Advances in Technology To Realize Fusion Energy in the International Context

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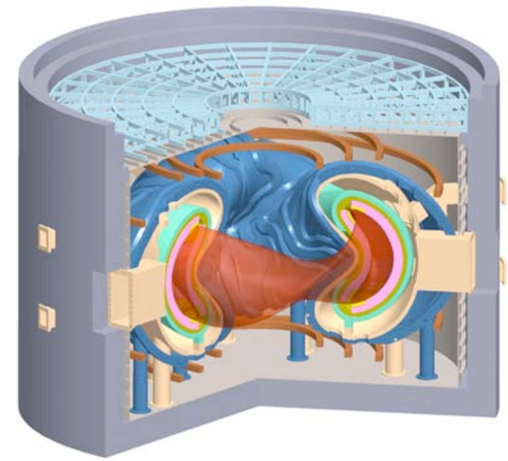
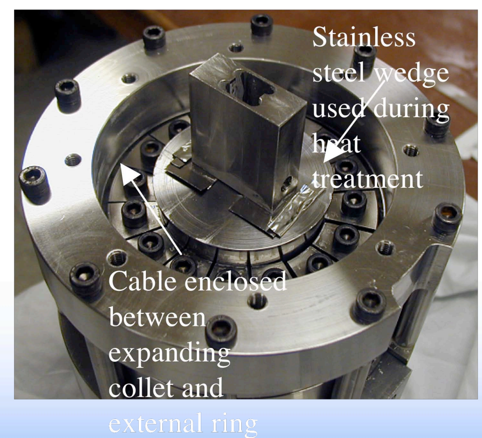
The US Enabling Technology Research Mission

- To contribute to the science and technology base by
  - Developing the enabling technology for existing and next-step experimental devices
  - Exploring and understanding key materials and technology feasibility issues for attractive fusion power sources
  - 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





