Relation of US VLT Program to ITER

by
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for the
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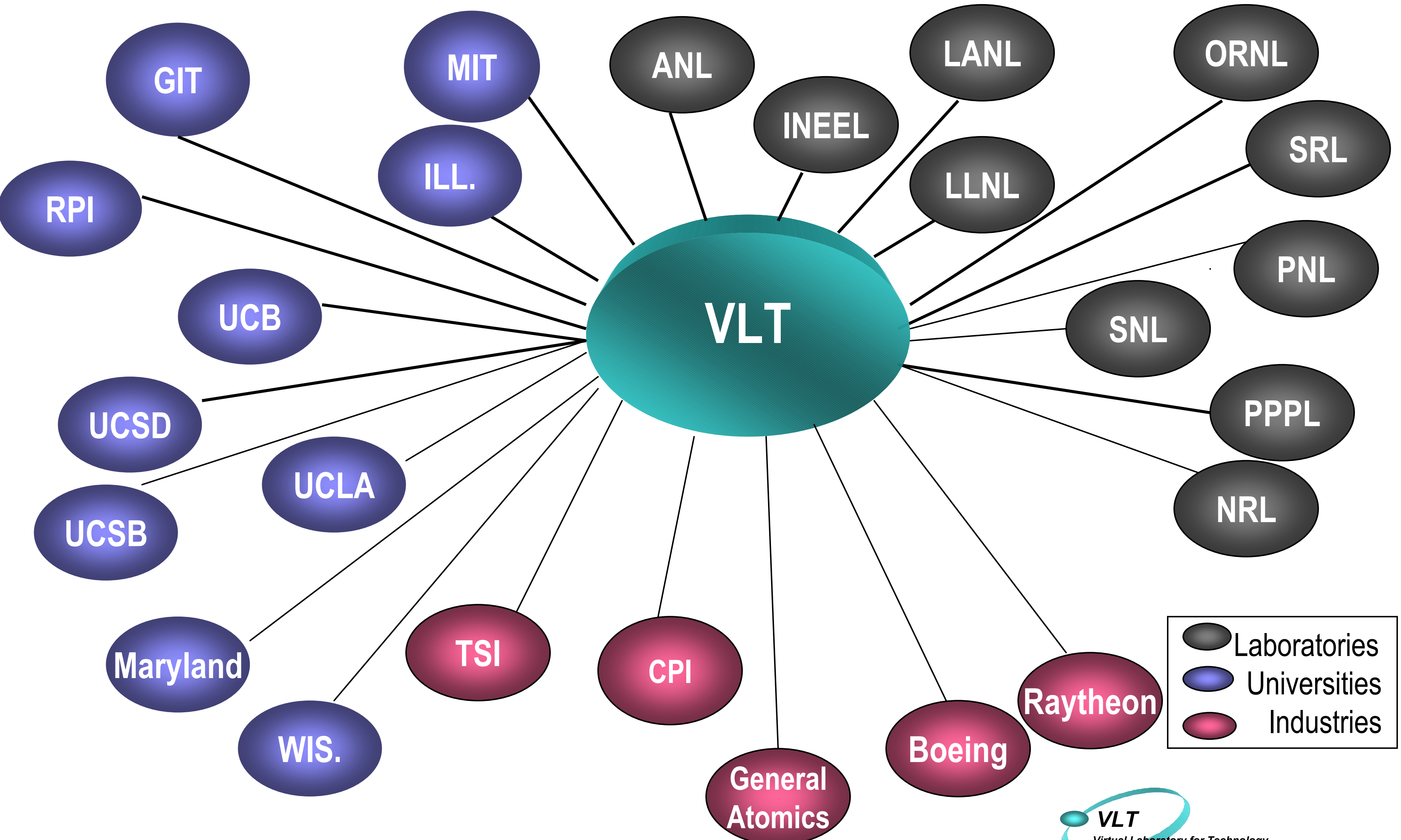
The Enabling Technology Research Mission

To contribute to the national science and technology base by developing the enabling technology for existing and next-step experimental devices, by exploring and understanding key materials and technology feasibility issues for attractive fusion power sources, by conducting advanced design studies that integrate the wealth of our understanding to guide R&D priorities and by developing design solutions for next-step and future devices.

The Technology Program is a Multi-institutional National Resource



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VLT Magnetics Base Program Support for ITER in 2004

- The Magnetics team has been working on magnet technology issues related primarily to the ITER Central Solenoid.
- Task Agreements are underway in 4 areas:
  - **1. Qualification of industrial suppliers of Nb3Sn strands with increased value of Jc (ITA 11-18-UA). (*note: strand program uses direct ITER funding*)**
  - **2. Stress Analysis of the Helium Inlet Regions (ITA 11-20)**
  - **3. Conductor Performance and Design Criteria (ITA 11-22)**
  - **4. CS Jacket Weld Defect Assessment (ITA 11-23)**
- VHTP
  - The US has sent Nicolai Martovetsky/LLNL and Philip Michael/MIT to work with the IT at Naka JWS on CS procurement issues where they are developing specification documents, as well as contributing to other design issues. They each spend several weeks in Naka on an alternating basis at the level of about 0.5 FTE. This will increase to 1.0 FTE next year.
- Jacket Material Characterization
- Investigation of strand/cable degradation through lab scale test program:
  - fundamental characterization of a single strand under pure bending conditions,
  - sub-size cables exposed to transverse compressive stress at relevant magnet field, current, and force levels.
- CS Conductor Analysis
- CS Procurement Preparations
- CS Design Activities
  - design of the helium inlet,
  - joints design,
  - analysis of CS decentering forces

