Support of ITER in the VLT's Base Technology Program

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Stan Milora, ORNL
Director, Virtual Laboratory for Technology
USIPO Chief Technologist
and
Richard Nygren, SNL
Deputy Director, Virtual Laboratory for Technology

U. S. ITER Technical Advisory Committee Meeting

April 14-15, 2009

Research Mission of the VLT:

Contribute to the national science and technology base.

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1) Develop the enabling technology for existing and next-step experimental devices*.

-- in particular --

2) Explore, understand and resolve key issues in materials and technology to make fusion both feasible and attractive as a power source.

3) Integrate our wealth of understanding using design studies to guide R&D priorities and to find design solutions for next-step and future devices.

focus today is ITER, first introduce VLT

The Virtual Laboratory for Technology: R&D and diverse technology in 25 institutions

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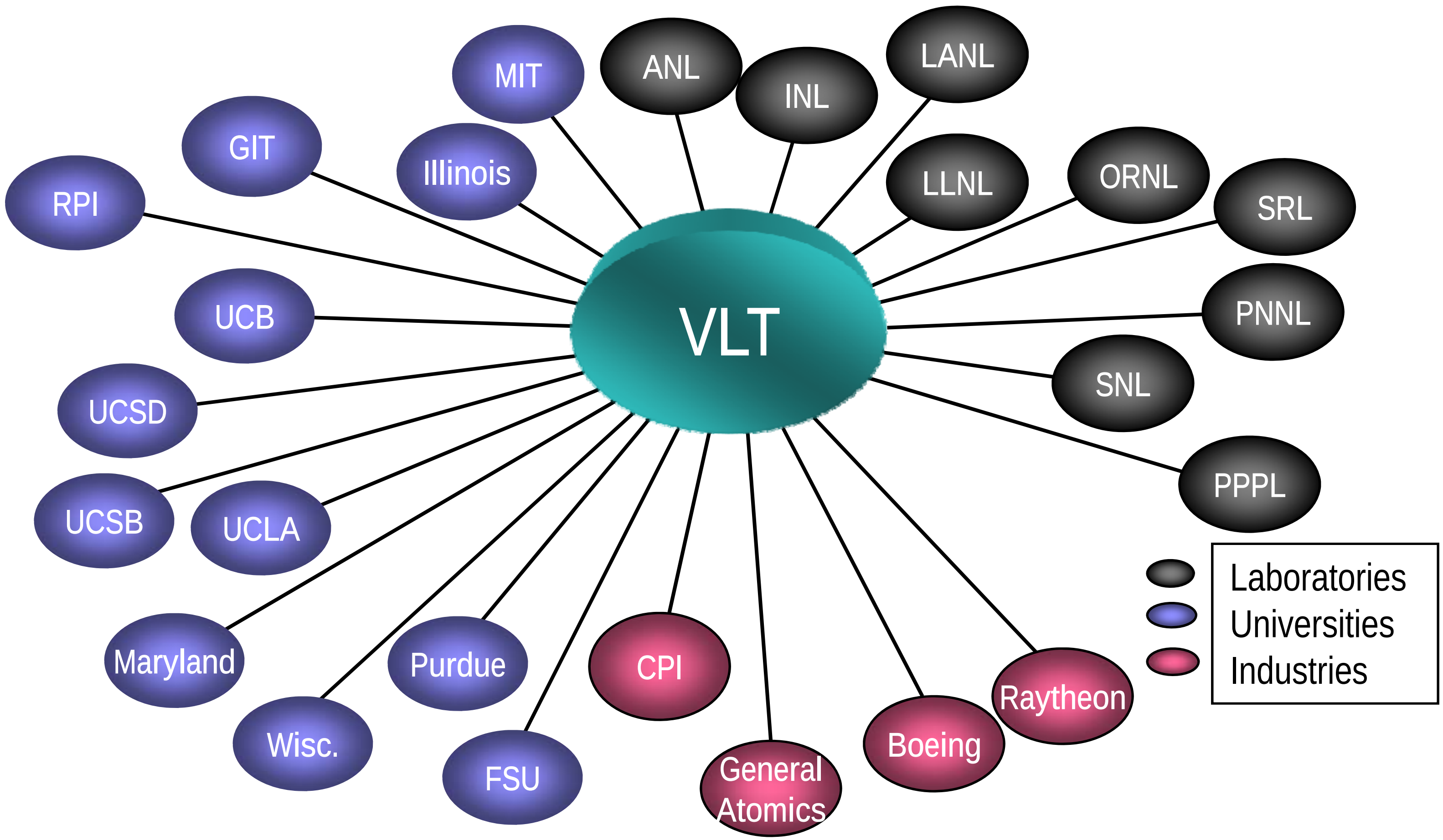

VLT Program Element Leaders

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Program Element	Element Leader	
Magnets	J. Minervini	MIT
PFC	R. Nygren	SNL
Chamber	M. Abdou	UCLA
ICH	D. Swain	ORNL
ECH	R. Temkin	MIT
Fueling	S. Combs	ORNL
Tritium Processing	S. Willms	LANL
Safety & Tritium Research	P. Sharpe	INL
Materials	R. Kurtz	PNNL
ARIES	F. Najmabadi	UCSD
Socio-Economic	L. Grisham	PPPL

Outline: VLT's active engagement in ITER
-- *many aspects of ITER Technology* --

- **Direct support**: work funded by US IPO

- **Base program research**: R&D that uses existing facilities and addresses high priority issues and performance enhancements for ITER
  - *in concert with the USBPO*

- **ITER as a test bed**: R&D in fusion engineering science for complementary facilities and next step devices

VLT's active engagement in ITER:
procurement package R&D and design

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15% of port-based diagnostic packages

~~7 Central solenoid windings~~

8% of TF conductor

Steady-state power supplies

All Ion Cyclotron transmission lines (20MW)

All ECH transmission lines (24MW)

