Japan-US Joint Project TITAN 2007-2012

# Progress of the TITAN program

# Explorations toward Fusion Nuclear Power Systems

Presented by:

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UCSD, USA, NIFS, Japan

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# Introduction

- TITAN is an US-Japan collaboration program with long history.
- The JUPITER/JUPITOR-II and TITAN collaborations have been beneficial to both sides.
- The TITAN program can be an example for other type of collaboration among parties.
- Well planned collaboration will be beneficial for all.

Official Project Title is :

Tritium and Thermofluid Control in Magnetic and Inertial Fusion Energy Systems

Abbreviated Designation was Agreed as :

**TITAN Project**

**T**ritium, **I**rradiation and **T**hermofluid for **A**merica and **N**ippon

http://www.nifs.ac.jp/collaboration/Japan-US/TOP.html
http://titan.sci.shizuoka.ac.jp/

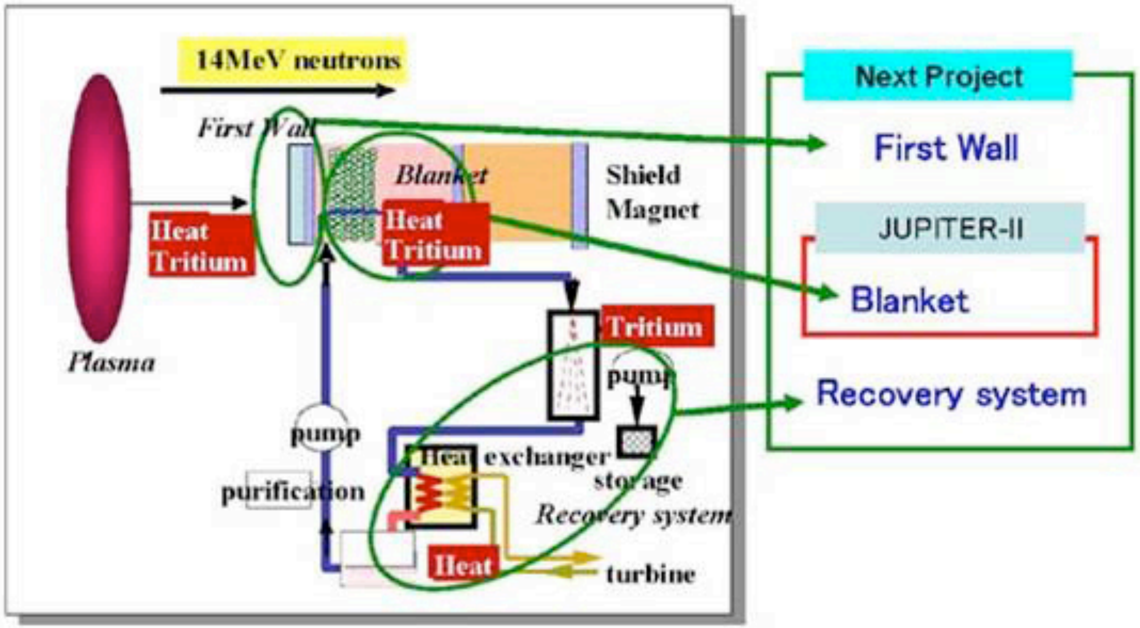
# *TITAN Program Background*

- Joint endeavor in the US and Japan to study *"Tritium and Thermofluid Control in Magnetic and Inertial Fusion Energy Systems"*
- 6-year R&D program involving several Japanese Universities/ Institutes and US Fusion R&D Facilities
- Follow-on to the JUPITER and JUPITER-II collaborations; JUPITER-II focused on each key technologies of materials, tritium and thermofuild for advanced blankets.
- In the next step, the principle concern is matching the first wall, blankets, and systems for tritium recovery and thermal performance, advancing the technologies for an integrated fusion power handling system.
- Short name TITAN derived from *"**T**ritium, **I**rradiation, and **T**hermo-fluid studies for **A**merica and **N**ippon"*

# Objectives of the TITAN Program

To obtain fundamental understanding for establishing tritium and thermofluid control throughout the first wall, blanket, and heat exchange/T-recovery system of MFE and IFE systems by experiments under specific conditions to fusion, such as irradiation, pulse high heat flux, circulation and high magnetic field.

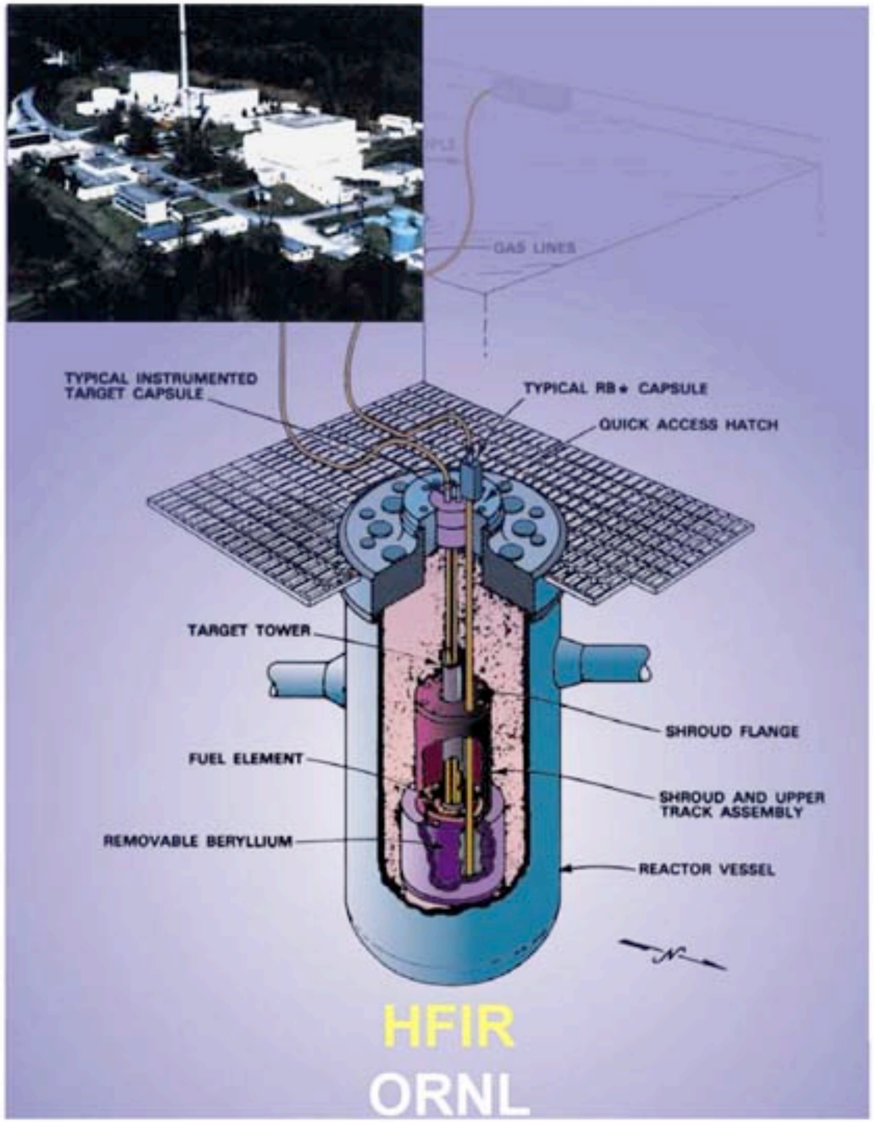
The results will be applied through the integrated modeling to advancement of design for tritium and heat control of MFE and IFE systems.