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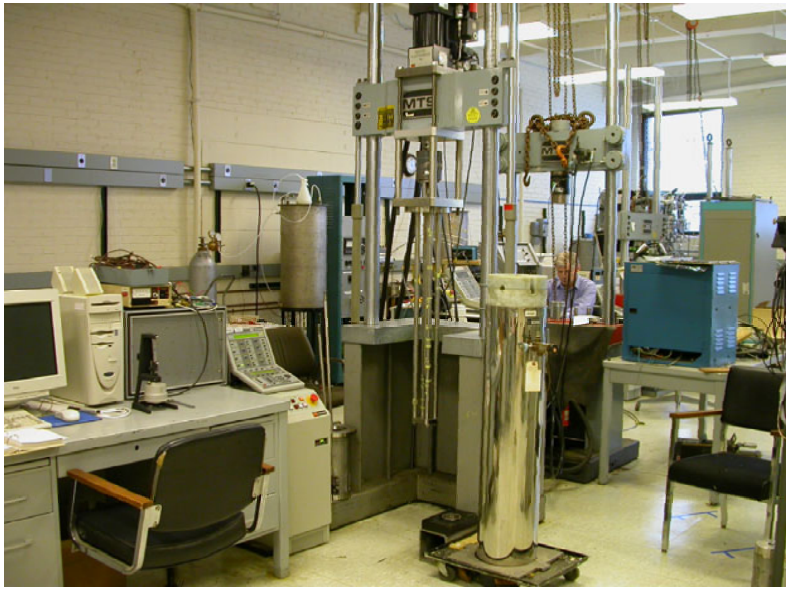
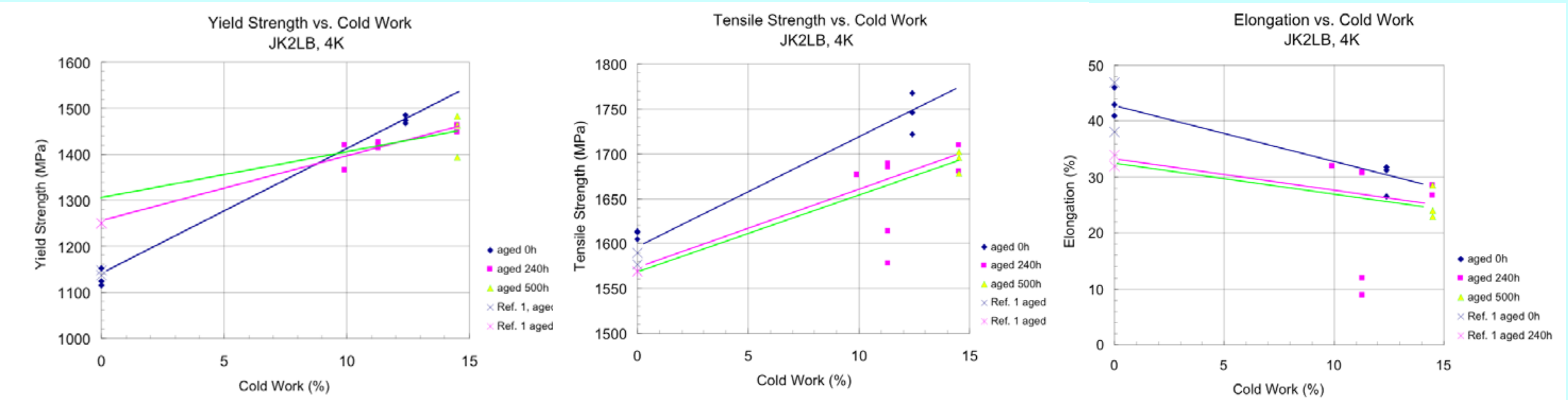
Mechanical Properties of Jacket Material JK2LB

JK2LB properties are being characterized to determine if it can satisfy jacket material criteria:

- Yield, tensile, elongation at RT and 4K
- Fracture toughness at RT and 4K
- Fatigue crack growth rate at RT and 4K
- Base metal and weld metal (limited samples)
- Effect of cold work
- Defect inspection



