savings should be possible through greater collaboration between partners within the framework of the ITER-TBWG.

The main elements of the R & D programme for both the blanket specific work and the related structural materials work are listed in the annex.

Table 1

Medium-term blanket R & D programme cost estimates up to module testing in ITER
(1995-2010)
(MECU)

Blanket R & D Phase	HCPB	WCLL	WCLL + HCPB
A: Technology oriented phase 1995-2000 (6 years)	90.5	64.5	155 (Av. 25.8/year)
B: Test blanket oriented phase 2001-2005 (5 years)	66.7	47.6	114.3 (Av. 22.9/year)
C: Manufacturing R & D for ITER test blanket inc. mock-up	29	36.6	65.6
D: Manufacturing costs for test modules & infrastructure	19.2	14.0	33.2
TOTALS (MECU)	205.4	162.7	368.1

NOTE: Whilst the figures were derived for a programme spanning eleven years (1995-2005), the current status of development on ITER indicates a more probable test date of 2010, thus giving a sixteen year period. On this basis a first approximation for an average annual cost is 23.06 MECU/year.

Table 2

Long-term technology programme - current blanket related budget figures
(1995-1998)

(IFMIF not included)

Blanket: 50 MECU

Materials: 26.26 MECU

Safety: 8 MECU

TOTAL: 84.26 MECU (Average: 21.1 MECU/year)

(Note: Materials budget includes 26.26 MECU relevant to ITER test modules + 2.17 MECU for SiC/SiC & Vn studies, giving a total of 28.43 MECU)

Annex

Work Packages (WP) for EU Blanket programme

Group A: Water-cooled Lithium-Lead Blanket (WCLL)

WP-A-1: Design and Analysis

- A1-1 DEMO blanket segments and system (i.e., external components)
- A1-2 ITER test module and external circuits
- A1-3 Analysis and Modelling
- A1-4 Reliability/Availability Analysis

WP-A-2: Fabrication, Assembly and Development Studies of Blanket Segment

- A2-1 Segment-box and headers
- A2-2 Double wall tubes fabrication and testing
- A2-3 Nuclear qualification for licencing of components and fabrication procedures

WP-A-3: Pb-17Li Physico-Chemistry Experiments

- A3-1 Purification from corrosion products, impurities, activation products (hot cell work) and from products from reaction with water
- A3-2 Products redeposition within the blanket system
- A3-3 On-line monitoring and stabilisation of the Li-content

WP-A-4: MHD

- A4-1 Evaluation of the MHD effects
- A4-2 MHD-related experiments
- A4-3 R&D activities for self-cooled concepts

WP-A-5: Tritium Control including Permeation Barriers

- A5-1 Pb-17Li-side and water-side permeation barrier development
- A5-2 In-pile testing
- A5-3 Out-of-pile testing on permeation barrier
- A5-4 Investigations on electrical insulation barriers for self-cooled concepts

WP-A-6: Tritium Extraction

- A6-1 Experiments and evaluation on T-extraction from Pb-17Li
- A6-2 Experiments and evaluation of T-extraction from water

WP-A-7: Safety related Activity for DEMO and ITER Test Module

A7-1 Blanket system safety-assessment
A7-2 Definition of safety-related devices
A7-3 Water-Pb/17Li interaction - Large-leak experiments
A7-4 Water-Pb/17Li interaction - Small-leak experiments
A7-5 Water-Pb/17Li interaction - Reaction products behaviour experiment

WP-A-8: ITER Test Module System and Testing

A8-1 Small-size test-object system out-of-pile testing
A8-2 External circuit components testing
A8-3 Pb-17Li-circuit instrumentation and minor components development

Material Compatibility Experiments

(NOTE: The following tasks will be covered by the Materials Unit but there will be an interface with the blanket specific work)

Interaction with Materials unit on:
- Pb-17Li corrosion of structural material and T-permeation barriers in presence of magnetic field and in the external circuits
- Water corrosion of structural material and T-permeation barriers
- Water-chemistry definition
- Structural material embrittlement

Group B: Helium-Cooled Pebble Bed Blanket (HCPB)

WP-B-1: Design and Analysis

B1-1 Design optimisation and modifications on present design inc. first wall box:
B1-2 Test module design
B1-3 Analysis and Modelling
B1-4 Reliability/Availability Analysis