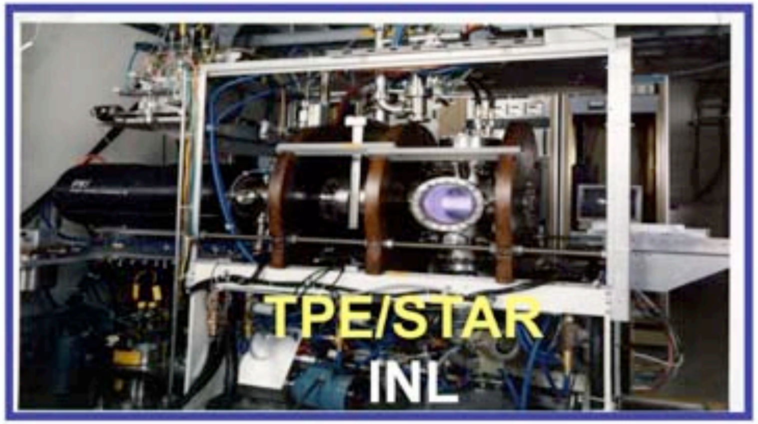



The JUPITER-II Project focused on key technologies for advanced blankets

The TITAN Program will focus on consistency of the blankets with first wall and recovery systems with respect to tritium and heat control

# US Facilities to be Used





# Task Structure and Research Items

| Task | Subtask | US Facilities | Research items |
|---|---|---|---|
| Task 1 **Tritium and Mass Transfer Phenomena** | 1-1 Tritium and mass transfer in first wall | STAR/TPE PISCES | Tritium retention and transfer behavior and mass transfer in first wall |
| | 1-2 Tritium behavior in blanket systems | STAR | Tritium behavior through elementary systems of liquid blankets |
| | 1-3 Flow control and thermo-fluid modeling | MTOR | Flow control and thermo-fluid modeling under strong magnetic fields |
| Task 2 **Irradiation-Tritium Synergism** | 2- 1 Irradiation-tritium synergism | HFIR STAR | Irradiation effects on tritium retention and transfer behavior in first wall and structural materials |
| | 2-2 Joining and coating integrity | HFIR | Synergy effects of simultaneous production of tritium and helium on healthiness of joining and coating integrity |
| | 2-3 Dynamic deformation | HFIR | Effects of irradiation and simultaneous production of tritium and helium on dynamic deformation of structural materials |
| Common Task **System Integration Modeling** | MFE/IFE system integration modeling | | Integration modeling for mass transfer and thermo-fluid through first wall, blanket and recovery systems of MFE/IFE |