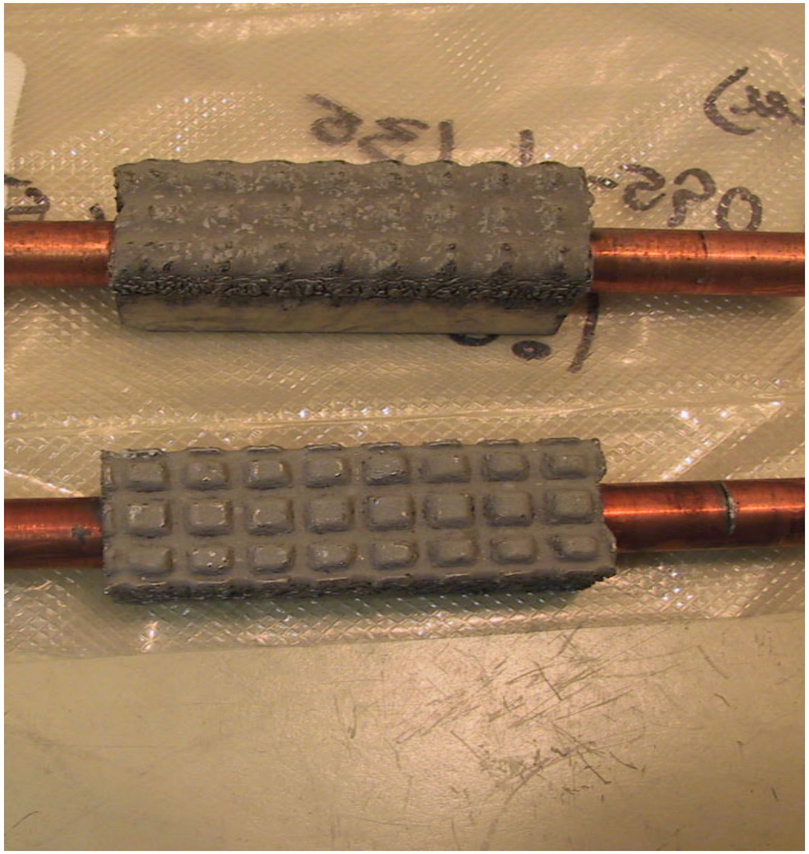
Cryogenic mechanical test facility at MIT



Yield strength, tensile strength and elongation vs. cold work of JK2LB jacket base material at 4K for aging at 650C with various aging times. The blue, red and green lines represent respectively the best guesses of trend-lines for 3 different aging time (0h, 240h, 500h.)

First Wall Testing for ITER

- Our small electron beam system (EBTS) is being used to determine the capabilities of Plasma Sprayed Be on the first wall.
- Plasma spray is one of the options for applying Be 5-10 mm thick to the copper first wall.
- We are setting up to do fatigue testing up to 3 MW/m^2 under steady state conditions.



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ELM Simulation on Divertor PFC

- One of the two beams on EB-1200 is used to provide normal heat flux
- The other beam is focused to a small spot to simulate ELM heat loads for ~0.1ms
- Thousands of cycles will be completed to determine long term effects of ELMs on PFCs
- This is a very high priority for ITER divertor

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ICRF Base Program Supports ITER R&D and Design Needs

Base R&D Program is

- Evaluating different design options for load-tolerant ICRF antennas that can operate during ELMs
  - General topic, needed for C-Mod, JET, DIII-D
  - Applying knowledge gained to ITER antenna design

- Studying high-voltage breakdown properties in presence of plasma and gas
  - Needed for near-term domestic programs
  - Particularly important for ITER, since antenna will have to operate at 40 kV+ voltages to deliver desired power to the plasma

- Developing and applying improved 3D electromagnetic modeling of antennas to optimize antenna designs
  - Using for JET, C-Mod, ITER, DIII-D,....

- Testing antenna designs that may be applicable for ITER
  - High-power prototype of JET "ITER-like" load-tolerant antenna

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High Power Prototype (HPP) of JET “ITER-like” Antenna

US-EU collaboration to test antenna on JET with possible ITER application

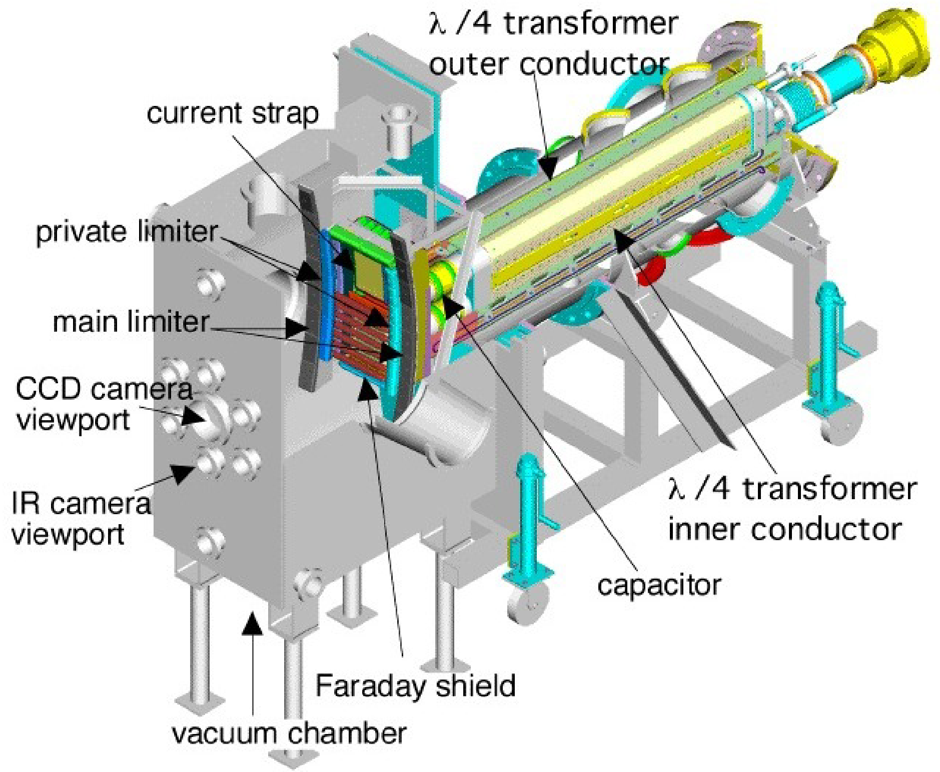
- Prototype designed collaboratively between US and EU
- ORNL and PPPL built prototype, tested at ORNL in 2003