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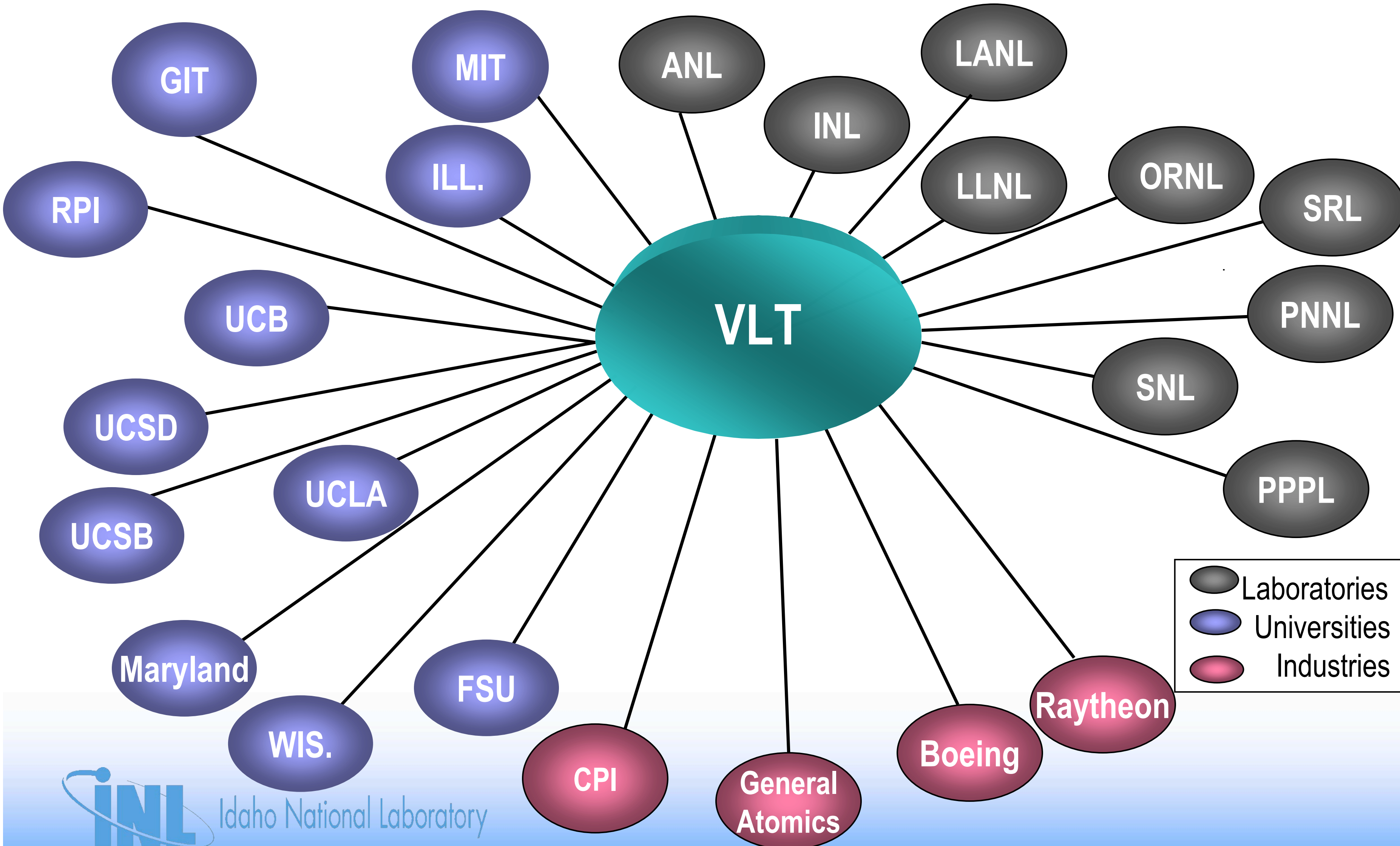
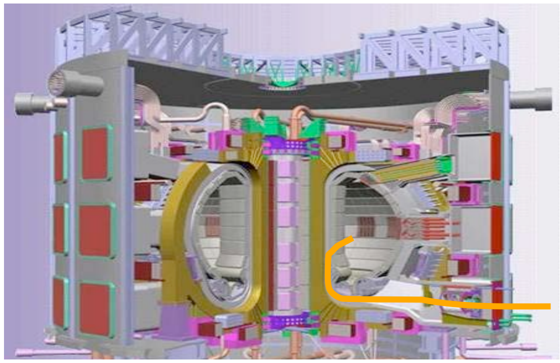
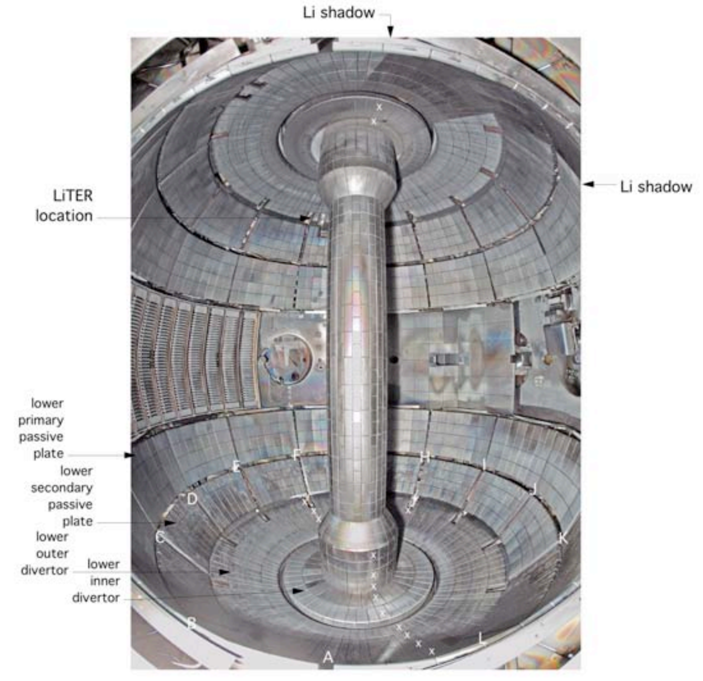
The US Technology Program is multi-institutional, involving national laboratories, university, and industry