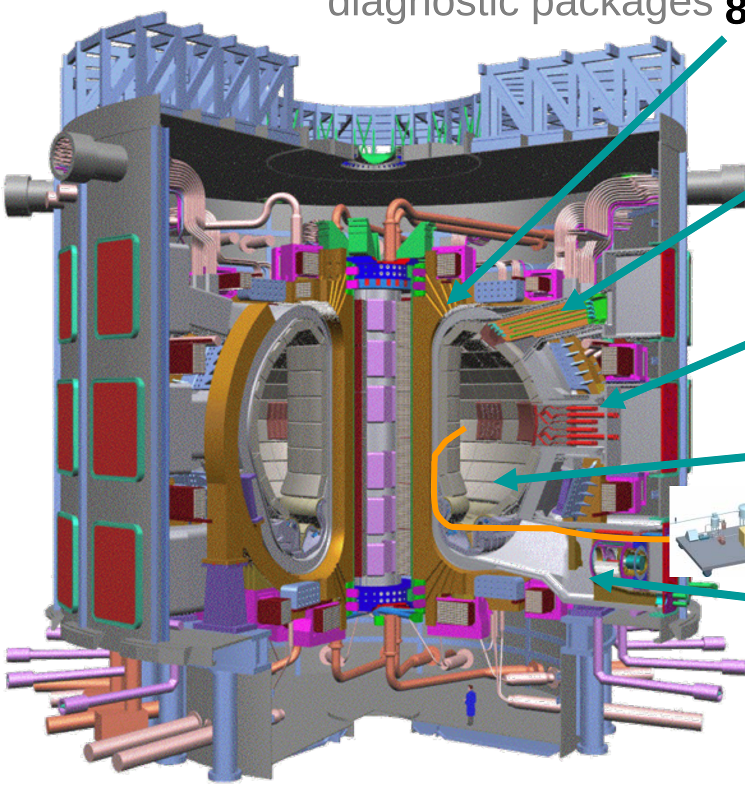
20% of FW, blanket/ shield; limiters

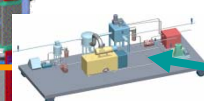
Pellet injector

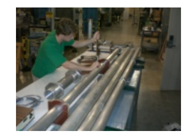
Roughing pumps, standard components

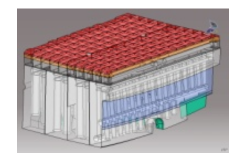
Tokamak exhaust processing system

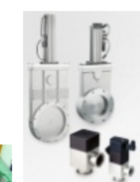
75% cooling for divertor, vacuum vessel, …

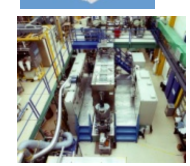












Cross cutting activities (materials, nuclear analysis, safety) and Design Working Groups

VLT's direct support for ITER:
procurement packages in R&D and design

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- 13-T, 277 V·s central solenoid assembly and TF conductor with the highest performance Nb_3Sn superconducting wire *(no longer by MIT)*
- **ICH:** Feed system for 20-MW heating & current drive antenna; *this requires development of actively cooled transmission line components with 5 MW steady state capability*
- **ECH:** Low loss transmission line components for 24-MW heating and current drive launchers with up to 2-MW capability
- **Fueling:** system (gas gun) to supply 5-mm cryogenic DT pellets continuously; *throughput significantly beyond present designs.*
- **PFCs:** 20% of actively-cooled Be-clad FW/shield modules; *heat loads of 0.5 MW/m² steady state, 1.4 MW/m² MARFEs, erosion, and nuclear heating levels of ~10 MW/m³.*
- **Exhaust gas processing:** *system separates D & T from water, methane and inert gases in the exhaust of 400 to 3000 s shots; very high throughput and very high decontamination factors*

DaveR

MikeH/ MikeU

ScottW

US IPO WBS Mgr/TechLdr

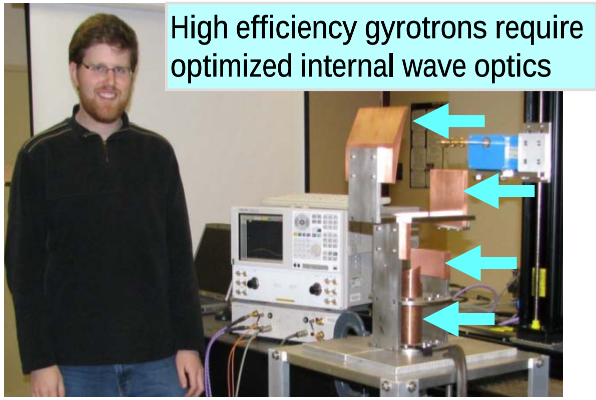
VLT's direct support for ITER:
plasma control tools - heating & current drive

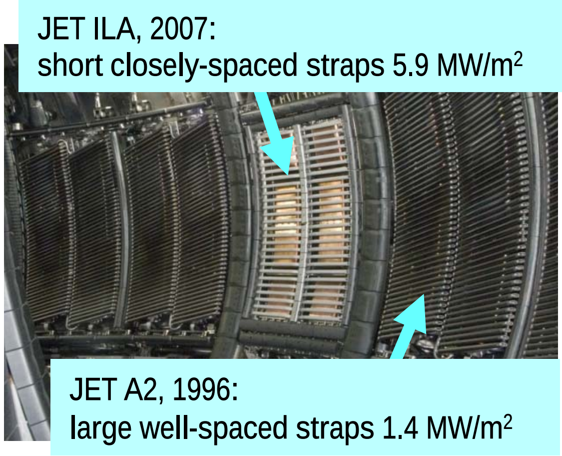
VLT Virtual Laboratory for Technology For Fusion Energy Science — ORNL

- **Research on electron cyclotron heating systems**
  – Collaboration with JAEA/NIFS - Transmission Line R&D
  – Gyrotron Output Wave Optimization
  – Studies of Gyrotron Efficiency and Tunability

- **ITER-like load tolerant, high power density IC antenna deployed on JET (JET-ILA).**
  VLT collaboration with EFDA & UKEA. Coupled L mode power densities to 5.9 MW/m^2 (limited by generator)
  – H mode operation with 42 kV antenna voltage (at capacitor limit), $P_{coupled}$ = 2 MW/m^2 during ELMs
  – Passive ELM resilient operation demonstrated
  – Internal tuning components are problematical. ITER design uses external components.

