Revised 3/3/04

Plasma Chamber Systems

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Presented to:

VLT-PAC

UCSD, San Diego

March 2, 2004

Summary for Plasma Chamber Systems (PCS)

- The Budget for PCS has been reduced yet again to only $1.89M in FY05 (compared to $3.1 M /yr during the past several years and >$7M/yr prior to 1996) – This has very Serious Negative Consequences for the US program (See numerous community presentations/letters from last year)
- Deliberations among the PCS Community, DOE, and VLT led to redirecting PCS activities toward the ITER Test Blanket Module (TBM)
  - The US has had the Intellectual Leadership on ITER testing.
  - Gain access to vital R&D information from international partners
  - Retain/Develop vital skills that the US needs for any future BP/other experiments
  - The US can actually have a very strong ITER TBM Program with Modest, Existing Resources within the Fusion Program
- Budget Need Summary:
  - The US Plan requires only $5M/yr assuming International collaboration, Ferritic structure, and coordinated efforts among PCS, Materials, PFC, Safety. EU and Japan spend $15M/yr each on ITER TBM research.
  - This $5M is made up from the following sources:
    - Restoring the Plasma Chamber funding to $3.1M (roughly $2M for ITER TBM and $1.1M for ITER basic machine support and other research activities)
    - Focusing some of the current Material Program Activities on ITER-TBM
    - Leveraging off the already ongoing work in the PFC and Safety Programs
    - Starting in FY 2006, provide 1-2 M$/yr to a National Lab/Industry for activities related to ITER TBM fabrication, mockup, etc.

Mission of Plasma Chamber Systems

- Advance the engineering sciences and develop technologies for plasma chamber systems that allow current and future plasma experiments (e.g., ITER) to achieve their goals and improve their performance potential.

- Support the ITER mission: "*The ITER should serve as a test facility for neutronics, blanket modules, tritium production and advanced plasma technologies.*" as stated by the *ITER Quadripartite Initiative Committee (QIC), IAEA Vienna 18-19 October 1987.*

- **Resolve key feasibility issue for DT fusion:** Ensure that tritium can be sufficiently produced, efficiently extracted and safely controlled, while simultaneously extracting heat at high temperature, in a practical engineering system surrounding the DT plasma and compatible with its operation under extreme conditions of high heat and particle fluxes, high temperature, strong magnetic field, and ultra low vacuum.

- Advance technologies of plasma chamber systems to realize an economically and environmentally attractive fusion energy source.

Scope of Plasma Chamber Systems Activities

1. ITER test blanket module (TBM) program

- Active participation in ITER test blanket working group (TBWG).
- Evaluate blanket options for DEMO and evaluate R&D results for key issues to select primary US blanket concepts for testing in ITER in collaboration with materials, PFC, and safety communities.
- Perform concurrently R&D on the most critical issues required (e.g., MHD flow and insulators, tritium recovery and control, SiC inserts, solid breeder/multiplier/structure/coolant interactions).
- Enhance and focus current international collaborative R&D to provide data for ITER TBM.
- Develop engineering scaling and design, in collaboration with ITER partners, for TBMs.

2. Support for the basic ITER device

- Provide more accurate prediction in the nuclear area for critical ITER components as we move toward construction (e.g. diagnostics damage, personnel access, activation to assess site specific safety issues)

3. Predictive capabilities and tools needed by elements of fusion program

- Improve our predictive capabilities in areas of neutronics, activation, neutron-material interactions, heat transfer, fluid mechanics, MHD, tritium recovery and control, fuel cycle dynamics, reliability and availability.

4. International collaboration: JUPITER-II (Funds from Japan), IEA

ITER's Principal Objectives Have Always Included Testing Tritium Breeding Blankets

- *"The ITER should serve as a test facility for neutronics, blanket modules, tritium production and advanced plasma technologies. The important objectives will be the extraction of high-grade heat from reactor relevant blanket modules appropriate for generation of electricity."*
  —The ITER Quadripartite Initiative Committee (QIC), IEA Vienna 18–19 October 1987
- *"ITER should test design concepts of tritium breeding blankets relevant to a reactor. The tests foreseen in modules include the demonstration of a breeding capability that would lead to tritium self sufficiency in a reactor, the extraction of high-grade heat and electricity generation."*
  —SWG1, reaffirmed by ITER Council, IC-7 Records (14–15 December 1994), and stated again in forming the Test Blanket Working Group (TBWG)