Challenges

- Materials and plasma chamber systems must provide simultaneously for power extraction and tritium breeding
- These systems will play a critical role in determining the ultimate attractiveness of fusion power
  - Need high power density, high thermodynamic efficiency, high reliability, fast maintainability, long lifetime, and low long-term radioactivity
- Meeting these simultaneous demands in the multiple-field, intense fusion environment, and complex plasma configurations are a challenge that requires advances in several scientific fields and engineering applications





x means tile removed
some removed tiles are out of view

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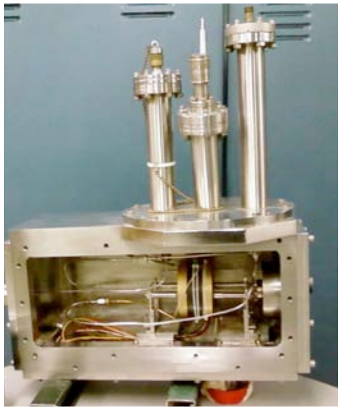
The US enabling technology mission translates into three major categories

- ITER Project Support
  - Design, R&D, and qualification of many of the ITER hardware packages
- Research Supporting ITER and utilization of ITER as a test bed
  - In addition to direct contributions to the ITER project, advanced technologies are being developed and deployed on fusion research facilities that could be incorporated in ITER in the future to improve operation and performance
- Beyond ITER
  - ITER is the stepping stone to devices that must employ (or develop) high performance materials and fusion nuclear technologies for electrical power production
  - R&D is conducted in materials science, chamber systems, safety and tritium research, and systems studies



Pipe-Gun Pellet Injector

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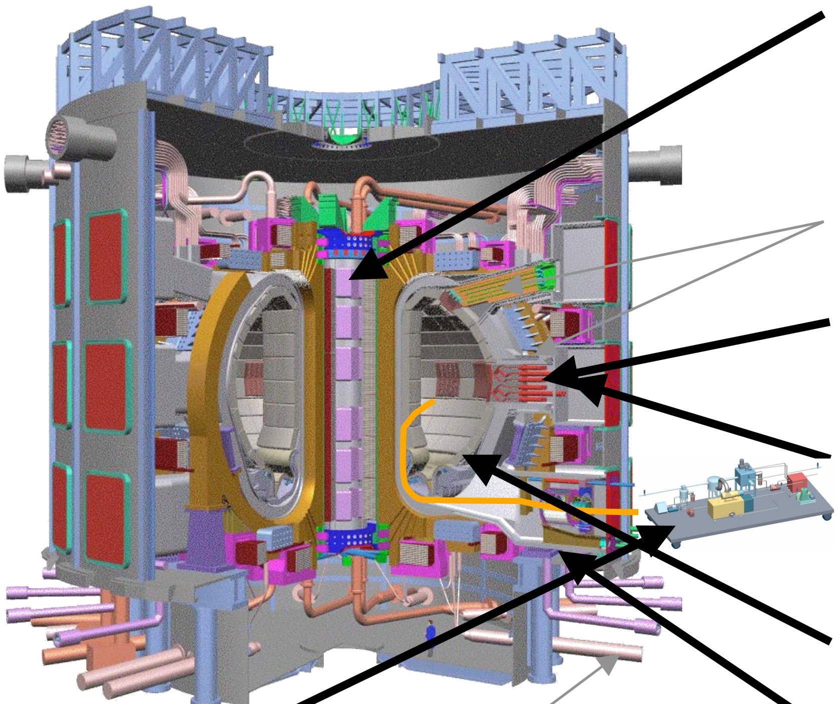
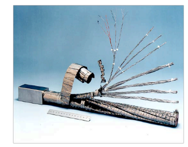
Technology program supports all aspects of the ITER Project