Initial tests achieved original objectives, found ways to improve antenna

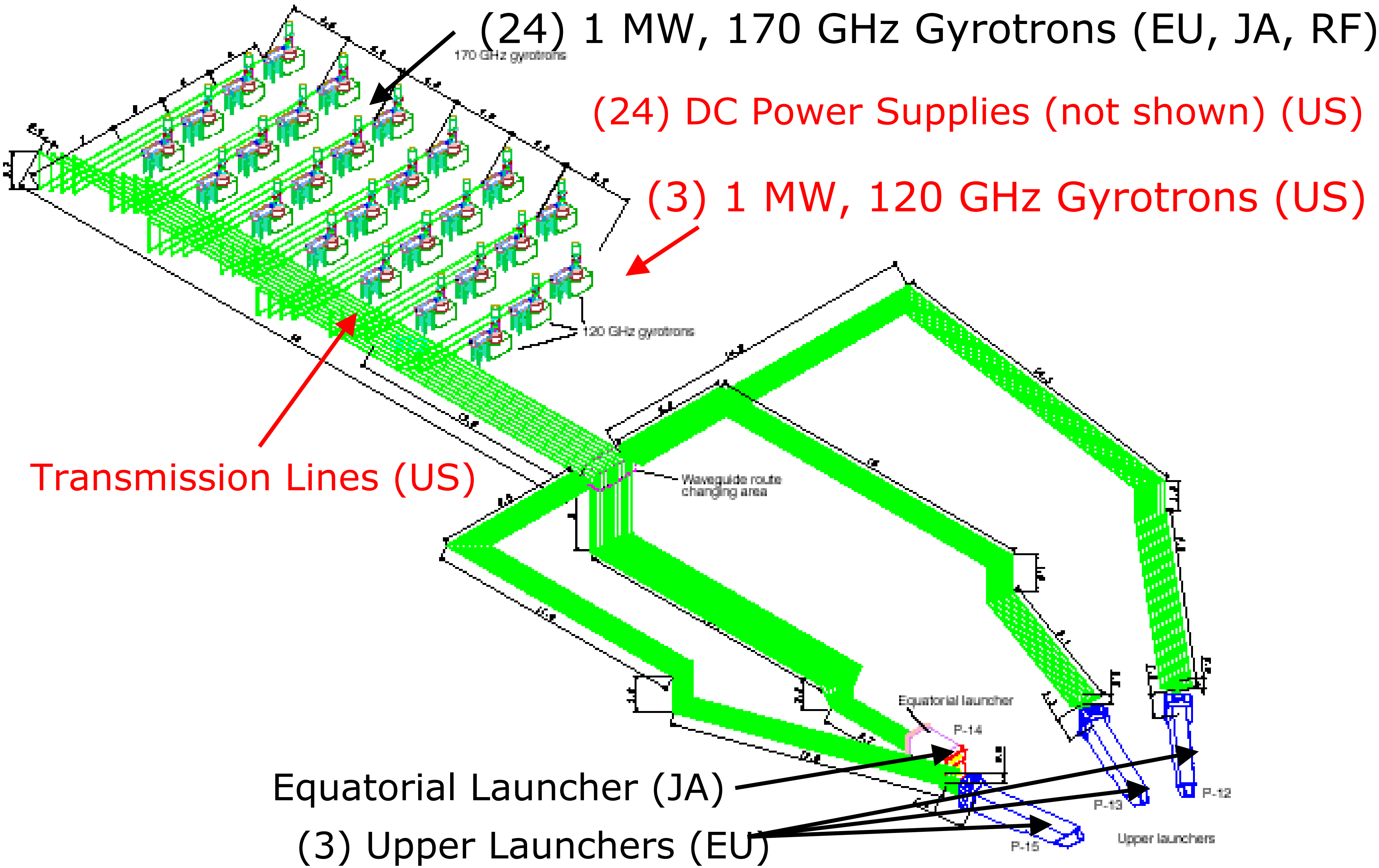
- Tested voltage limits in vacuum
- Tested thermal & electrical behavior of components during long-pulse operation