WP-B-2: Fabrication, Assembly and Development Studies of Blanket Segment

B2-1 Fabrication, assembly and development studies of segment box and blanket cooling plates

WP-B-3: Ceramic Breeder Pebbles

reference : 0.3-0.6 mm Li_4SiO_4 + 2wt% TeO_2
alternatives: Li_2ZrO_3 and Li_2TiO_3 pebbles

B3-1 Pebble characterization and optimization of large scale production

B3-2 Reactor irradiations

- HFR, SILOE, Phenix irradiations inc. on $LiAlO_2$ & Li_2TiO_3 pellets: mechanical integrity, tritium release, purge gas/ceramics/tritium barriers interactions (corrosion and permeation) including TRINE type experiments with Li_4SiO_4, Li_2ZrO_3 and Li_2TiO_3 pebbles and martensitic steel as structural material
- P.I.E.: structure, density, crush tests, thermal cycle tests, pebble bed heat transfer tests

WP-B-4: Beryllium Pebble Development

B4-1 Characterization and optimization of mechanical properties of 2mm and 0.1-0.2mm pebbles
B4-2 Behaviour under irradiation

WP-B-5: Tritium Control including Permeation Barriers

B5-1 Calculations of tritium permeation losses from the purge system and from the first wall
B5-2 Permeation tests in martensitic structural material and Incoloy 800 as a function of temperature and H_2O/H_2 ratio (preoxidation of structural material and Incoloy 800)
B5-3 Permeation barriers and compatibility with ceramic breeder pebbles

WP-B-6: Tritium Extraction

B6-1 Ancillary loops inc. helium purification plant and tritium purge flow system
B6-2 Ancillary loop tests with a small pilot plant

WP-B-7: Safety related Activity for DEMO and ITER Test Module

B7.1 Safety studies

WP-B-8: ITER Test Module System and Testing

B8-1 Out-of-pile tests
B8-2 In-pile tests

Overview of the EU development programme (1995-1998) on low activation (LA) martensitic 7-10% Cr steels for blanket structural material

Development work on martensitic steels for their potential use as low activation structural materials has been ongoing in Europe for some time. The EU development programme for the 1995-1998 period on martensitic 7-10% Cr alloy steels for their potential use in tritium breeding blankets is summarised below and includes the following elements:

- Screening of eight alloys by comparative tests for the selection of a primary candidate alloy. The main criteria to be addressed include radiation hardening and its understanding including some characterisation and optimisation work for all the variants.

- Conducting tests on a typical alloy to determine the critical properties for the application which are characterisic of martensitic steels. The alloy F-82H modified, of Japanese origin, is available in sufficient quantity and fabricated on an industrial scale. This will be used mainly for the tests within the framework of the IEA Implementing Agreement on Fusion Reactor Materials. Tests will include: sensitivity to weldability problems (hot and cold cracking, toughness of TIG, EB and diffusion weldments), stress corrosion cracking by relevant tests in a simulated fusion environment, investigation of hydrogen/tritium problems (diffusion, trapping, cracking).

- Comparison of LA materials using F-82H as the representative material by spot check inspection and examination for comparison with modified 9%Cr or MANET type steel. Design relevant properties for comparison will include fracture toughness, fatigue, fatigue crack growth and creep.

- Preparatory work on the development of a code for martensitic materials suitable for a DEMO-type reactor.

Second Meeting of the
Test Blanket Working Group
San Diego Co-Center
Jan. 17 - 19, 1996