7 Central solenoid windings
8% of TF conductor

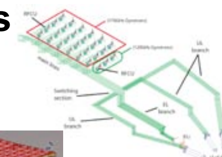


Steady-state
power supplies

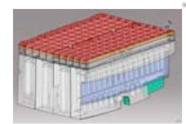
15% of port-based
diagnostic packages

All Ion Cyclotron transmission lines (20MW)

All ECH transmission lines (24MW)



Blanket/shield 20%; limiters



Roughing pumps, standard components

Tokamak exhaust processing system

Pellet injector

75% cooling for
divertor,
vacuum vessel, …

Cross cutting activities (materials, nuclear analysis, safety) and Design Working Groups

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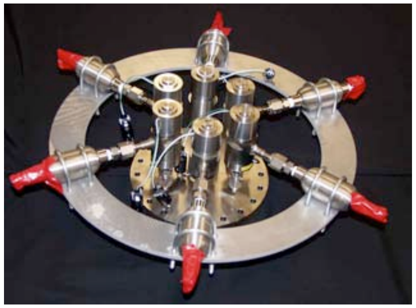
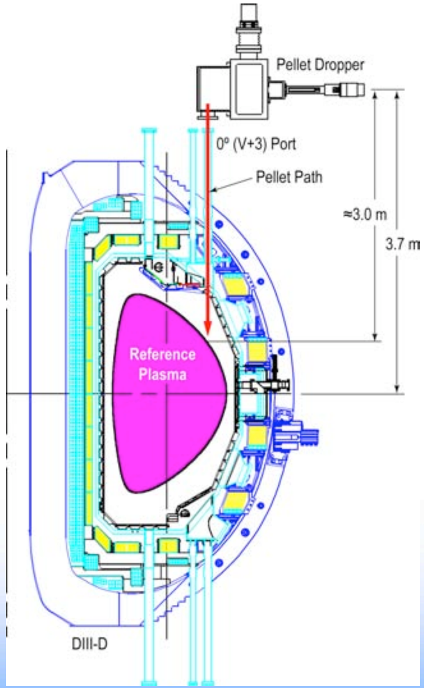
Technology addresses high priority issues for ITER —*disruptions, ELMs*

- **A new massive gas injection system for mitigating the effects of plasma disruptions has been deployed on DIII-D.**
  - **6x higher throughput compared to earlier design**
- **A pellet pacing system has been designed to reduce heat loads on plasma facing components caused by ELMs and has been deployed on DIII-D.**
  - **Can operate at 50Hz**





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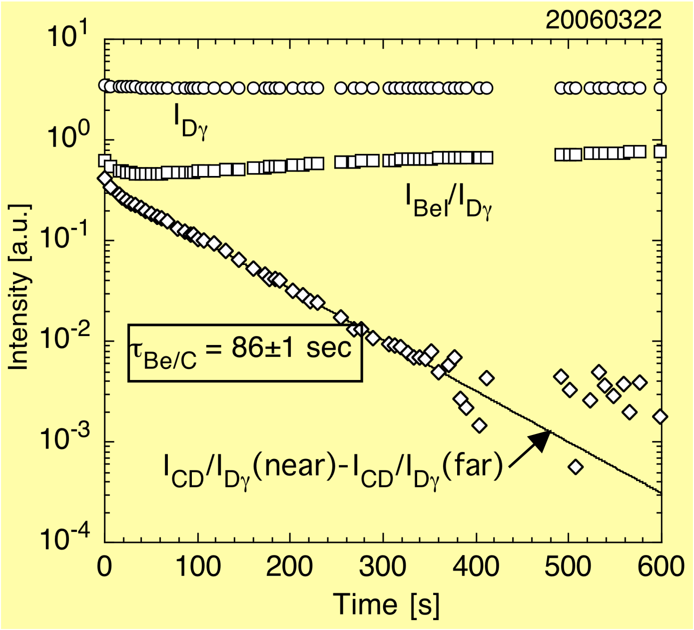
Technology address high priority issues for ITER — *tritium retention and PFC choice*