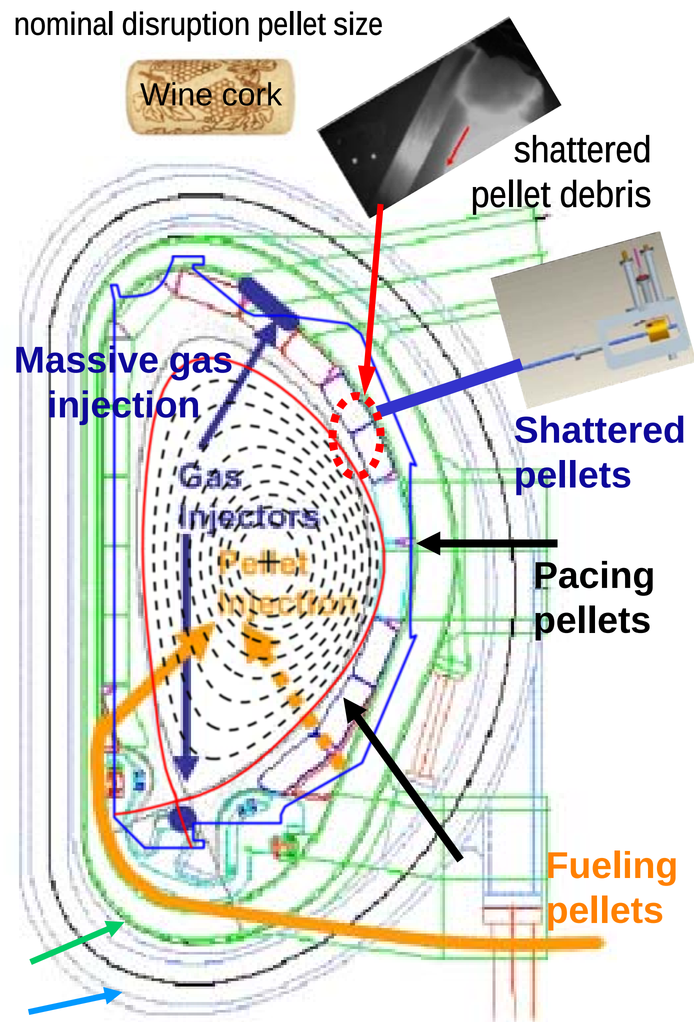
- Informal discussions on possible US role in ITER Lower Hybrid technology development





VLT's direct support for ITER:
plasma control tools – ELM & disruption control

- **Large shattered pellet & massive gas injection systems for mitigating the effects of plasma disruptions being deployed on DIII-D.**
  - –Test shattered pellet concept and compare with gas jet for disruption mitigation and runaway electron suppression.
- **Pellet pacing systems to reduce ELM heat loads on PFCs to be tested on DIII-D and JET.**
  - –Pellet dropper momentum not sufficient to penetrate separatrix and trigger ELMs.
  - –Utilize gas gun injectors, higher velocity & mass.
  - –JET 50 Hz; DIII-D 60 Hz from 3 injectors
  - –Adjust speed, pellet size, launch location to optimize ELM triggering in the H-mode with minimal fueling



DIII-D injector geometr
overlaid on ITE

VLT's direct support for ITER:
FW Design (EM loads, hydraulics); FW R&D

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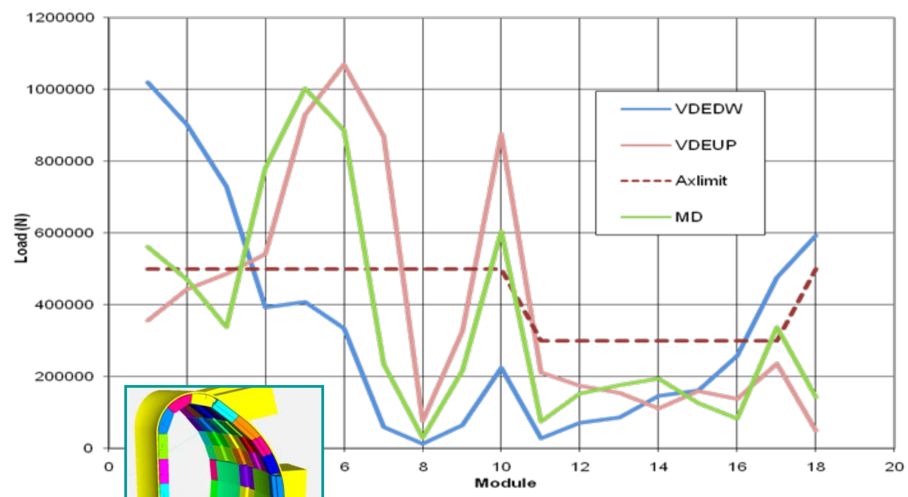
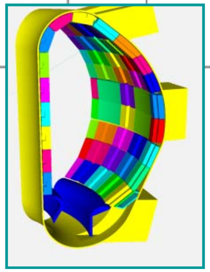
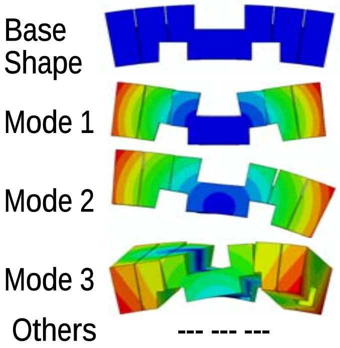
The IO values the responsiveness of the US Team

- **EM analysis of disruption forces**:
  Compare forces: solid 316LN modules (no cooling holes, poloidal slits) versus cases with radial cooling holes and toroidal slits
  - Cooling holes & toroidal slits: Inclusion reduces calculated loads on the mounts
  - MD & VDE up: reduction insufficient; allowable load exceeded in some places
  - VDE down: reduction barely sufficient to be under the allowable load





- **Dynamic analysis**:
  Normal modes of shield module: solid module with poloidal slits and solid module with cooling holes and toroidal slits.
  Lowest frequency (normal mode spectrum) is ~100 Hz; frequency content of force overlaps with normal mode frequencies.