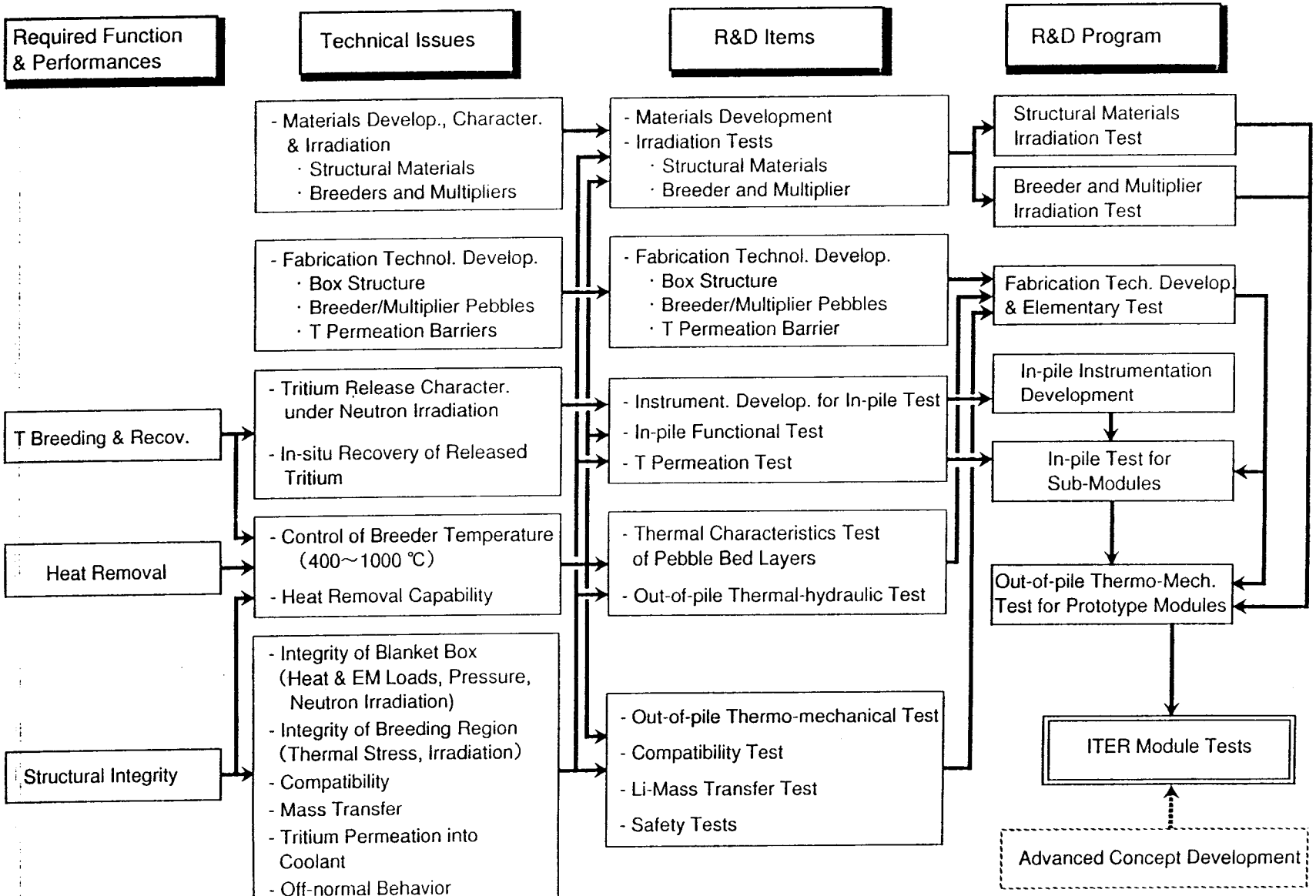
DEMO Blanket Development R&D Program

Presented by H. Takatsu

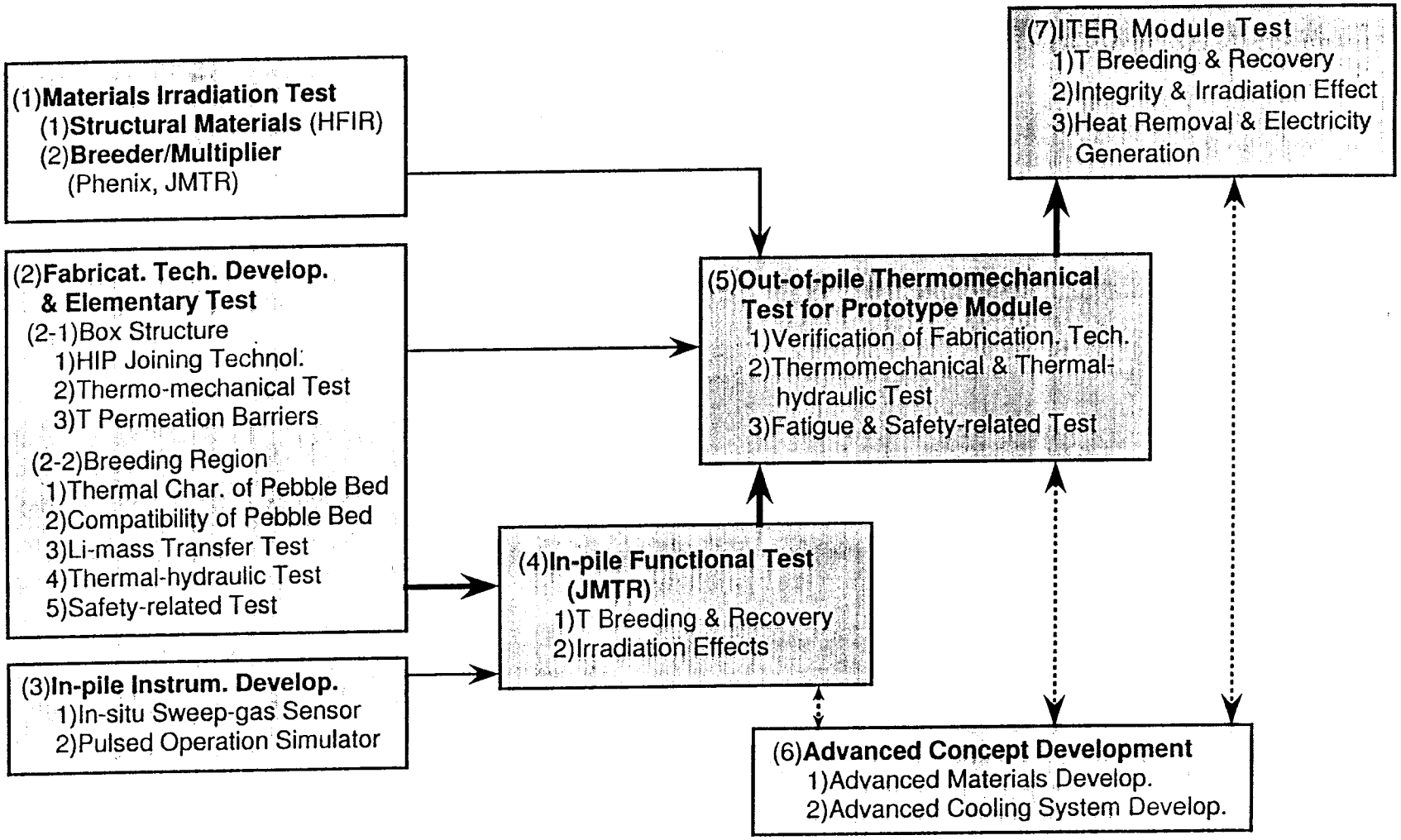
JAERI

Contents

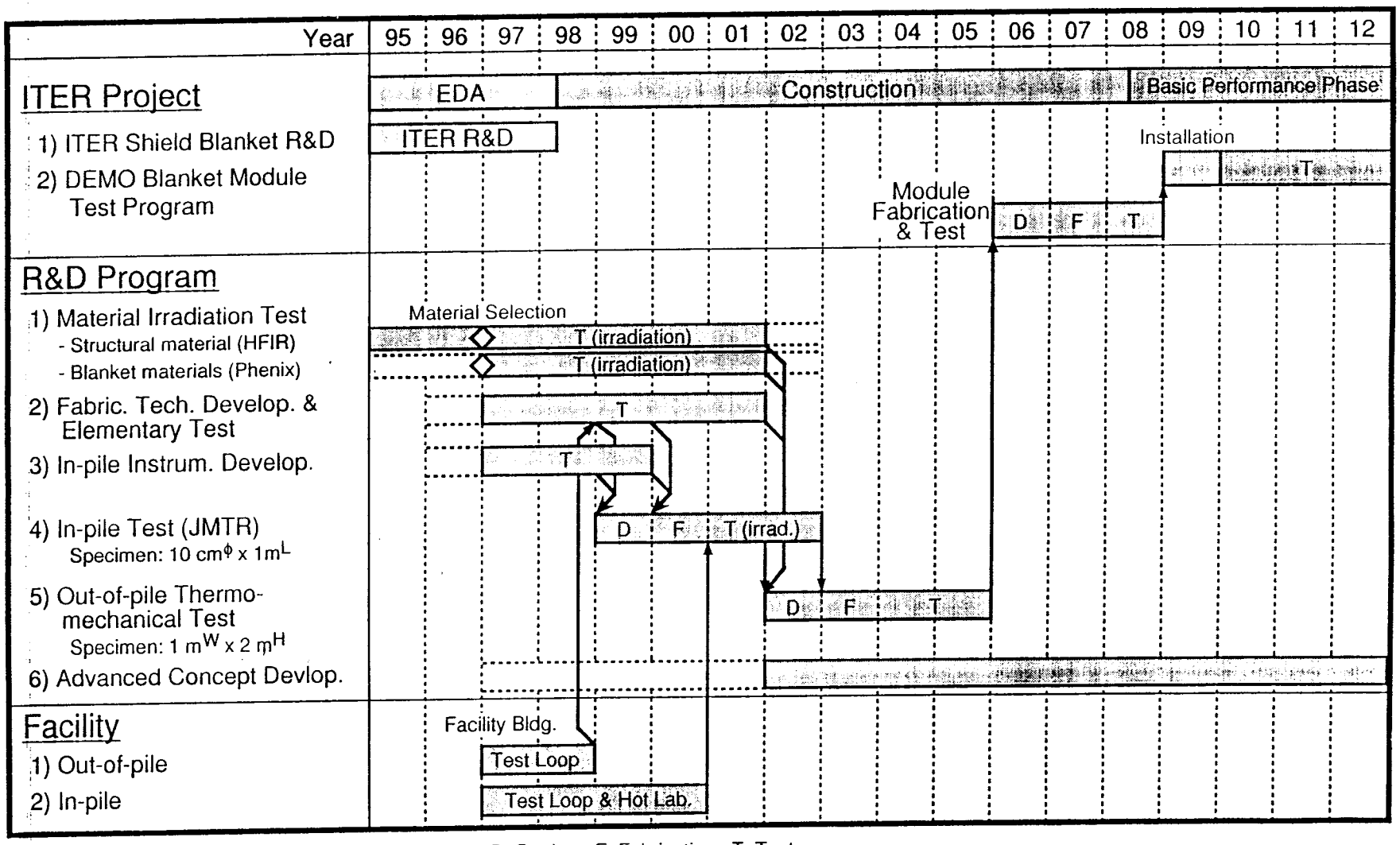
Functions and R&D Issues for DEMO Blanket Development



R&D Items and Program for DEMO Blanket Developemnt



DEMO BLANKET DEVELOPMENT PROGRAM FOR ITER MODULE TEST



D: Design, F: Fabrication, T: Test

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Cost Estimation

- Near-term R&D Plan Developed for Module Testing in ITER
  - Limited to JAERI Activities (IFMIF not included)