New test program underway

- Goals
  - Test new current strap design to improve power-handling capability
  - Show modified antenna can operate for full-current 10-s pulses.
  - Test new capacitors with stainless steel internal components.
  - Determine operating limits for the JET “ITER-like” antenna



ECH System/Allocations



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VLT Program Plans for ITER

- **Design Study of 120 GHz, Start-Up Gyrotrons**
  - 1 MW, 120 GHz gyrotron needed; gyrotron operating at up to 2 MW would be useful for both ITER and DIII-D.
  - Milestone: Complete design by September, 2005.
- **Advances in remotely steerable launcher design** will be made to permit steering at larger angles and with the incorporation of miter bends in the line at GA.
  - Now part of design for ITER ECH antennas.
- **Industrial 120 GHz Gyrotron for ITER**
  - Useful for both ITER and DIII-D.
  - Milestone: complete engineering design and fabricate long lead time components by September, 2006.
- **Testing of Short Pulse Prototype of 2 MW, 120 GHz Gyrotron at MIT.**
- **These tasks will be supported by the US VLT Enabling Technology program for ECH.**

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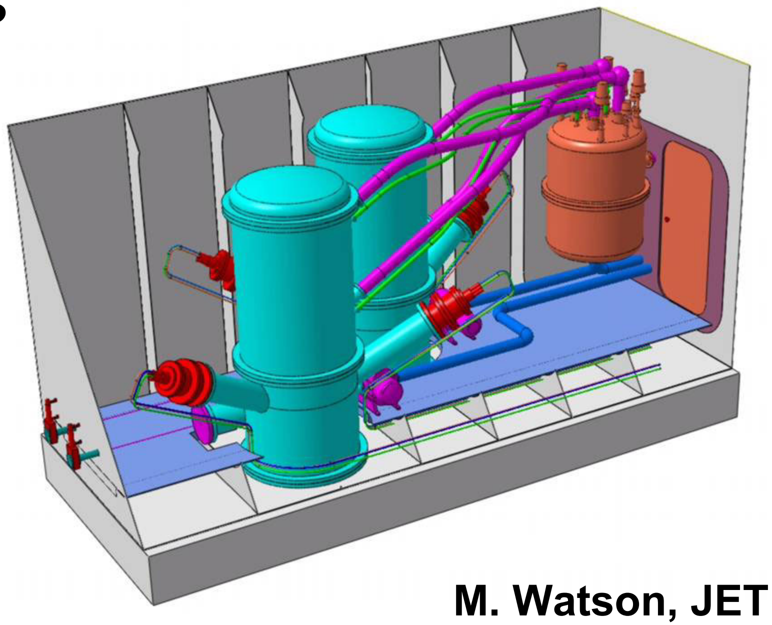
ITER Fueling System

- Gas injection system for edge fueling
- Multiple pellet injectors for deep core fueling, are the primary ITER fuel delivery system.
- Requires long pulse, highly reliable, high throughput, tritium rich pellets
  - Significant extension of present-day designs.
  - Centrifuge accelerator with a continuous screw extruder.
  - Inner wall pellet injection with curved guide tubes