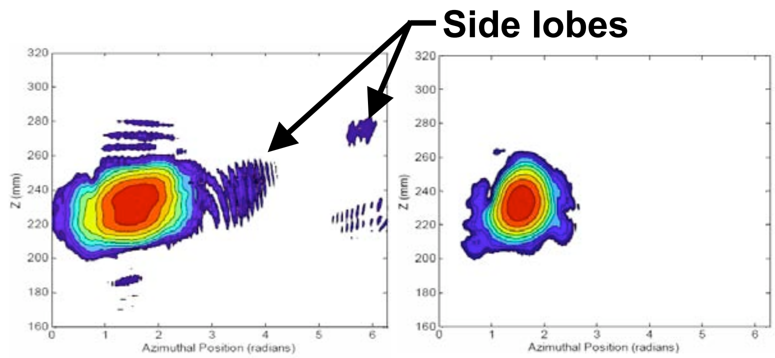
- Mixed material experiments on the PISCES device have revealed a synergistic effect of Be in deuterium plasmas that substantially reduces chemical sputtering of carbon from graphite targets and hence the source of tritium co-deposition from the ITER divertor
- The PMI/PFC materials and safety communities are investigating the potential of tungsten as an alternative to carbon and Be as the materials for plasma facing components of the first wall and ITER divertor.

CD Light Intensity Reduction at C Target



Technology is improving the performance of plasma control tools on ITER — *heating and current drive*

- **Research on electron cyclotron heating systems, using gyrotrons that employ depressed collector technology and improved internal mode convertors, promises to deliver 1.5 MW systems at overall efficiencies exceeding ITER's target of 50%.**
- **An ITER-like load tolerant high power density (9 MW) ion cyclotron antenna concept that allows the radio frequency transmitters to operate closer to full power output – this has recently been deployed on JET in collaboration with the European Fusion Development Association.**