VLT's direct support for ITER:
FW Design (EM loads, hydraulics); FW R&D

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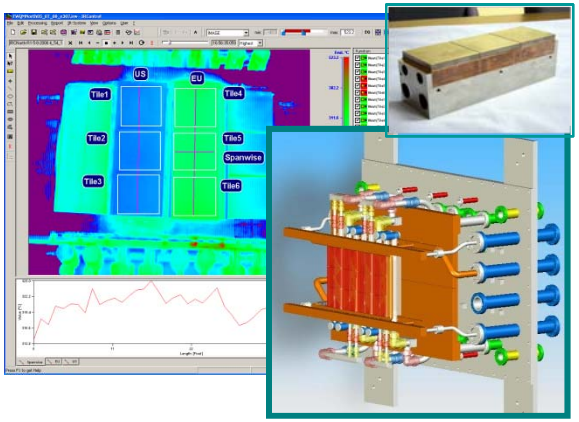
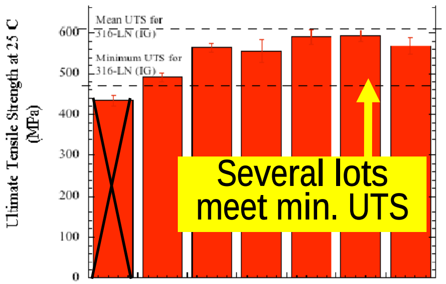
US FW Team: SNL, UW, UCLA, UCSD, ORNL ~$3M/yr by US IPO

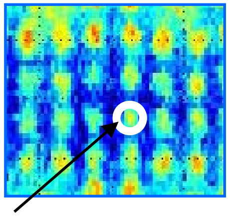
- **Development of FW module design:** *R&D includes joining and testing for US FW components.* **(SNL)**
- ***FW Quality Mockups:*** *EU & US FWQMs tested in 2008 in the Plasma Materials Test Facility; tests of FWQMs from Japan, Korea, China and Russia are in progress.* **(SNL)**

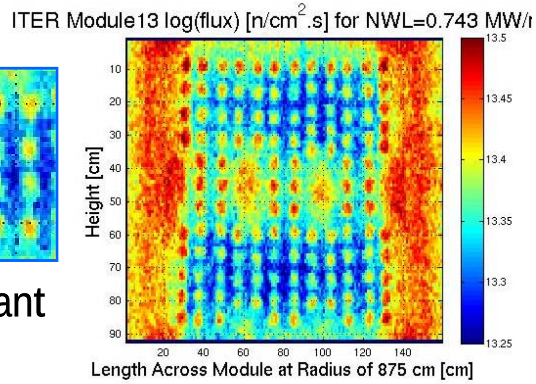


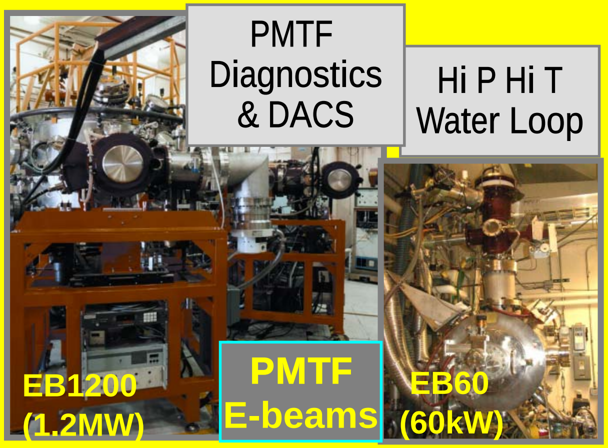
- **Development of cast SS:** *Reduce cost of shield fabrication* ***(ORNL)***



- **3-D CAD based high fidelity neutronics models (UWisc)**







Base funding for PMTF readiness

The US is responsible for the ITER Tokamak Exhaust Processing (TEP) System

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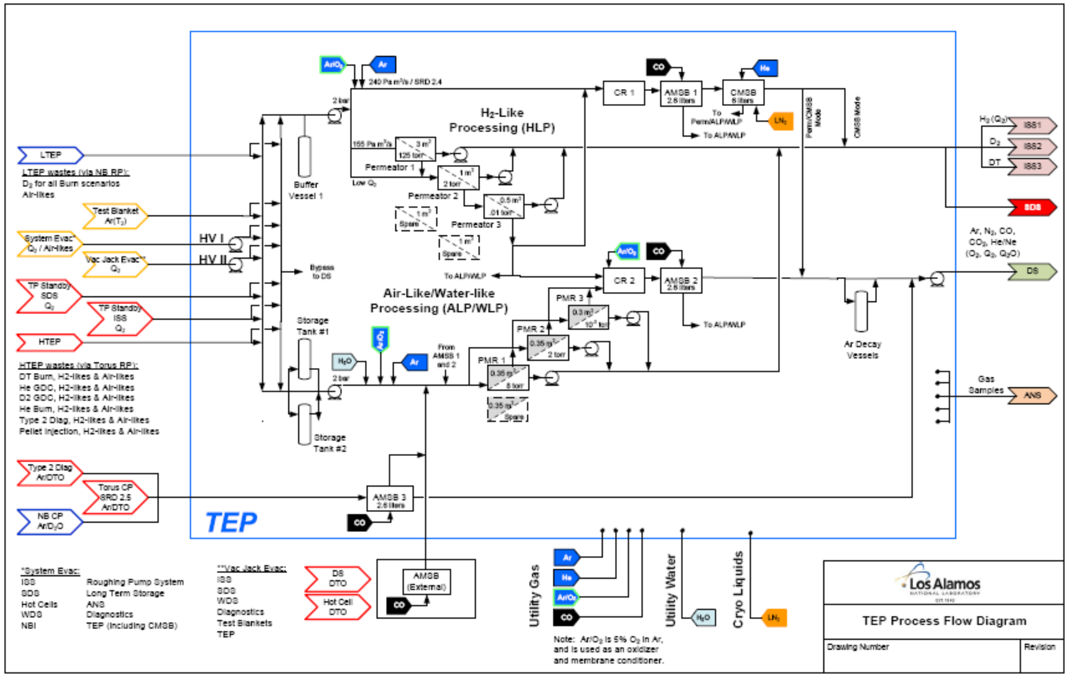
TEP Team: SRNL, LANL
~$3M/yr by US IPO