M. Watson, JET

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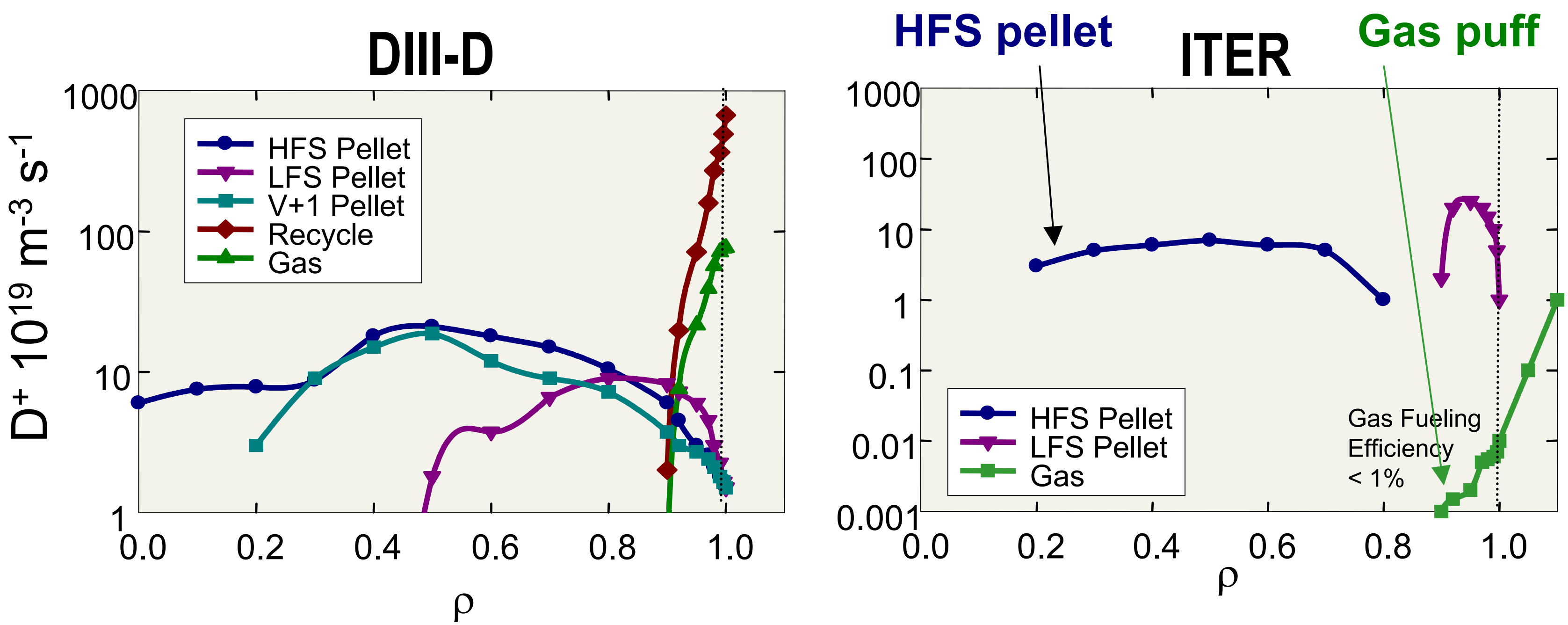
Pellet Injection is Crucial for Effective Core Fueling in ITER as Shown in H-mode Fueling Source Profile Comparison with DIII-D



- **Gas puff core fueling in ITER will be much less effective than in DIII-D**
  - **ITER pellet profiles are from PRL (P. Parks) (10-mm, 1 Hz)**
  - **gas fueling rate of ~1000 torr-L/s for ITER case (L. Owen and A. Kukushkin) B2-Eirene slab calculation**

Redirecting US Plasma Chamber Systems 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 (March 2003)
- Extensive deliberations have occurred in the US since March 2003 among the community, DOE and VLT
- Reached consensus on a general framework for the direction of activities in the US Chamber/Blanket Program:
  - Provide fusion nuclear technology (FNT) support for the basic ITER device as needed
  - Participate in ITER TBM program and redirect good part of resources toward R&D for TBM
  - Encourage partners in international collaborations, such as JUPITER-II to focus more on ITER TBM
- Important work has been carried out to implement the strategy
  - A study of ITER TBM issues and US options was initiated
  - Some R&D was initiated
  - Rejoined TBWG, strong participation
  - The US interacted with all the other 5 parties to identify areas of collaboration

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Highlights of US Strategy for ITER TBM

(Evolved over the past year by the community, DOE and VLT)

- The US will seek to maximize international collaboration. There is a need for all parties to collaborate, and to possibly consider a more integrated plan among the ITER parties for carrying out the R&D and construction of the test modules.

- ITER TBM should be viewed as a collaborative activity among the VLT program elements. While the Blanket/Chamber Program provides the lead role for ITER TBM, major contributions from other programs (e.g., Materials, Safety, PFC) are essential.

- The US community has now reached consensus on preferred options for ITER TBM (see separate slide), following assessment of new technical results obtained over the past few years

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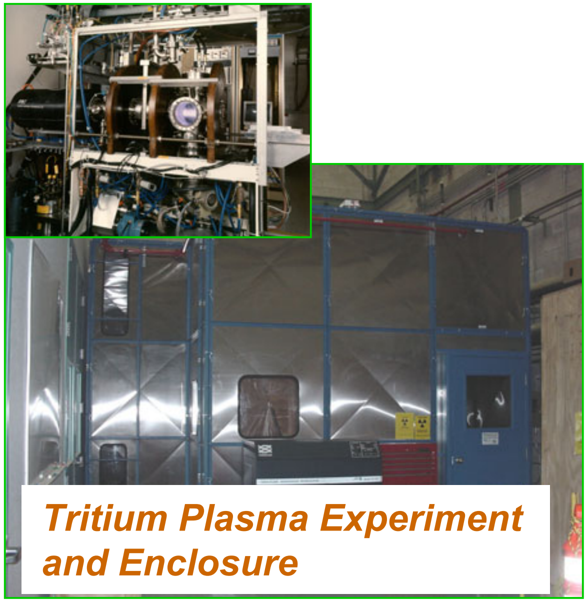
Key Accomplishments: Safety and Tritium