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# Structure

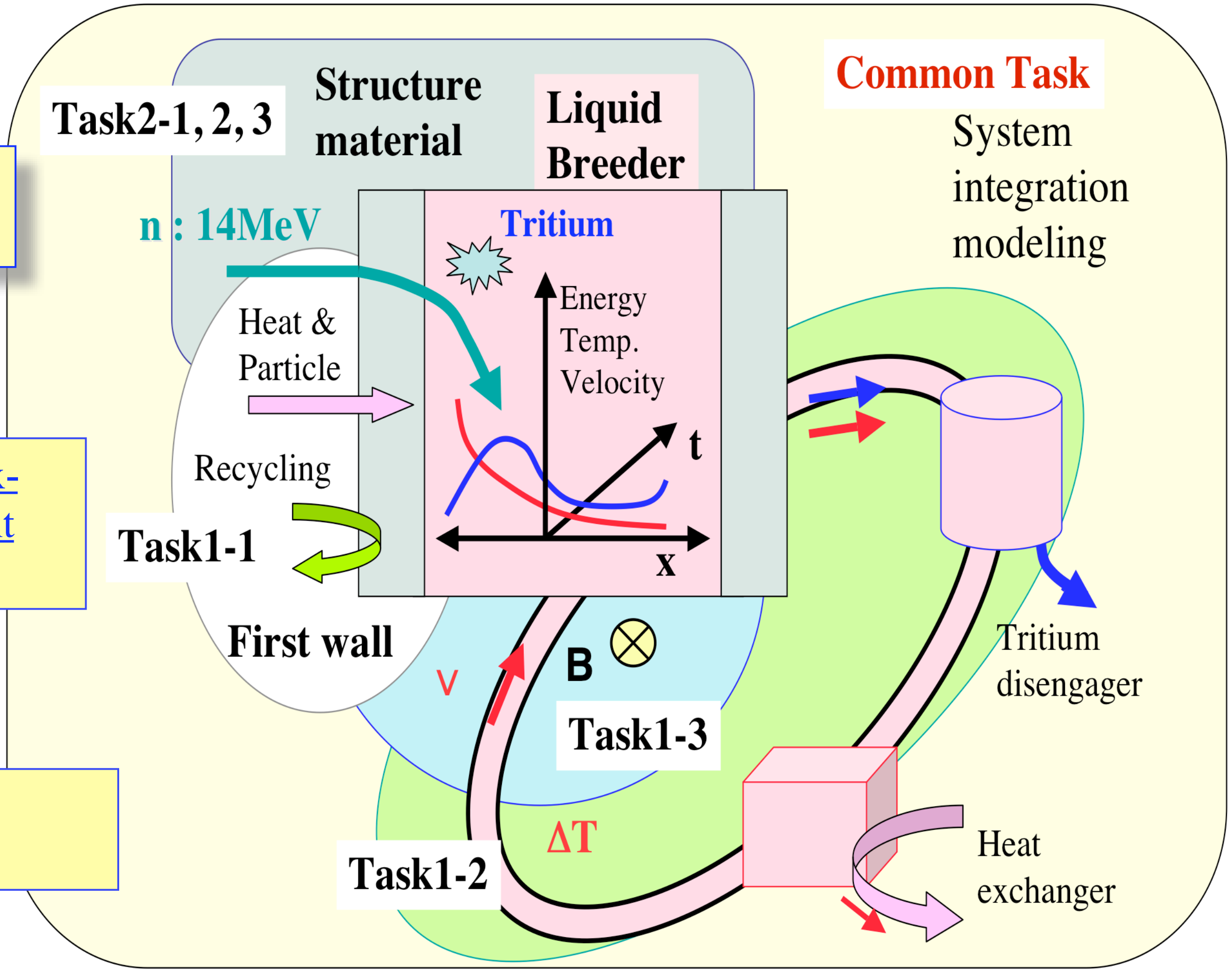
| Representatives<br>Coordinators | | JP : K. Okuno (Sizuoka U.)<br>JP : T. Muroga (NIFS) | | US : G. Nardella (USDOE)<br>US : D. Sze (UCSD) | | |
|---|---|---|---|---|---|---|
| **Task** | **Subtask** | **Facility** | **TC (JP)** | **STC/Deputy (JP)** | **TC (US)** | **STC/Deputy (US)** |
| Task 1<br>Transport phenomena | 1-1 Tritium and mass transfer in first wall | TPE<br>PISCES | T. Terai<br>(U.Tokyo) | Y. Ueda (Osaka U.)/<br>N. Ohno (Nagoya U.)<br>K. Tokunaga (Kyushu U.) | D. Sze<br>(UCSD) | R. Doerner<br>(UCSD) |
| | 1-2 Tritium behavior in blanket systems | STAR | | T. Terai (U. Tokyo)/<br>S. Fukada (Kyushu U.)<br>S. Konishi (Kyoto U.) | | P. Sharpe<br>(INL) |
| | 1-3 Flow control and thermofluid modeling | MTOR | | T. Kunugi (Kyoto U.)/<br>T. Yokomine<br>(kyushu U.) | | N. Morley<br>(UCLA)/<br>K. Messadek<br>(UCLA) |
| Task 2<br>Irradiation synergism | 2-1 Irradiation-tritium synergism | HFIR<br>STAR | A.Kimura<br>(Kyoto U.) | Y. Hatano (Toyama U.)/<br>Y. Oya (Shizuoka U.) | R. Kurtz<br>(PNNL) | T. Yamamoto<br>(UCSB)/<br>Y. Katoh (ORNL)<br>P. Calderoni<br>(INL) |
| | 2-2 Joining and coating integrity | HFIR<br>ORNL-HL<br>(incl. T-test) | | A. Kimura (Kyoto U.)/<br>N. Hashimoto<br>(Hokkaido U.) | | T. Yamamoto<br>(UCSB)/<br>Y. Katoh (ORNL) |
| | 2-3 Dynamic deformation | | | A.Hasegawa<br>(Tohoku U.)/<br>T. Hinoki (kyoto U.) | | Y. Katoh (ORNL) |
| Common Task<br>System integration modeling | MFE/IFE system integration modeling | | A.Sagara<br>(NIFS) | A. Sagara (NIFS)/<br>H. Hashizume<br>(Tohoku U)<br>T. Norimatsu (Osaka U.) | R. Nygren<br>(SNL) | R. Nygren (SNL) |
| Laboratory Liaisons | ORNL :<br>INL :<br>IMR-Oarai (Tohoku) : | R. Stoller (ORNL)<br>D. Petti (INL)<br>T. Shikama (Tohoku U.) | | | | |
| IFE Liaisons | | | K. Tanaka<br>(Osaka U.) | Kodama(Osaka U.)<br>Yoneda(UTC) | M. Tillack<br>(UCSD) | |

# *Task 3 Studies:* MFE/IFE system integration modeling

Tritium and thermofuid system designs

A burning core plasma and the ex-vessel environments are important boundary conditions.

Approach: cross-connect TITAN tasks



# Plan for 6 years

| | Fiscal Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|

Interim review

| Task | Subtask | Plan |
|---|---|---|
| Task1 Tritium and mass transfer blanket | 1-1 Tritium and mass transfer in first wall | Equipping PISCES First wall test Deuterium-Materials test Combined conditions |
| | | Equipping TPE First wall test Tritium-Materials Test First wall/blanket test |
| | 1-2 Tritium behavior in blanket systems | Tritium solubility measurement Tritium permeation test Tritium recovery test Flow test |
| | 1-3 Flow control and thermofluid modeling | Modification of test section MHD thermofluid test System construction MHD pressure drop test for liquid breeders |
| Task2 Irradiation-tritium synergism | 2-1 Irradiation-tritium synergism | Design, Fabrication, Irradiation, Disassembling and PIE |
| | 2-2 Joining and coating integrity | Design, Fabrication, Irradiation, Disassembling and PIE |
| | 2-3 Dynamic deformation | Design, Fabrication, Irradiation, Disassembling and PIE |
| Common Task System integration modeling | | PMI, T/mass transfer、Thermofluid、 Integration, System analysis for MFE/IFE |