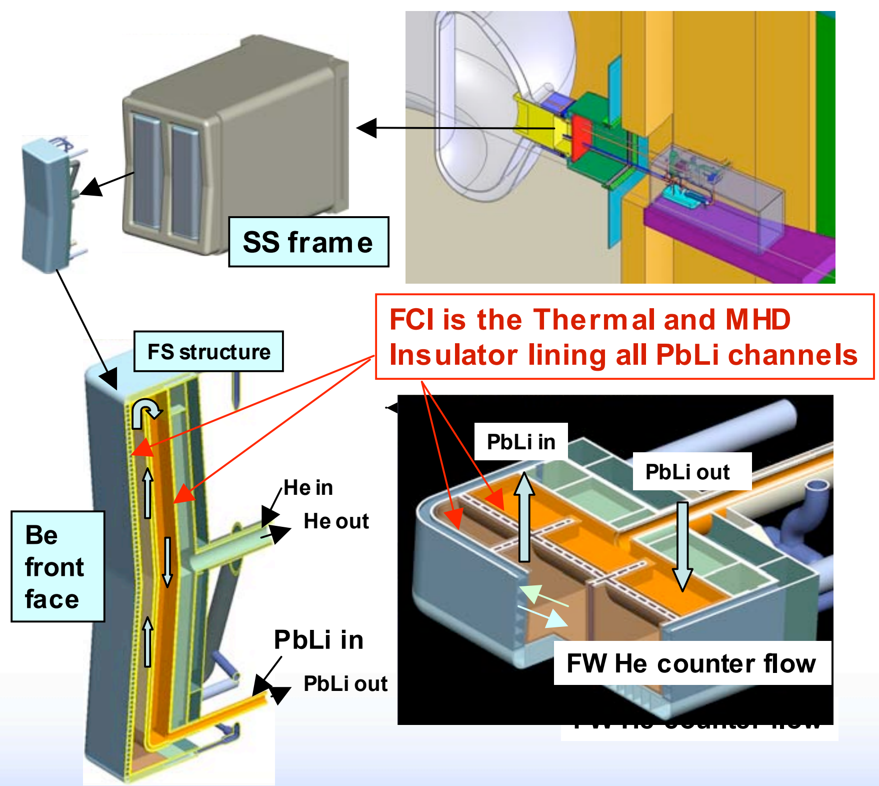


Old Design **New Design**

Utilizing ITER as a test bed — *tritium breeding and heat extraction*

- **Testing of tritium breeding and heat extraction blanket concepts in special ports is one of the objectives of ITER.**
- **Chamber technology R&D and planning has focused on test blanket options for potential ITER application**
  - **1) US led dual coolant lead-lithium (DCLL) concept for high temperature potential**
  - **2) Helium cooled ceramic breeder (HCCB) "unit cells" in EU test blanket module**
- **This activity integrates the efforts of several technology program elements (chamber systems, materials science, neutronics, PFC/PMI, and safety and tritium)**

US DCLL TBM module



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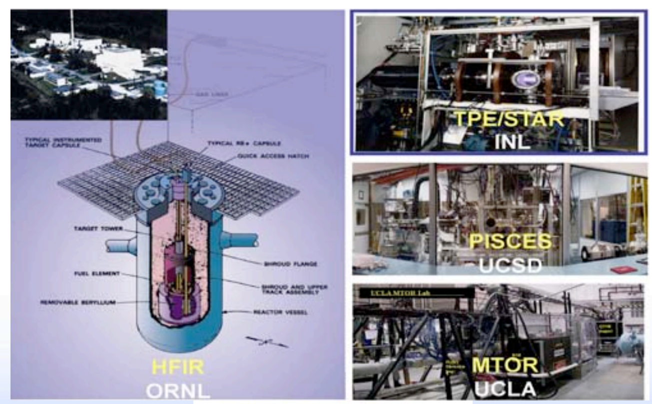
ITER and beyond — *materials and fusion nuclear science and technology*

- **The VLT conducts broadly based research through its Materials Science, Chamber Systems, Safety and Tritium Research and ARIES (systems studies) program elements.**
- **Long-standing joint research programs with Japan strengthen and augment these efforts**
  - **JAEA: reduced activation ferritic steels**
  - **NIFS: Tritium and thermal fluid control through first wall, blanket, heat exchange/T recovery system**
    - **irradiation**
    - **high heat pulses**
    - **liquid metal MHD flow**