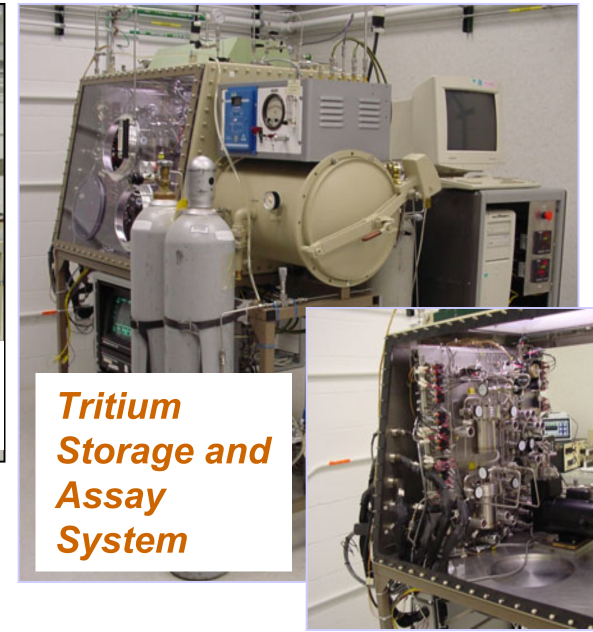
- Completed Management Self-Assessment to commence tritium operations up to 1.5 g-T in STAR
- Demonstrated Be as a REDOX agent for molten salt Flibe at high HF concentrations as part of JUPITER-II collaboration
- Measured Flibe mobilization in air and hydrogen behavior in Flibe as part of JUPITER-II collaboration
- Completed analysis of dust from JT-60 and NSTX
- Provided safety support for ARIES, ITER-TBM, APEX and FIRE

Key systems in STAR



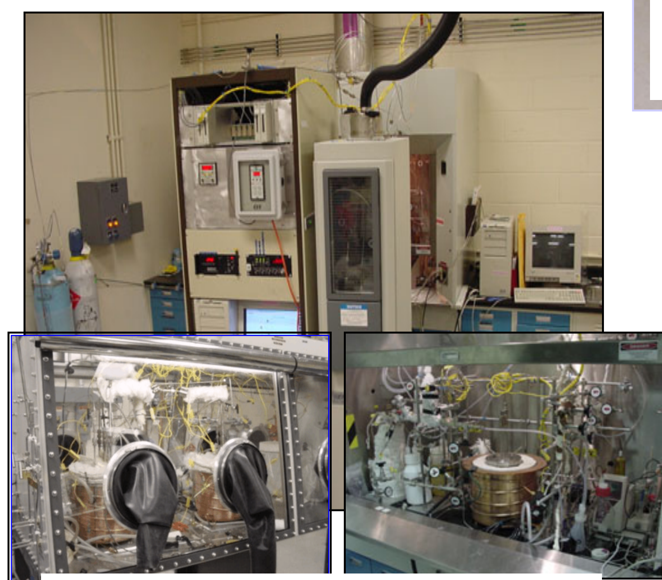
Tritium Plasma Experiment and Enclosure

Molten Salt Tritium Behavior Experiment

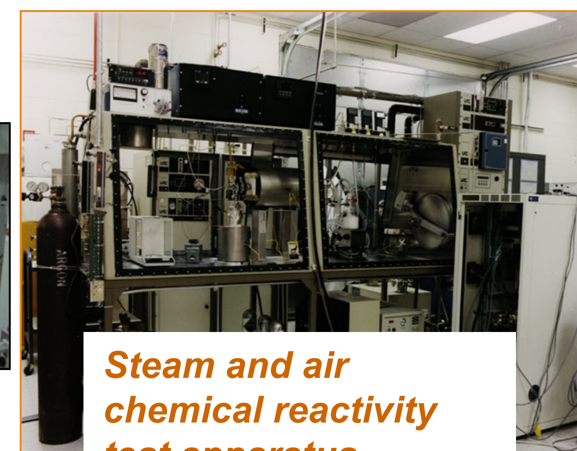


Tritium Storage and Assay System

Tritium Cleanup System



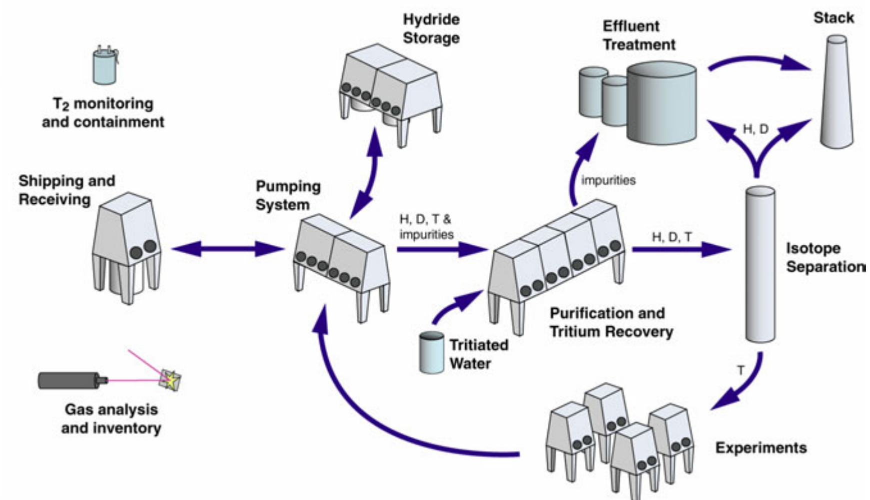
Molten Salt Preparation, Purification, and REDOX Experiments