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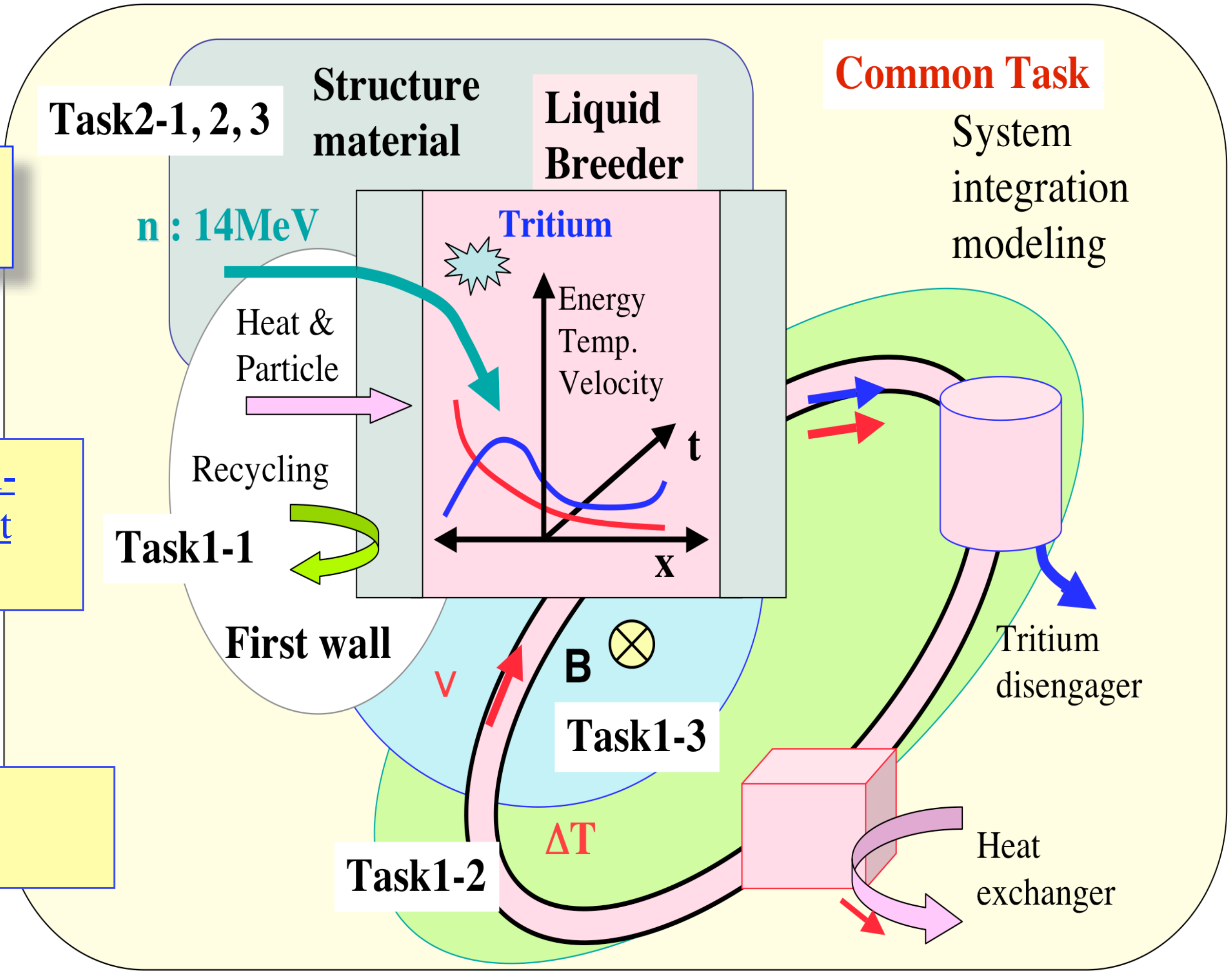

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# Task 1-1
# Tritium and mass transfer in first wall

- Plasma-surface interactions and material response are investigated.
- PISCES at UCSD and TPE at STAR/INL are the key facilities.
- PISCES focuses on retention in mixed materials and effects on transient heat load.
- TPE specialize specializes in retention and permeation studies in normal and irradiated material using tritiated plasma.

# Activities at PISCES

- PISCES-B will initially focus on the response of tungsten surfaces exposed to mixed D/He plasma.
- Surface characteristics of the plasma-exposed tungsten, with and without the presence of the Be impurities added to the mixed D/He plasma, will be examined.
- Codeposited layer will also be collected and analyzed.
- A high-power laser system will be installed and eventual irradiation of samples during plasma exposure.
- This activity will be coordinated with the UCSD laser-matter interaction group.

# Activities at STAR/TPE

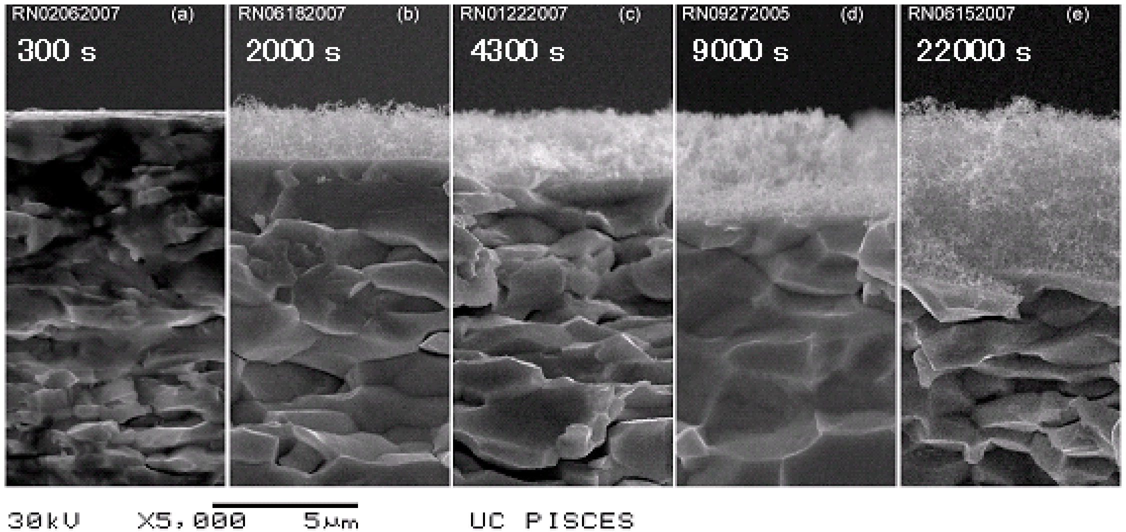
- The operation of STAR facility began in 2002, with the capability of handling 1.5 g of tritium.
- This facility also can handle irradiated material with radioisotopic quantities acceptable to Hazard Category 3 Radiological Facility.
- Existing experiment systems include steam reactivity, fusion liquids safety testing, advanced coolant and breeder preparation and purification, ion implantation, plasma-surface interactions, and the interactions of steam and air with candidate plasma facing materials.
- TPL will study the retention and permeation in normal and irradiated materials using tritiated plasma.
- Low-level detection limit of tritium is used for the diagnostic purpose.

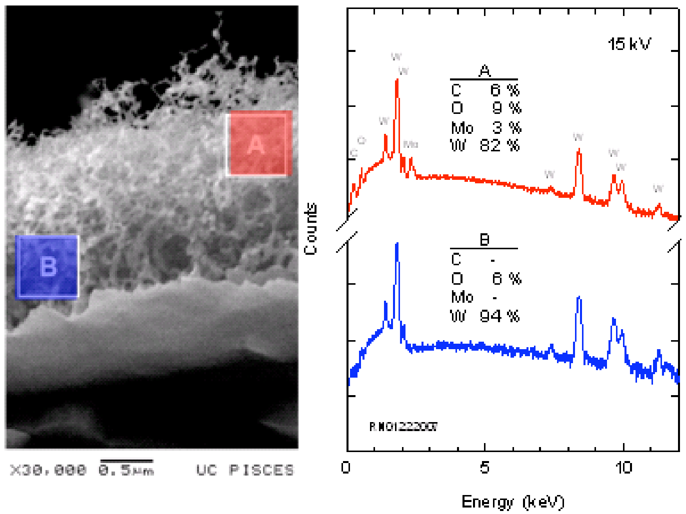
# Initial Achievements 1

## Mass Transfer at First Wall

Irradiation with D/He/Be mixed plasma (PISCES)