- **R&D - tritium recovery from tritiated H_20 and tritiated CH_4:** Successful methods being demonstrated; scalable design data collected.
- **New generation of computer models:** Dynamic model based on “unit operation” based is proving invaluable for TEP design.
- **Design:** (activities)
  - *- interface definition*
  - *- functional requirements*
  - *- technology selection*
  - *- process flow diagram*
  - *- hazard analysis*



VLT's active engagement:
USBPO activities - VLT base program

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Program Leaders active in VLT

- STAC, US ITER Chief Technologist, ITER Research Plan - **S. Milora**
- ITER Test Blanket Module Program Committee - **M. Abdou**
- BPO Directorate - Assistant Director for ITER Liaison - **N. Uckan**
- BPO Advisory Council - **M. Ulrickson, S. Milora (ex-officio)**
- BPO Research Council Topical Groups
  - Fusion Engineering Science – **Uckan/Nygren leader/co-leader**
  - Boundary - **T. Rognlien co-leader**
- BPO Tasks Forces:
  - **Ad hoc PFC group supplied "two pagers" to STAC and WG1 for ITER DR; continued work on choice of PFC materials**

VLT's active engagement in ITER:
USBPO activities - VLT base program

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1. Active coil system for ELM suppression and RWM stabilization
2. Limitations to startup flexibility for advanced scenarios
3. **ELM mitigation scenario**
4. ITER CODAC architecture design
5. **ITER disruption mitigation system design & physics understanding**
6. Requirements for stabilization of (3,2) and (2,1) NTMs
7. **ICRF antenna performance and coupling**
8. **Heating & current drive mix on ITER, impact on achievable scenarios**
9. Review measurement requirements related to US diagnostic packages
10. ICRF heating and current drive scenarios
11. **Tritium retention and H/D/T control***
12. Feasibility of lost and confined fast ion diagnostic systems for ITER
13. Pedestal and L-H transition
14. Specifications for locked-modes and error field correction

continuing work on "PFC materials choice" and "dust & safety"

VLT's active engagement in ITER: *tritium codeposition with Be*

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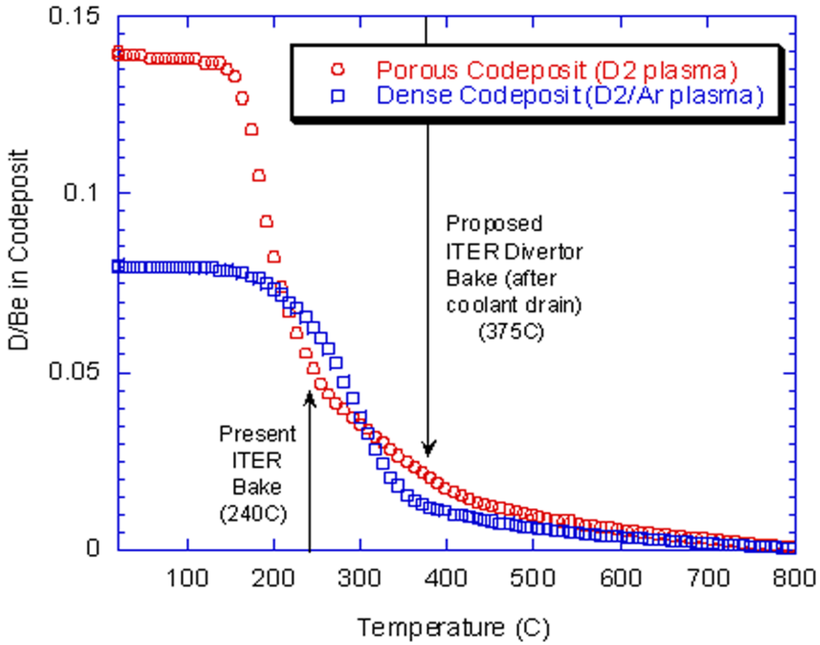
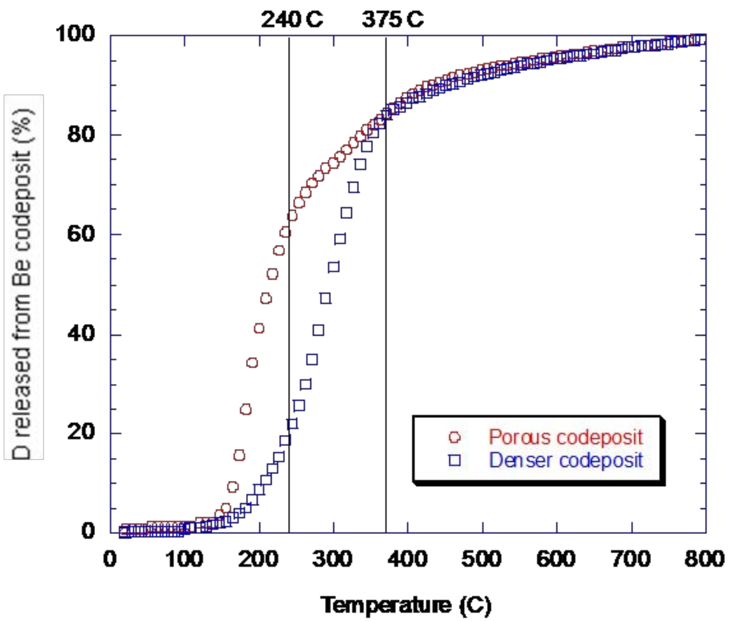
PISCES

Deposition rate governs accumulation, release behavior can control inventory.