Steam and air chemical reactivity test apparatus

Tritium Processing-Overview

- Mission
  - To research, develop and design safe and effective tritium processing systems needed to accomplish the OFES mission



- Scope
  - **Separations**: Many unique separations are required for tritium impurities processing, isotope separation, purification, and gas and water detritiation
  - **Storage and delivery**: Isotopes must be safely stored and delivered to systems as needed
  - **Effluent cleanup**: High efficiency cleanup systems are needed to prevent worker & public exposure
  - **Analysis**: A variety of analyses are required for process monitoring, inventory control and contamination control
  - **Handling**: Tritium's unique properties lead to materials compatibility and containment issues
  - **Control**: Unique control issues arise from the challenge of producing on-spec product with this radioactive material while maintaining minimal inventory

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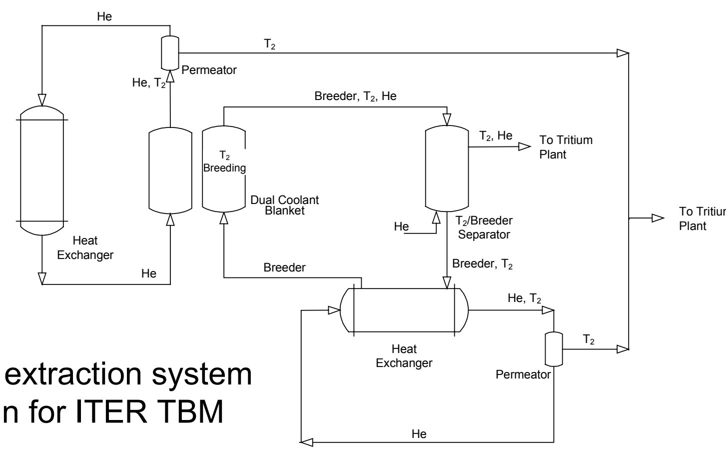
Tritium Processing-Recent Results

- Completed initial testing of a continously regenerable cryopump that can be used for ITER pellet fueling system (Cryogenic Applications/LANL/ORNL)

- Completed initial design of a tritium extraction system for the ITER Test Blanket Module program. Included evaluation of tritium permeation pathways.

- Performed evaluation of ITER Tritium Plant design. Plant will be much larger than current knowledge base. Propose dynamic model to bridge gap.

Continuously regenerable cryopump in operation at LANL



Tritium extraction system design for ITER TBM

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US Fusion Materials Research Portfolio

Material	FY04 budget (k$)	ITER relevance (incl. TBM)	Program leverage
Crosscutting theory & modeling	2000	60%	BES, NSF, ASCI
Ferritic/martensitic/ODS steel	2200	80%	DOE-NE (Gen IV, INERI, AFCI), JAERI, NRC, BES, LDRD
SiC/SiC	1600	40%	DOE-NE (Gen IV, NERI), DOE-NR, JUPITER-II, PBMR
V alloys	1200	10%	NASA JIMO, NASA SRTP, DOE-NR (refractory alloys), JUPITER-II
Functional materials (MHD insulators, Cu, plasma diagnostics, etc.)	450	40%	
ITER machine R&D	100	100%	
Neutron source	170	0	

Summary of ITER Fusion Materials Activities

- The US program (in collaboration with JAERI in several cases) provided key materials data during the 1990s for the ITER design
  - Type 316 austenitic stainless steel
  - Cu alloys for first wall and divertor heat sinks (CuCrZr, dispersion strengthened Cu)
  - Beryllium
  - Carbon-carbon composites
  - Ceramic insulators for plasma diagnostics and heating systems

- Current ITER tasks are focused on critical assessment of properties data for superalloys, Cu alloys, and other materials systems
  - Research on a very high strength Cu alloy has also been requested

- In addition to ITER machine tasks, critical data for the ferritic/martensitic steel and other materials for the ITER test blanket modules is being obtained as part of the DOE/JAERI and Jupiter-II collaborations, as well as from the US base program (e.g., SiC compatibility with Pb-Li)

Next Step Options (ITER/AT)

- ARIES studies have shown the benefits of advanced tokamak (AT) operating modes in achieving high power density and steady-state operation for an economically attractive tokamak power plant.

- Successful implementation of AT operating modes in ITER would increase power densities and pulse duration allowing **extended performance** for physics exploration and nuclear testing.

- The goal is to develop ITER/AT scenarios with $\beta_N \approx 4$, and a bootstrap fraction of $\approx$75% and to determine the systems requirements so that discharges approaching 1000 MW for ~3000 sec could be produced.

- The key activities include development of:
    - AT scenarios using integrated self-consistent simulations,
    - MHD stabilization coils compatible with neutron environment,
    - High power density divertor and first wall components, and
    - operating range that exists within system and facility constraints.

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