Enhancement of tritium sensing technology (Imaging Plate,--)




Surface morphological change of W by He plasma irradiation

Impurity analysis (PISCES)

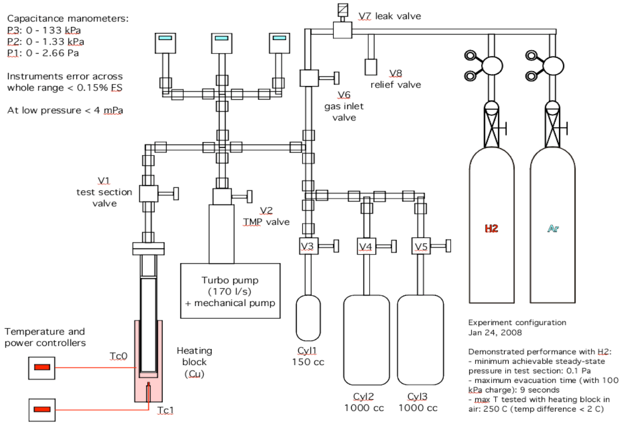
# Task 1-2
# Tritium behavior in blanket system

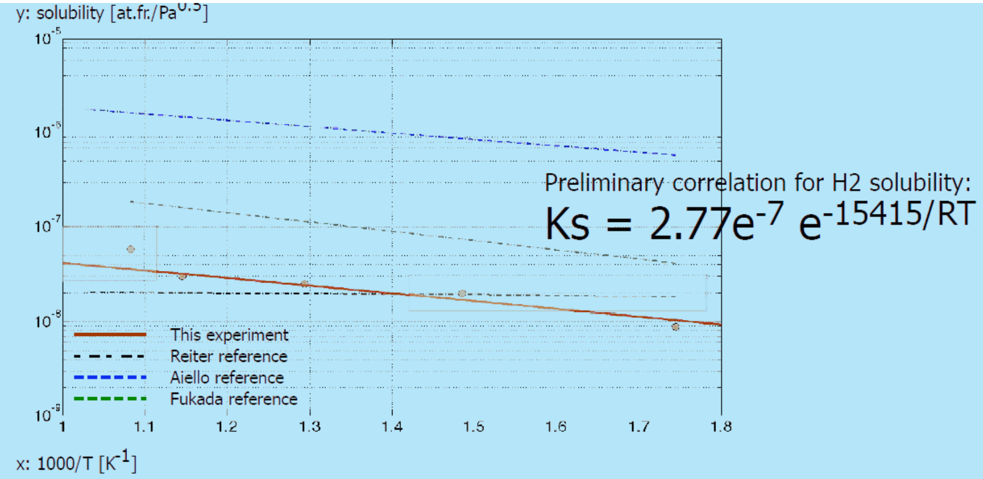
- This task concentrates on developing and extending the knowledge base for tritium extraction from lead-lithium eutectic.
- The first objective of this task is to measure of the mass transport parameters of hydrogen isotopes particularly at low tritium concentration.
- The solubility of hydrogen isotopes in the eutectic is the most uncertain, and most important.
- A bench-scale flowing system will be constructed to demonstrate tritium recovery process.
- A similar system is being constructed in Japan with SiC structures at very high temperature.

# Initial Achievements 2

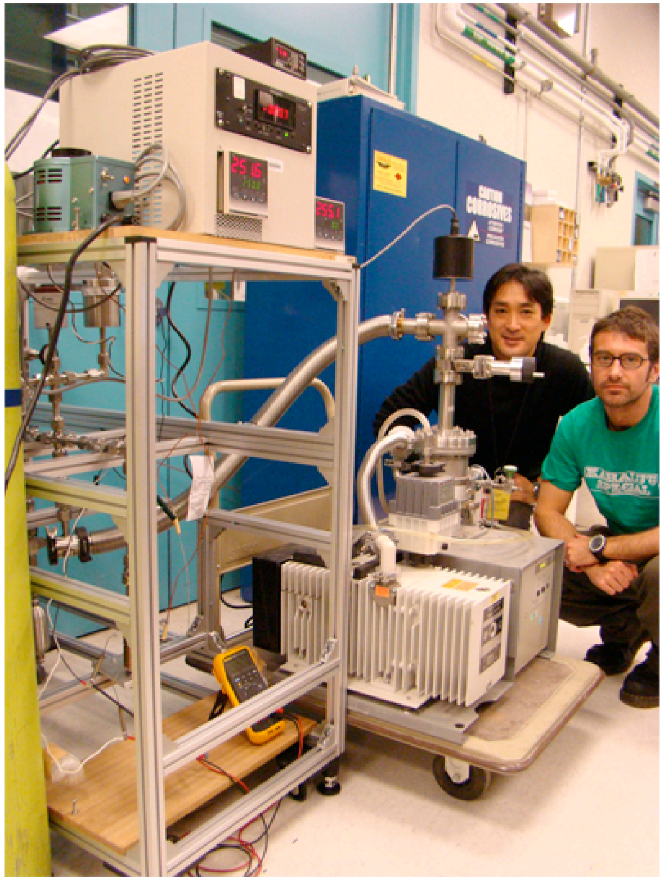
# Tritium Transfer in Blanket

Installation of apparatus for tritium solubility measurements in STAR




H solubility in Li-Pb



Apparatus installed

# Task 1-3
# Flow Control and Thermofluid Modeling

- The main subtasks are:

  1. Flow behavior in 3D flow elements, in particular expansions and manifold.

  2. Velocity/temperature fluid coupling and mixed MHD convection.

  3. Insulation technique effectiveness, in particular flow effects in the SiC-based flow channel insert.

* UCLA MTOR laboratory is the US facility to handle this activity.