Plasma Chamber is not just for power reactors:
It is essential for continuing burning plasma and fusion research

<u>Tritium Consumption in Fusion Is HUGE!</u>

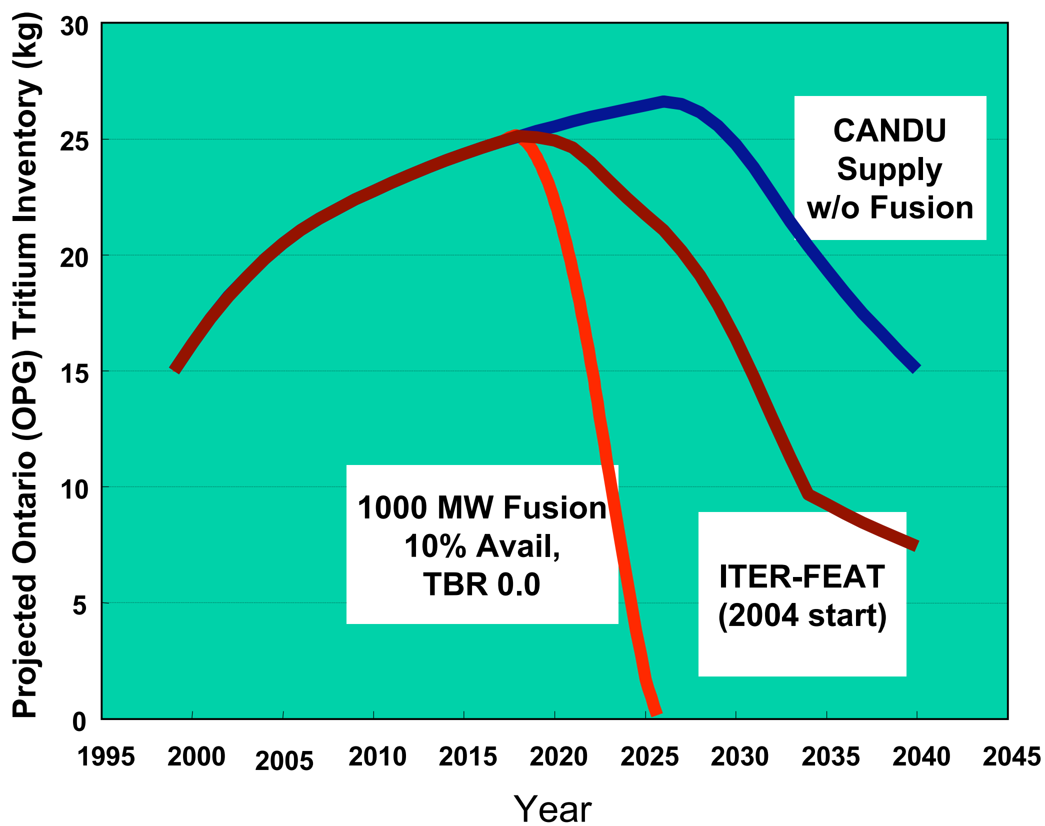
- 55.8 kg per 1GW·year fusion power

<u>Production & Cost from fission are LIMITED & EXPENSIVE!</u>

- CANDU Reactors: 27 kg over 40 years, $30M/kg (current)
- DOE Inspector General report (12/2003) Tritium costs in the range $84M to $130M per kg

Powerful DT burning plasma experiments such as ITER must breed their own Tritium

World Tritium Supply *Exhausted by 2025* by ITER at 1000MW at 10% Availability or ITER at 500 MW at 20% Availability



Why should the US Participate in ITER TBM?

- Test critical technologies for any further US development of fusion (CTF, DEMO, DT alternates, power plants)
- Access R&D information from much larger ($10-20M per year) blanket programs (EU and Japan) and other international partners
- To build US knowledge, experience, and competence in fusion nuclear and tritium technologies needed to develop practical and safe DT fusion devices (Building competence takes decades)
- Tritium breeding technology in fusion will make tritium production in fission reactors for weapons obsolete. The US cannot possibly stay out of fusion tritium breeding technology development while the EU, Japan, Russia, Korea and China are doing it. (National Security Issue?!)