- Porosity of Be-rich codeposits influences the release of D.
- higher neutral pressure – more porous
- lower neutral pressure - denser

formed at ~100°C



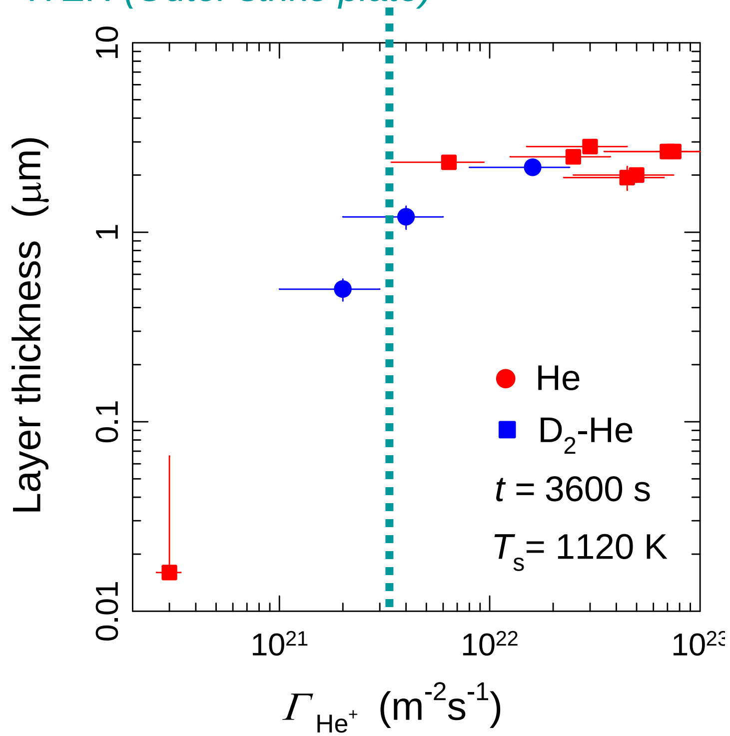
- Temperature during formation also plays a role in release characteristics.

VLT's active engagement in ITER: *W nano-morphology*

PISCES

In D_2-He plasmas, W nano-morphology persists, but growth rate depends on He+ flux.

A. Kukushkin, ITER Report, [ITER_D_27TKC6] 2008
ITER (Outer strike plate)

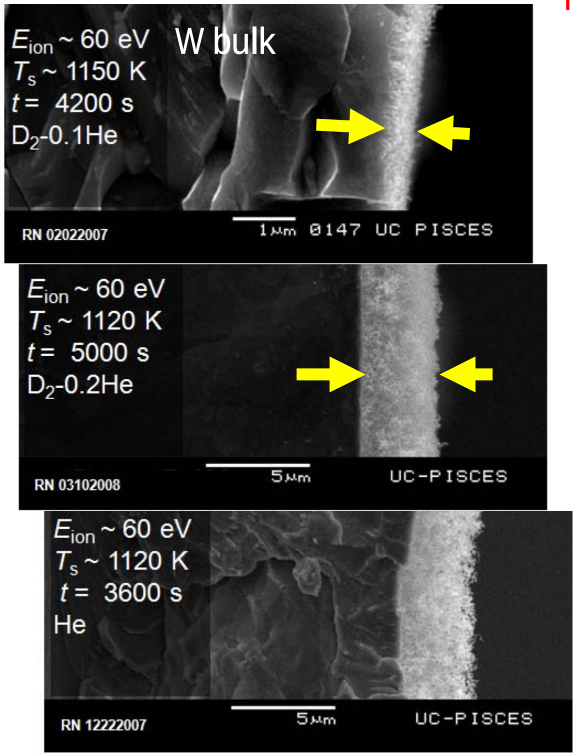


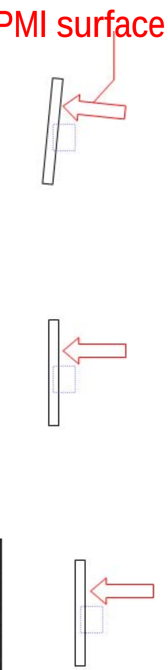
layer thickness

D_2-0.1He ~0.5 mm

D_2-0.2He, ~2.0 mm

pure He, ~2.0 mm





Γ_{D+He}**= 4–6×10^{22} m^{-2}s^{-1}**

1+ h exposures

VLT's active engagement in ITER:
critical issue - erosion of ITER PFCs

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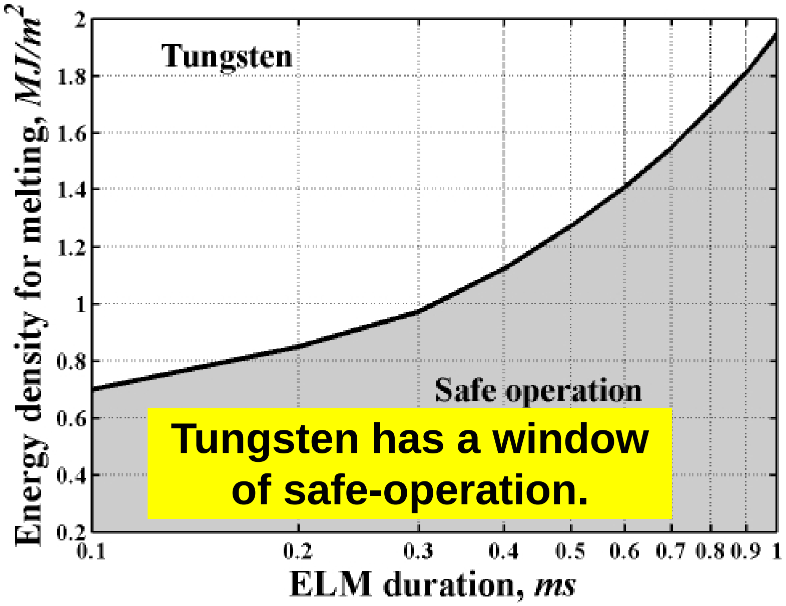
PURDUE UNIVERSITY
PURDUE NUCLEAR ENGINEERING

Integrated analysis of PSI issues* for an all-metal ITER PFC System

*J.N. Brooks, J.P. Allain, R.P. Doerner, A. Hassanein, R. Nygren, T.D. Rognlien, D.G. Whyte, Nucl. Fus. 49 (2009) 035007

- No C in divertor in D-T phase.
- Acceptable sputtering of Be (~0.3 nm/s)
- T/Be codeposition is concern (~2g/400s)
- Transients will restrict the plasma operating regime for any divertor mat'l
- reasonable operating window with W seems possible.



Key R&D needs: impingement effects of He, Be, N on W; ELM effects & mitigation; continuing analysis & code/data validation of edge/PMI.