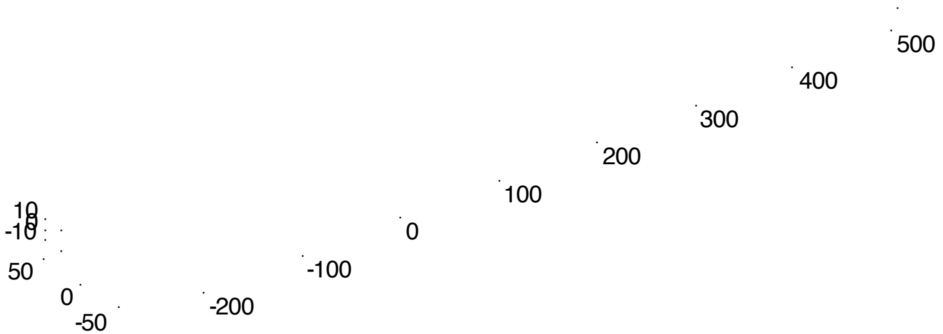
# Progress of Task 1-3

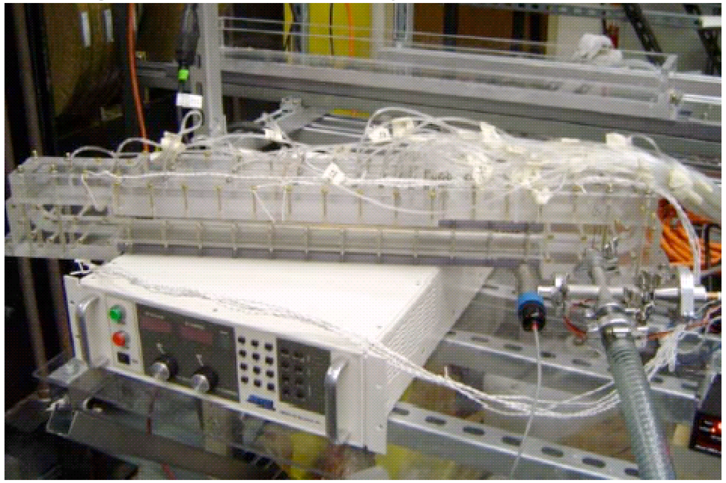
- A series of experiments studying the impact of MHD on turbulence and heat transfer was completed for molten salt.
- The interpretation of the data is continuing.
- A series of experiments to study flow distribution in a 3-channel, electrically insulated manifold test article was performed to study fluid distribution.
- The results confirms a highly uniform distribution with moderate and high magnetic field strength.
- A series of small scale experiments to measure contact resistance of SiC in contact with PbLi.
- Although a contact resistance exists at the beginning, it disappears after the temperature is raised above 400C.

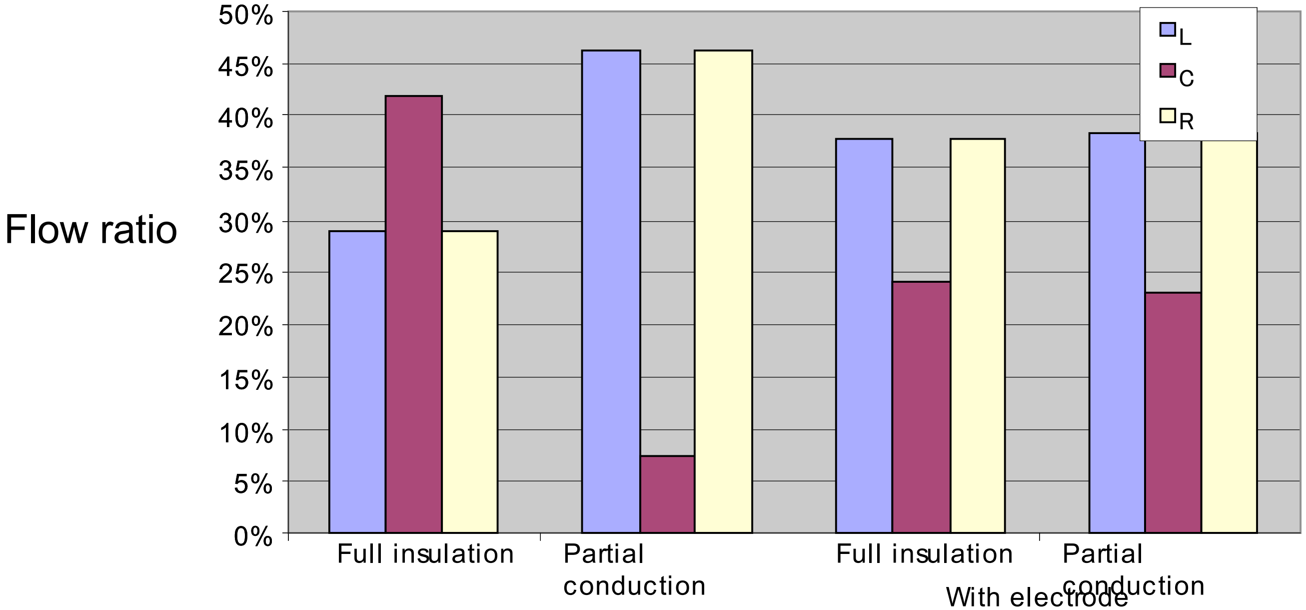
# Initial Achievements 3

## Thermofluid Control and Modeling

Control of flow partitioning in a manifold in magnetic field by electrodes





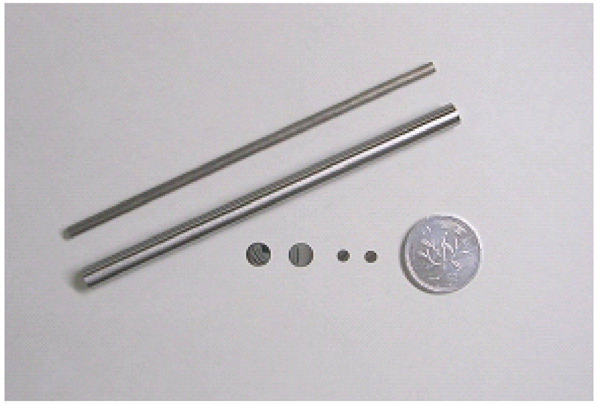
# Task 2-1
# Irradiation-tritium synergism

- The possible radiation damage and tritium transport synergism effects will be studied in the task.
- TPE and TRIIX (Tritium Ion Implantation Experiment) will be used for this task.
- Samples of material will be irradiated in HFIR to pre-determined dose level.TPE and TRIIX will be used for tritium retention measurement.
- The STAR facility is unique in the world for such measurements with tritium on irradiated materials.
- The irradiated sample will be provided by Tasks 2-2 and 2-3.