> • *For a few million dollar expenditure on test blanket modules, we will acquire vital data and develop critical technologies*
>
> *- an excellent return on the billions of dollars invested in ITER.*

DOE Office of Science Strategic Plan Calls for Blanket Testing in ITER Starting 2013

The U.S. Department of Energy's Office of Science unveiled on February 12, 2004 its Strategic Plan which charts a course for science over the next two decades

Strategic milestone for 2013:

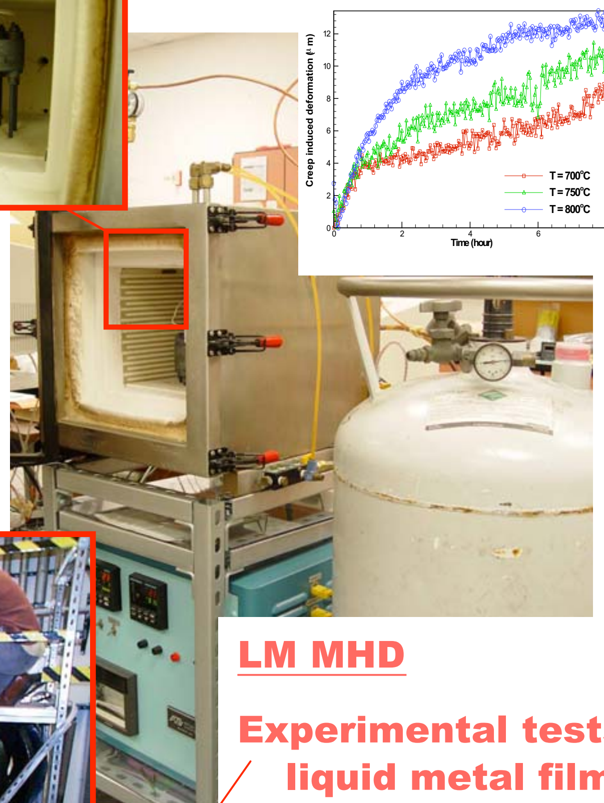
"Deliver to ITER for testing the blanket test modules needed to demonstrate the feasibility of extracting high-temperature heat from burning plasmas and for a self-sufficient fuel cycle"

Redirecting Chamber Technology Effort to support ITER

- With the US rejoining ITER, the Blanket/Chamber community concluded that it is very important for the US to participate in the ITER Test Blanket Module (TBM) Program. Reached consensus on a general framework for the direction of activities in the US Chamber/Blanket Program
- Key elements of the emerging framework are:
  1. The US will have strong participation in ITER TBM program and will redirect good part of resources toward R&D for TBM
  2. The near-term TBM activities will involve:
     A. The US has rejoined and will continue to participate in the ITER TBWG
     B. Evaluate and select the US favored blanket concepts for TBM
     C. TBM Design/Analysis/Engineering Scaling to support ITER through the TBWG
     D. R&D activities to support TBM as agreed to internationally in TBWG
  3. Enhance international collaboration between all ITER Parties to in carrying out the R&D and construction of the test modules. An example is JUPITER-II program between US and Japanese Universities
  4. Provide fusion nuclear technology (FNT) support for the basic ITER device as needed

FY04 Experimental Accomplishments

Understanding phenomena and producing data for code benchmarking

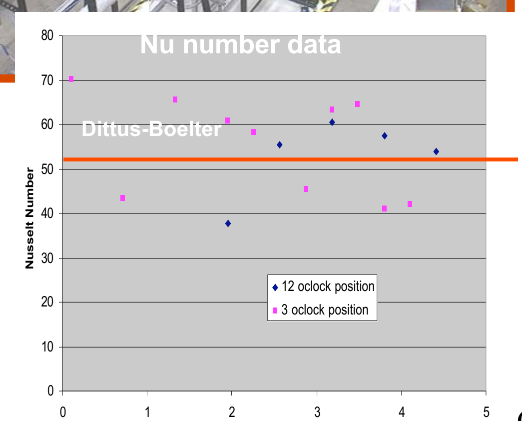


Solid Breeder Thermomechanics

Temperature experiments on pebble bed thermal creep shows creep mechanism influence