  - Limited to Baseline (Advanced Concept Development not included)
  - Under negotiation with STA

- R&D category
  1) Materials Irradiation Test (1996 - 2001)
  2) Technology Development (1996 - 2001)
  3) In-pile & Out-of-pile Module Testing (1999 - 2005)
  4) Facility Upgrade (1997 - 2000)

- R&D Program
  1)Materials Irradiation Test
    - Structural Materials
    - Breeders and Multipliers
  2) Technology Development
    - Fabrication Tech. Develop. & Elementary Test
    - In-pile Instrum. Develop.
  3)In-pile & Out-of-pile Module Testing
    - In-pile Functional Test for sub-module
    - Out-of-pile Thermomechanical test for prototype module
  4) Facility Upgrade
    - Out-of-pile Loop Facility
    - In-pile Loop Facility & Tritium Recovery System

Cost Estimation (Cont'd)

- Estimated Cost (preliminary)
  1) Materials Irradiation Test
     1,600 MYen for 6 years
  2) Technology Development
     1,855 MYen for 6 years
  3) In-pile & Out-of-pile Module Testing
     1,500 MYen for 7 years
  4) Facility Upgrade
     7,100 MYen for 4 years

  12,055 MYen in Total
  for Baseline Program
  in JAERI
  for Module Testing in ITER