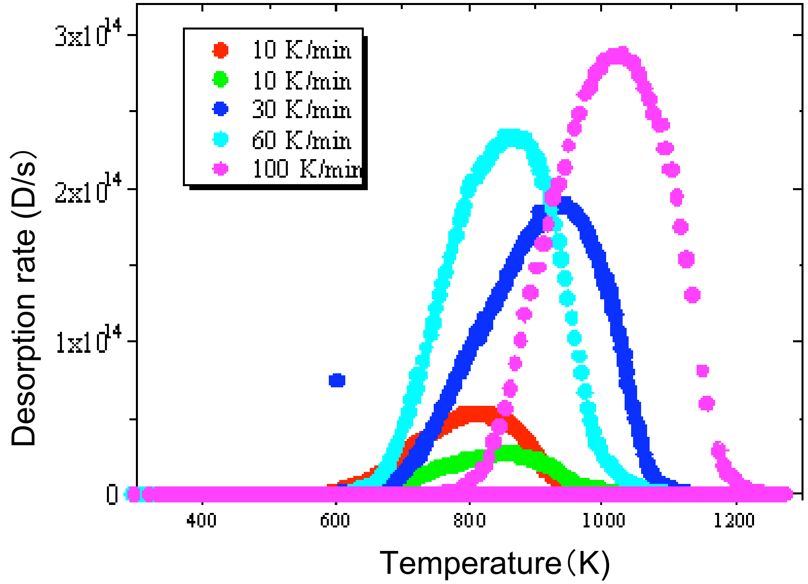
# Initial Achievements 4

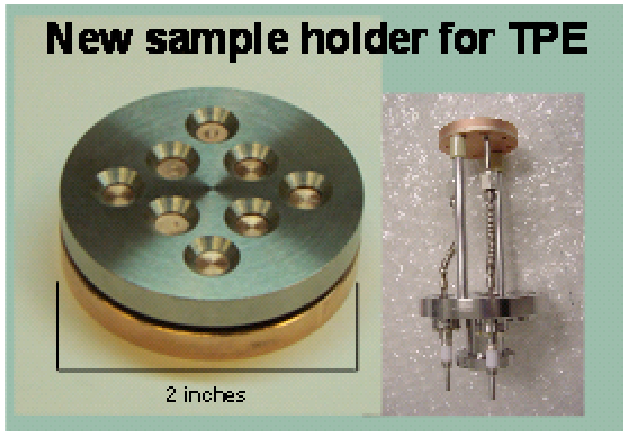
## Irradiation-tritium Synergism

Preparation for plasma irradiation on neutron-irradiated specimens



W specimens under preparation




Specimen holder for irradiation of neutron-irradiated samples

D plasma irradiation on W followed by thermal desorption

Tritium Plasma Experimental Facility (TPE)

# Task 2-2 Objectives

- Develop and evaluate irradiation performance of dissimilar joints such as W or Be on RAF, ODS, V-alloy, and ODS-RAF joints.
- Develop high performance ODS and RAF self-joints.
- Study synergistic effects of neutrons He and T(H) on material properties.
- Identify promising SiC/SiC and W/SiC joining methods and examine fundamental neutron irradiation performance.

# Progress on Task 2-2

- After intensive discussion, a test matrix was agreed.
- The rabbit capsules and specimens for the first set of irradiation experiments are being prepared.
- The experiments will be insert in HFIR in the cycle starting early FY08-09.
- New joints,coating and testing techniques are being developed.
- A in-situ He-neutron synergism experiments using NiAl He-implanter technique is being designed.

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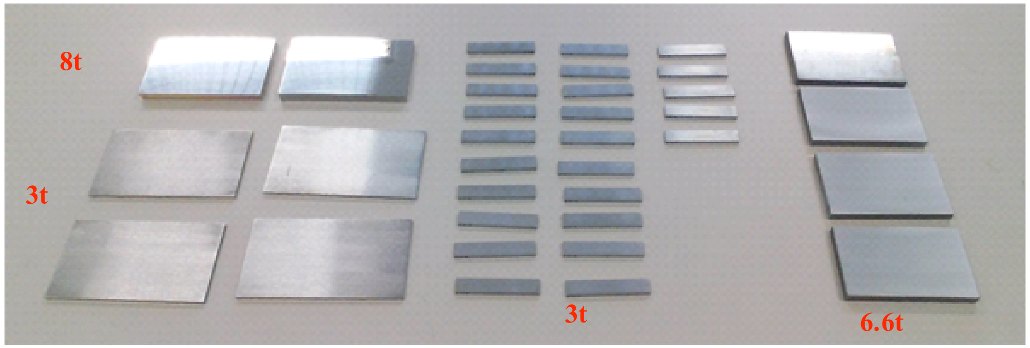
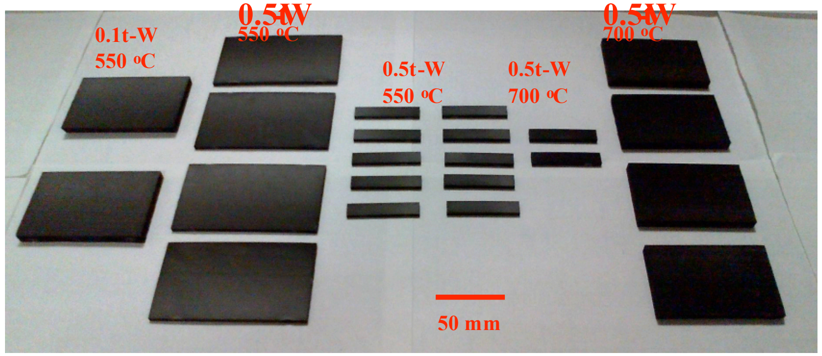
# Initial Achievements 5

## Integrity of Coating and Joining

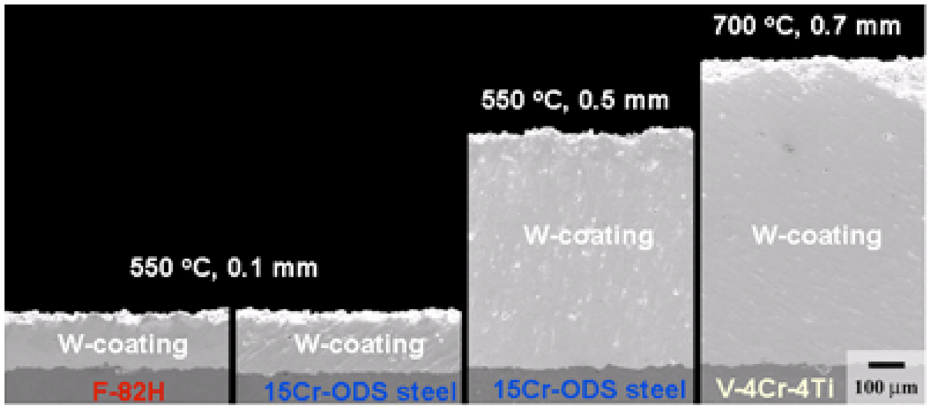
Fabrication of W coated low activation materials for HFIR irradiation




Before W coating




After W coating




Cross section of the coating

# Task 2-3
# Dynamic Deformation

- The primary objective of this task is to study stress-induced deformation behavior of SiC ceramics and composite in neutron radiation environment.
- Irradiation creep of ceramic materials is considered a new frontier of radiation material science.

We will study:

1. Transient irradiation creep and stress relaxation behavior of SiC ceramics and composites.
2. General irradiation creep of SiC ceramics, composites and other materials including metallic alloys.