VLT's active engagement in ITER: ITPA Dust Studies in DIII-D

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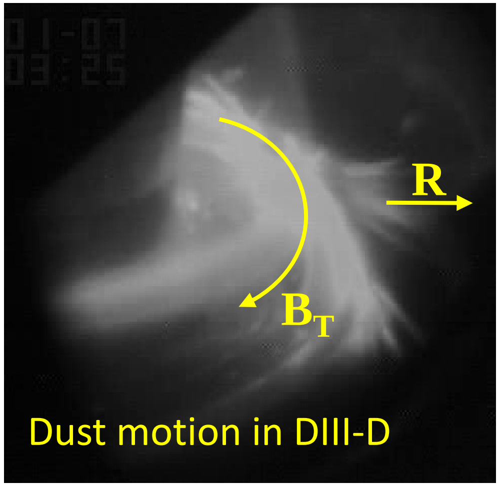
DIII-D NATIONAL FUSION FACILITY SAN DIEGO
UCSD

Introduction of pre-characterized dust for dust transport studies in the divertor & SOL is an approved joint ITPA experiment for DIII-D, TEXTOR, MAST, NSTX and LHD coordinated by Rudakov (UCSD) and Ashikawa (NIFS).

Recent Results:
Spherical graphite dust (3-15 μm dia.) started on DiMES probe in DIII-D's lower divertor.
In the initial exposure to plasma, over 10 mg of mobilized dust spread around the vacuum vessel, prevented normal startup and caused an early disruption.



?ITER Problem?

Significant amounts of dust are expected on plasma-facing surfaces.

VLT's active engagement in ITER: Fusion Safety Program supports ITER mission

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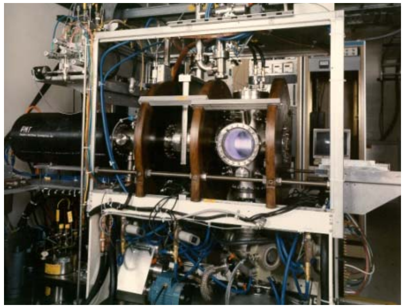
Idaho National Laboratory

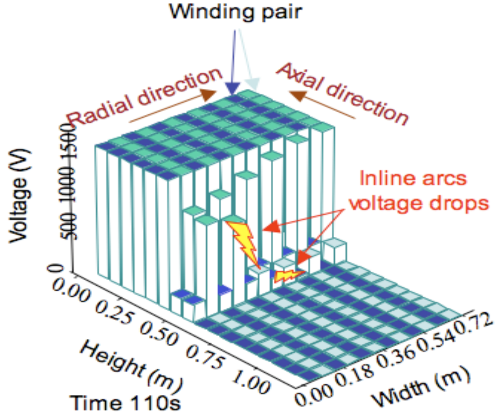
A major goal of ITER is to demonstrate the safe, environmentally acceptable attributes of fusion power.

- Develop, verify and validate safety assessment tools, e.g. *MELCOR-Fusion* applied in RPrS, and possible future regulatory submittals.
- Generate & characterize dust behavior in accident scenarios (reactivity, mobilization, explosion indices, etc.)

Tritium Plasma Experiment



MAGARC simulation of PF coil



- Model & assess magnet systems during fault and accident conditions.
- Estimate tritium retention in plasma exposed surfaces and irradiated materials.
- Asses reliability and maintainability of plant systems (e.g. TCWS, vacuum pumping system, magnets).

VLT's active engagement in ITER and beyond: *materials , fusion nuclear science & tech.*

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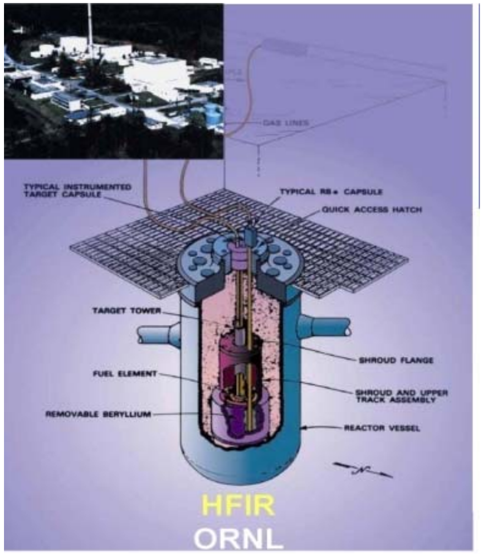
- The VLT conducts broadly based research in these areas primarily through its Materials Science, Chamber Systems, Safety and Tritium Research and AIRES program elements.
- Long-standing joint research programs with Japan strengthen and augment these efforts

<u>JAEA</u>: reduced activation ferritic steels

<u>NIFS</u>: Tritium & thermal fluid control through FW, blanket, HX/T recovery system

- Irradiation
- high heat pulses
- liquid metal MHD flow



Japan-US Joint Project
TITAN
2007-2012

VLT's active engagement in ITER and beyond: *JAEA collaboration - science based approach*