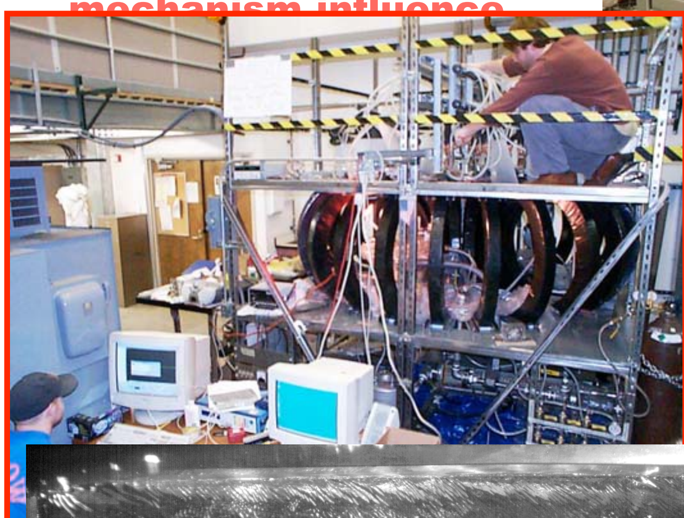
Jupiter-2 Flibe Thermofluid

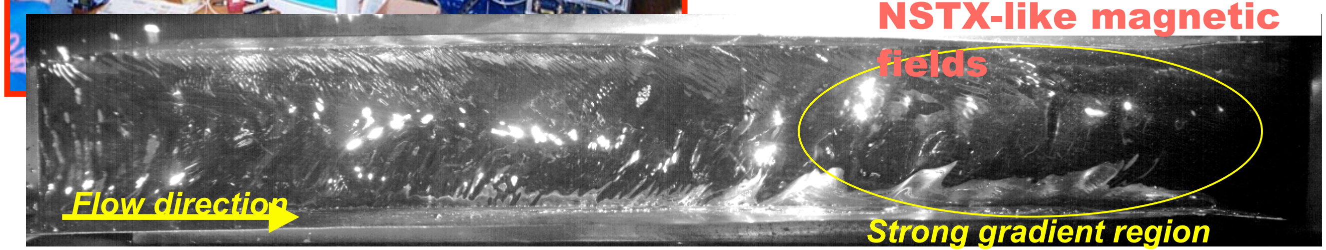
7 m heat transfer test section constructed, detailed experiments underway with high Pr molten salt simulants



LM MHD

Experimental tests of liquid metal film flows show significant MHD drag effect in scaled NSTX-like magnetic fields