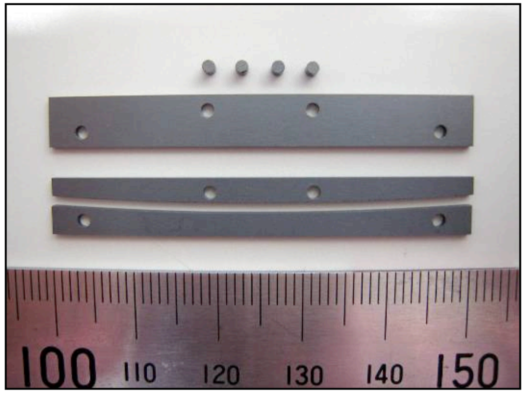
18 J experiment was planned during the J-II collaboration. The PIE of the 18J was included as a part of TITAN collaboration. This activity started in October 2008. The specimens will be sent to Low Activation Material Development and Analysis (LAMDA) facility for PIE.

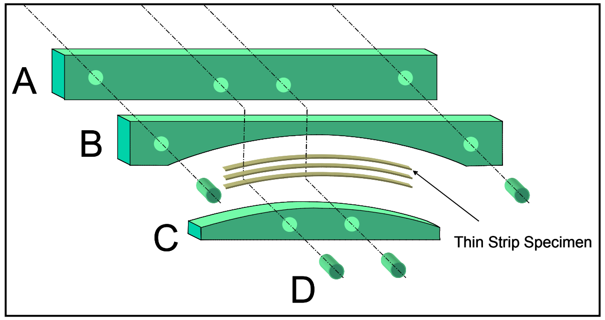
# Initial Achievements 6

## Dynamic Deformation during Irradition

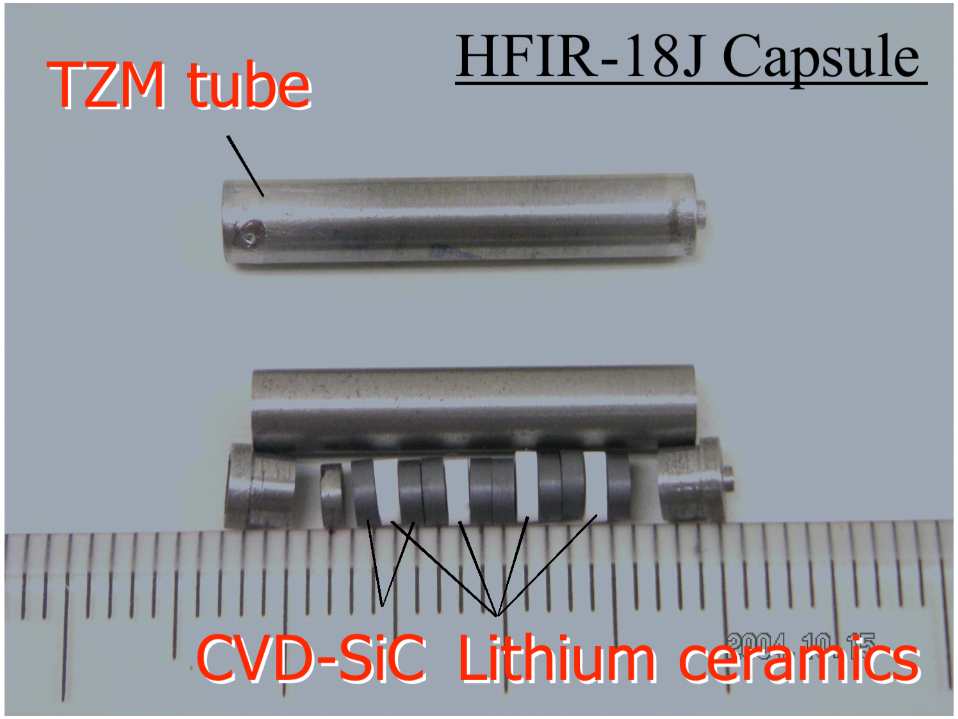
Development of radiation creep measurements technique for ceramic materials

Development of in-situ tritium injection technique during irradiation




Bend relaxation for measurement of radiation creep of ceramics



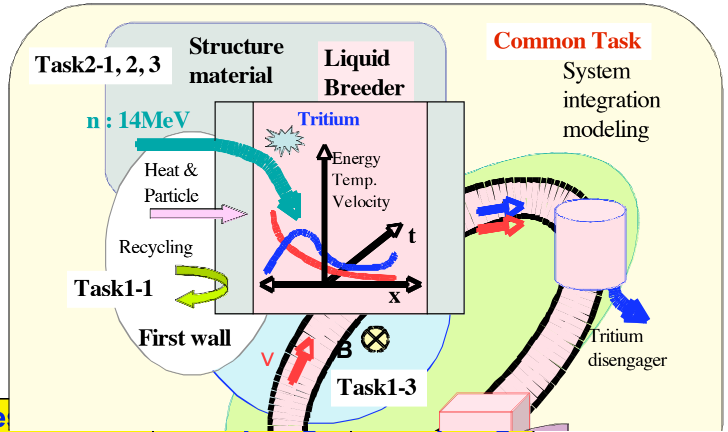

In-situ injection of tritium by sandwiching with lithium ceramics

# Initial Achievements 7

# MFE/IFE System Integration Modeling

Fabrication of working table for integrated modeling

- Reference reactor design
- Modeling of component processes
- Listing up of major parameters for design
- Methodology toward integrated modeling




Example of the working table

| item | task | parameters | model | physics | asse | / remakrs | |
|---|---|---|---|---|---|---|---|
| PFCS | | | | | | | |
| erosion | 1.1 | N,Te,Ti,lSOL,G (edge), impurity | REDEP HEIGHTS | •sheath •sputtering | Input: plasma edge, angular- | | |
| BLANKET | | | | | | | |
| nuclear response functions from | | material, plasma source, geometry, | MCNP, TRIM ANISN | | | coupling for activation | all material property |
| LM thermfluid | | Geometry, material properties, | HiMAG | 3D potential | good for complex geometries and 3D | also applicable to | |
| TRIT RECOVERY | | | | | | | |
| extraction | | | ASPEN, Wilms/Merrill | | | | |
| MATERIALS | | dose, dose rate, material, particle | codes: molecular | binary collisions, | | | thermomechanics, tritium |

# Conclusion

- The TITAN program addresses several key technical issues for long term fusion reactor power handling technologies.
- The discussion of this collaboration considered the scope of FNT for both US and Japan sides.
- A certain compromise from both sides was necessary to reach the agreement.
- Yearly Steering Committee Meeting is necessary to adjust the program direction based on the progress of the tasks.
- It is expected that the TITAN program will make contribution to the world fusion technology program in the next 6 year.