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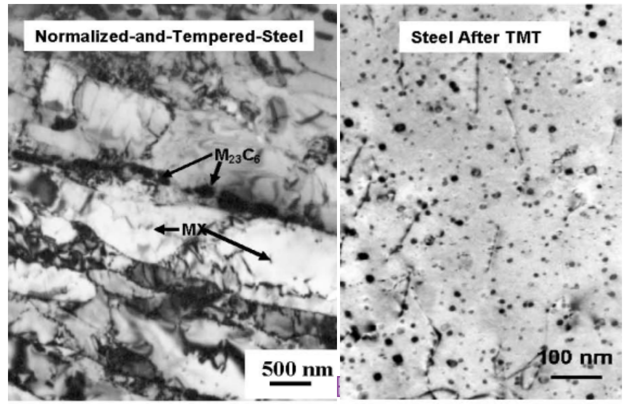
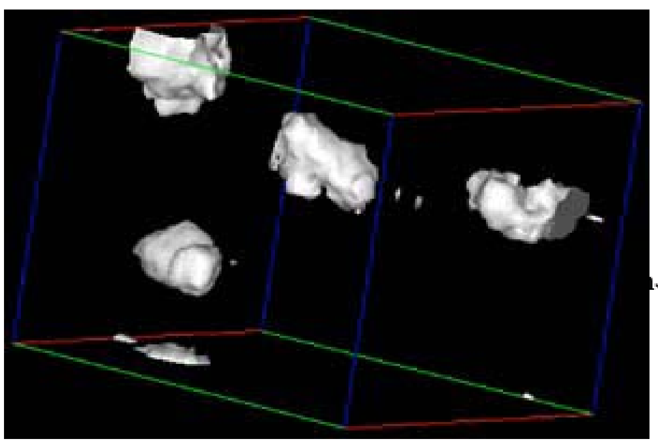
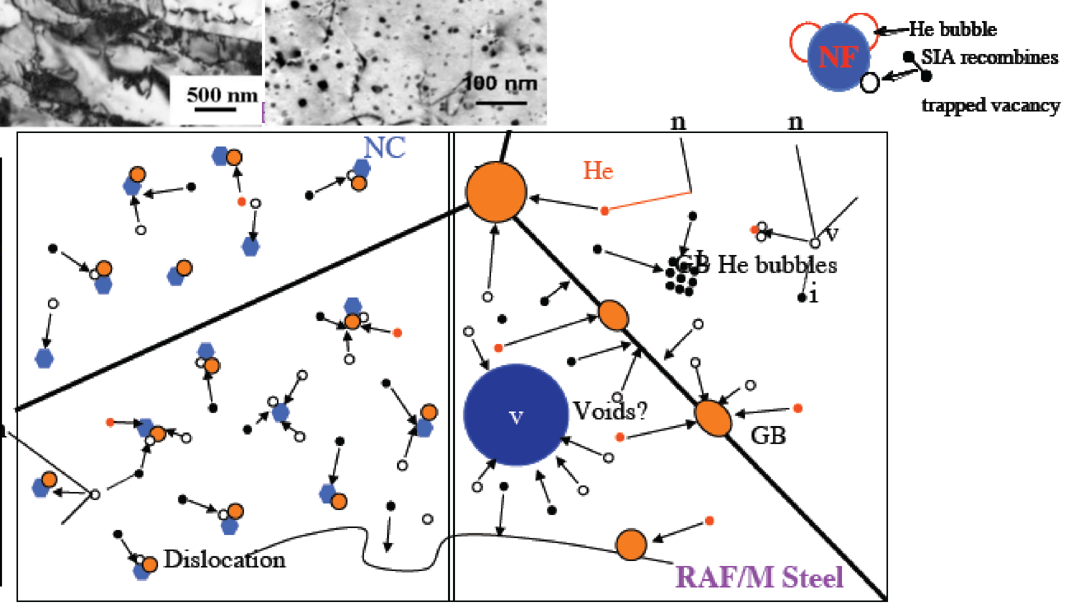
Develop materials with radiation resistant, tough microstructures for higher temperature operation. *Will see service in ITER technology program.*



9Cr-1Mo
before and after TMT
(thermo-mechanical treatment)



3-D atom probe image; ~100 atom clusters of Y, Ti, and O responsible for high strength of NFA materials



Movement of voids and neutrons in nano-composite RAFM steel.

VLT's active engagement in ITER and beyond: *Utilizing ITER as an integrated fusion test bed*

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DCLL Team

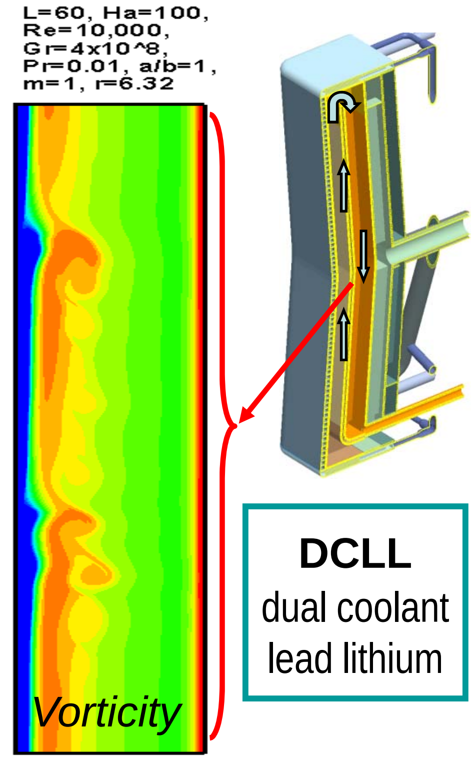
tritium breeding, heat extraction, FW experiments with relevant materials and temperatures

TBM Program: Nov08 constituted by ITER Council; Mar09 1st meeting TBM Program Committee.

- Main US interest: DCLL blanket, an innovative concept for high thermal efficiency (temperature) with current Reduced Activation Ferritic steels
- All parties consider the DCLL test important; EU and Japan are interested in collaboration.

VTL: active in defining/preparing TBM program plan

- ITER TBM-PC, IO TBM Interface & Safety Groups.
- Evolution of TBM module design - change He & PbLi flow paths for better thermal performance.
- R&D on critical issues of DCLL & ceramic breeder blankets - MHD, tritium & heat transport, neutronics, diagnostics, FCI material development and testing.



DCLL
dual coolant lead lithium

Simulations of buoyancy driven liquid metal MHD flow instabilities in DCLL blanket geometries
S. Smolentsev, UCLA

Conclusions

- ***The technology community is fully and productively engaged in ITER and committed to its success.***
  - Design, R&D and test facilities for the construction phase
  - Cross cutting research
  - Effort via BPO on physics tasks, ITER Design Working Groups
  - R&D addresses high priority issues & performance enhancements
  - R&D to utilize ITER as a test bed for other future devices
- ***ITER will require continuing involvement by the technology community as its design and research program evolve.***
  - Enable ITER to achieve its full research potential
  - Exploit ITER as the penultimate step to a demonstration reactor

Let's look ahead at the VLT.

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IPO activities and VLT longer term R&D will overlap.

- VLT organizations (24) have unique fusion engineering expertise.
- The VLT management, BPO Assistant Director for ITER Liaison and BPO Engineering Sciences Topical Group Leaders can facilitate improved communications between three organizations.
- **Start now:** improve exchanges of information (capabilities, plans, needs)
  - *Brad Nelson reporting opportunities/needs on VLT conf. calls*
  - *BPO Engineering Task Group Leaders attending the call*
  - *VLT Director as Chief Technologist identifying capabilities and ITER relevant R&D and plans within the VLT*