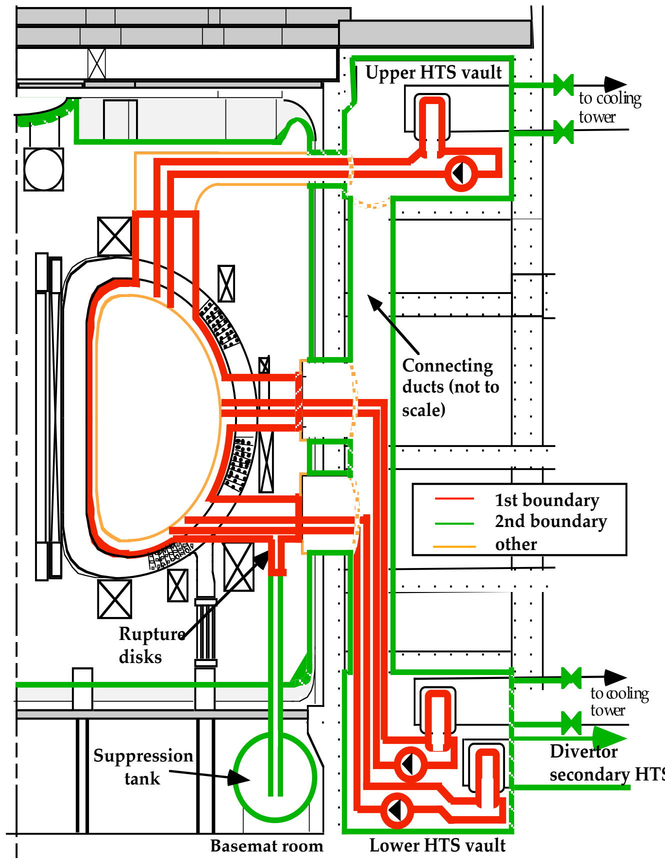


Japan-US Joint Project TITAN 2007-2012

Safety is an important cross-cutting activity

- **Analysis and mitigation of hazard potentials associated with substantial tritium inventories and various energy sources–chemically reactive dust, PF coils, etc.**
- **Close interactions with French regulators to expedite ITER construction license approval**
- **Experiments with molten salts to measure tritium mass transport properties, evaluate corrosion control methods, and determine compatibility level of certain materials**

ITER Confinement Model in MELCOR-Fusion Analysis for Licensing



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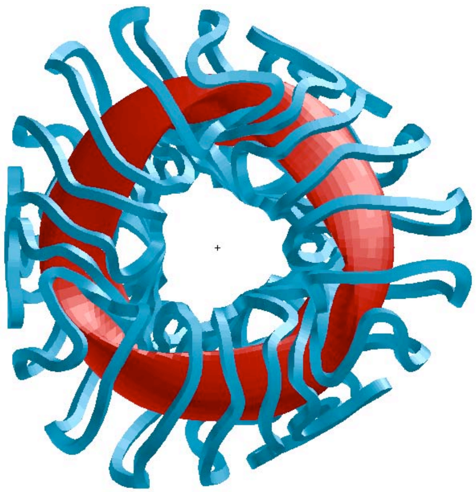
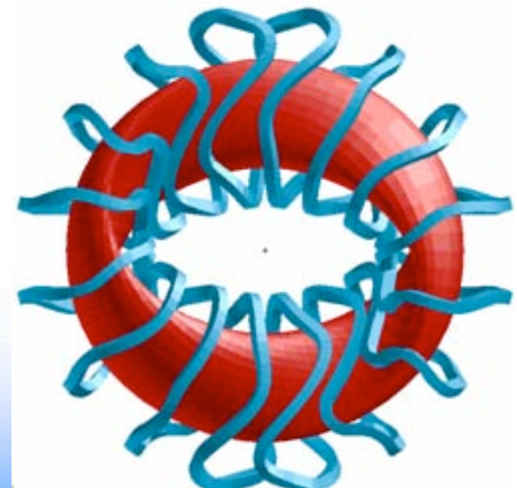
Systems Studies (e.g., ARIES) provide guidance to the fusion program

- **Can compact stellarator power plants similar in size to advanced tokamaks?**
  - **Compact stellarator power plants can be similar in size (mass) to advanced tokamaks**
- **Understand the impact of complex shape and geometry**
  - **Configuration, assembly, & maintenance drive the design**
  - **Hardware options are limited because of complexity-driven constraints (e.g., superconducting magnets)**
  - **3-D analysis is required for almost all cases (e.g., CAD/MCNP interface for 3-D neutronics, 3-D solid model for magnet support, divertor)**
  - **Feasibility of manufacturing of component has been included in the design as much as possible.**



NCSX-Like



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Summary

- Technology is essential to ITER
  - Design, R&D and test facilities for the construction phase
  - Cross cutting research
  - Participation on physics tasks and ITER Design Working Groups
  - Research to address high priority issues and performance enhancements
  - Research to utilize ITER as a test bed for complementary and follow-on devices
- Technology is essential to next-step and future devices
  - R&D is conducted in materials science, chamber systems, safety and tritium research, and systems studies
  - Systems studies

"In parallel the long-term technology programme has been generating the technological knowledge base that should allow Europe to design and operate fusion power plants. Without this accompanying work, JET would probably have not achieved its remarkable success. It is this coordinated effort and integration of the overall Fusion Community which has allowed Europe to lead the world in this field of research.“

Janez Potocnik,
European Commissioner for Science and Research
March 3, 2005 speech at the JET fusion facility