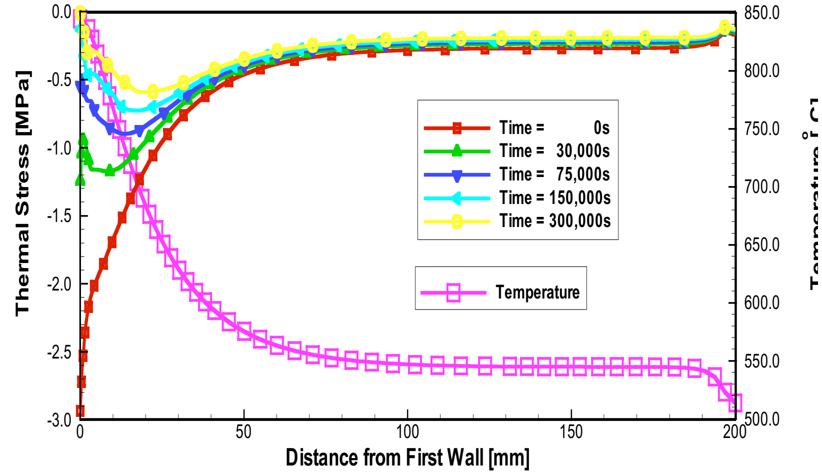




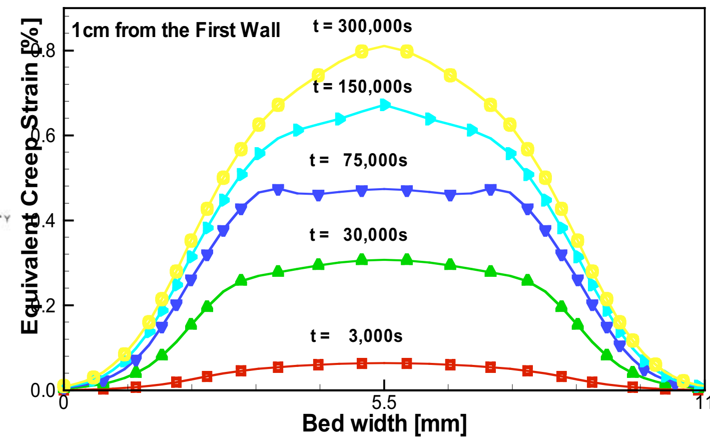
FY04 Chamber Modeling Accomplishments

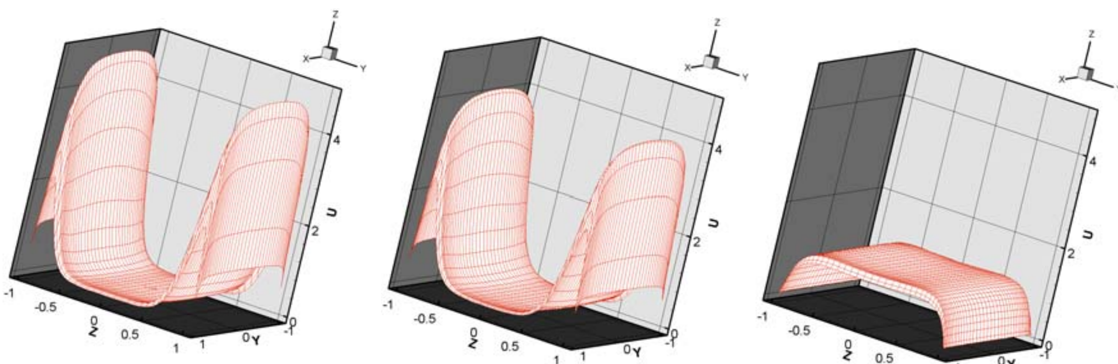
Understanding complex phenomena through high performance computational simulations

- **Progress in developing predictive capability for ceramic breeder pebble beds thermomechanics interaction**



- **3D MHD code extended to multiple conductor closed channels flows. Fully viscous solutions up to Ha=10^4 achieved.**





Ha = 200, N = 1000, Velocity profiles downstream of steep magnetic field gradient

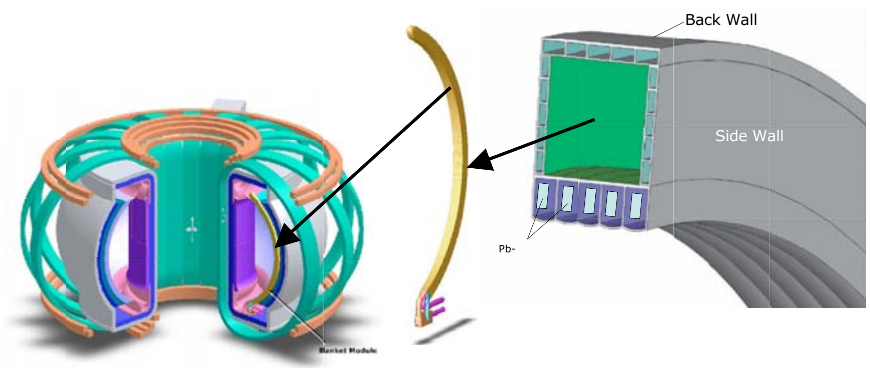
Stress and strain evolution at different blanket locations

ITER TBWG Highlights

- TBWG (test blanket working group) was reconstituted in July 2003. The newly reconstituted TBWG met in Garching (TBWG-11) October 22-24, 2003.
  - Chair: Luciano Giancarli (EU, CEA)
  - Co-Chair: Valeriy Chuyanov (ITER Garching, RF)
  - The US members of TBWG are M. Abdou, D. Sze, and M.Ulrickson.
- The US major contributions to the ITER Test Program since early CDA (and, even earlier, INTOR) were clearly recognized. The US is widely acknowledged as a primary “intellectual power” in fusion testing (many US studies in the 80’s and 90’s: FINESSE, VNS, etc.)
- The number of ports in ITER have been reduced to three, but the number of parties has increased to six.
- The US made many suggestions on strategy for the meaningful testing on ITER, stronger collaboration among the Parties on R&D and construction of TBM’s, etc.. These suggestions were well received.
- TBWG Plans, Port Allocation to Concepts, and Formation of Working Groups for various blanket concepts were accomplished.
- The next meeting (TBWG-12) will take place March 9–**11**, 2004 in Japan.

Molten Salt (MS) Blankets Assessment

- **We completed the conceptual design of a re-circulating FLiBe self-cooled blanket using Pb as the neutron multiplier and advanced nano-composited ferritic steel (AFS) (T limit @ 800°C) as structural material.**

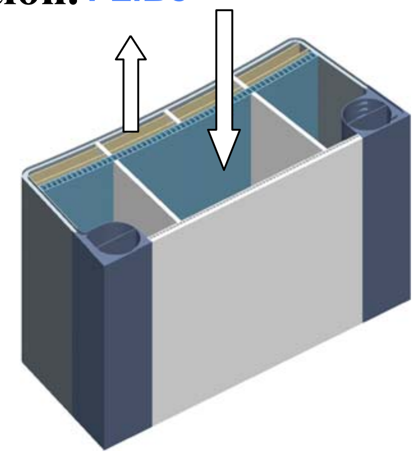


- **The design can handle max. Γ_n of 5.4 MW/m² and max. first wall heat flux of 1 MW/m² with gross efficiency of 46%.**
- **We will need to develop the AFS material and methods of fabrication and confirm the allowable interface temperatures for FLiBe/AFS and Pb/AFS. Be multiplier is also a credible option.**

We are evaluating three reduced activation ferritic steel MS blanket options for DEMO and ITER test module: Duel coolant (He and FLiBe) with neutron multiplier options of Be and Pb, and a self-cooled FLiNaBe option with Be.

FLiBe

He-cooled FW and structures



Technical highlights of the JUPITER-II collaboration on blankets

1. Flibe REDOX control

a. Completed flibe purification process.
b. Completed flibe mobilization experiment.
c. Started hydrogen isotopes (D) permeation, diffusion and solubility measurements.
d. Preparation for the REDOX experiments.
e. Presented two papers at ICFRM and Be workshop.

2. Flibe heat transfer and flow mechanics

a. Measured straight pipe velocity profile and turbulent statistics.
b. Constructed 304SS heat transfer test section, with some initial data available.
c. New acrylic PIV attachment section constructed and tested.
d. Prepared for the MHD experiment with a US supplied magnet.

3. MHD coating development

a. Coatings of AlN, Y_2O_3 and Er_2O_3 have been tested in Li up to 800C.
b. Vacuum distillation system developed and tested to remove residue lithium from test coupons.
c. Resistivity experiments conducted for Er_2O_3, Y_2O_3 and $(Y,Sc)O_3$ to confirm sufficient resistivity for MHD coating.

4. SiC/pebble bed system thermomechanics

Obtained data on interface conductance and time dependent deformation for the SiC/pebble bed systems

All experiments are directed to solve key feasibility issues for the molten salt, Li/V and solid breeder ITER test modules.

Tasks for FY05 and FY06

Plasma Chamber Systems Tasks divided in three categories:

A. **ITER TBM (TBWG/Design/Analysis/R&D) and Predictive Capabilities**
B. **JUPITER-II US-Japan Collaboration on Blankets**
C. **Support of Basic ITER Device (appears only under Incremental Budget)**

FY 05 Tasks: Task A. ITER TBM (TBWG/Design/Analysis/R&D) and Predictive Capability
(Total $1304K)

All tasks support ITER but are not funded directly from ITER project funds.

1. US contributions to developing Test Blanket DDD ($310K / May 2005)
2. Modeling and experimental results on ceramic breeder pebble bed time dependent deformation and interface conductance under ITER and fusion conditions ($300K / Sep 2005)
3. Assessment, predictive capability, selected R&D on critical issues, and roadmap for US-favored liquid breeder concepts for ITER TBM ($414K / Aug 2005)
4. Blanket test article design and engineering scaling for selected US TBM concepts ($200K / Sep 2005)
5. Participation in international experiments in fission reactors for selected US TBM concepts ($80K / Sep 2005)

FY05 tasks: Task B. JUPITER-II collaboration on blankets

(Total $590K)

All tasks support ITER but are not funded directly from ITER project funds. Matching funding is provided by Japan.

1. Operation of high temperature thermomechanic testing facility, fabrication of test articles, experiments and modeling for pebble bed thermomechanics interactions with SiC/SiC ($135K / Aug 2005)
2. Modification of JUPITER-II Thermofluid facility to include new magnet system ($100K / Jan 2005)
3. Experiments and modeling of heat transfer degradation by MHD effects in molten salt simulants ($290K / Aug 2005)
4. Diagnostic system modification for turbulence measurements in magnetic field ($65K / Aug 2005)

Additional Tasks for FY05 for 10% Increment Budget Case

All tasks support ITER but are not funded directly from ITER project funds

Under Task A: ITER TBM (Highest Priority)

1. 3-D Simulation of key MHD problems for closed channel liquid metal test modules ($130K / Sep 2005)
2. Develop material data base for FLiNaBe ($125K / Mar 2005)
3. Tritium processing from TBM ($75K / Sep 2005)

Under Task C: Support of Basic ITER Device (Medium Priority)

- Neutronics analysis to support US procurements packages (e.g., magnets, PFC) ($50K / Sep 2005)
- Activation and 3-D radiation streaming analysis to support safety assessment of site-specific issues and personnel access ($150K / Sep 2005)
- Fuel cycle dynamic modeling ($75K / Sep 2005)

FY06 Tasks Under FY05 Budget Case MINUS 10%

Task A: ITER TBM (TBWG/Design/Analysis/R&D) and Predictive Capabilities ($1304K - $130K = $1174K)

All tasks support ITER but are not funded from ITER project funds.

1. US contribution to TBWG for US ITER TBM concepts ($310K / Sep 2006)
2. Operation and experiments for unit cell thermomechanics interaction, high temperature facility for **ceramic breeder pebble bed** ($300K / Sep 2006)
3. R&D (experiments, modeling, design, and predictive capability) for US-favored **liquid breeder** concepts for ITER TBM ($464K / Sep 2006)
4. Blanket test article engineering scaling and design for selected US TBM concepts ($100K / Sep 2006)

FY06 Tasks Under FY05 Budget Case MINUS 10%

Task B: JUPITER-II collaboration on blankets
($590K - $59K = $531K)

All tasks support ITER but are not funded directly from ITER project funds. Matching funding is provided by Japan.

1. Experimental results of thermomechanical interaction between NITE SiC/SiC and ceramic breeder pebble beds ($170K / Sep 2006)

2. Complete heat transfer test section with heat transfer promoters ($100K / Jan 2006)

3. Experimental results for effectiveness of promoters under MHD conditions ($261K / Sep 2006)

FY06 Additional Tasks with total funding at FY05 level

HIGHEST Priority

Task A: ITER TBM and Predictive Capabilities

– Experiments on closed channel liquid metal MHD interactions ($130K)

Task B: JUPITER-II

– Begin construction of the helium loop high temperature for the unit cell pebble bed experiments ($59K)

Medium Priority

Task A: ITER TBM and Predictive Capabilities

– Participate in international experiments in fission reactors for selected US TBM concepts ($100K)

FY06 Additional Tasks
Under 10% Budget Increment Case

HIGHEST Priority

- Additional Task Under C. ITER Basic Device
  - Neutronics analysis to support US procurement packages (e.g., magnets, PFC, diagnostic) ($100K / Sep 2006)
  - Activation and 3-D streaming analyses for personnel and component assessments ($75K / Sep 2006)
  - Fuel cycle dynamic modeling ($75K / Sep 2006)

Medium Priority

- Additional Task Under A. ITER TBM and Predictive Capabilities
  - Design and analysis of mockup for ITER TBM ($100K / Sep 2006)
  - Instrumentation development for ITER TBM ($100K / Sep 2006)
  - Tritium processing and permeation from ITER TBM ($150K / Sep 2006)
- Additional Task Under B. JUPITER-II
  - Near wall turbulence and temperature measurement data with MHD (for low-conductivity fluids) for comparison to 3-D codes ($100K / Jan 2005)

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