The U. S. Fusion Technology Program

Stan Milora, ORNL
Director, Virtual Laboratory for Technology

Fusion Power Associates Annual Meeting and Symposium: Preparing for the NIF and ITER Era

December 4-5, 2007
Oak Ridge, TN

VLT
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For Fusion Energy Science

VLT Research Mission

To contribute to the national science and technology base by 1) developing the enabling technology for existing and next-step experimental devices, by 2) exploring and understanding key materials and technology feasibility issues for attractive fusion power sources, by 3) 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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Outline

- VLT contributions to the ITER Project

- Base program research addressing high priority ITER issues and performance enhancements using existing facilities

- Utilizing ITER as a fusion engineering science test bed and stepping stone to complementary facilities and next step options.

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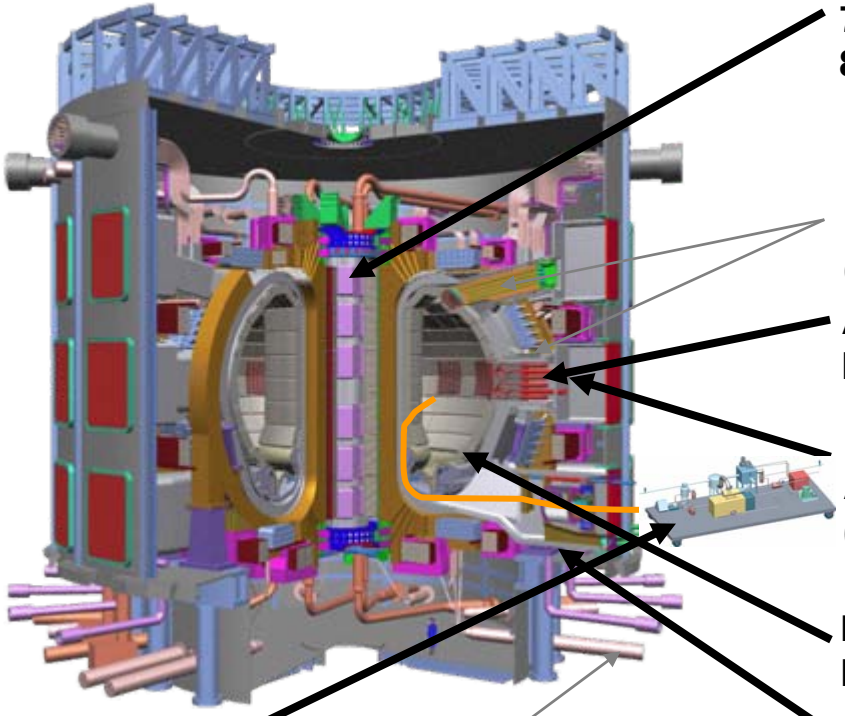
VLT participants are actively engaged in all aspects of the ITER Project



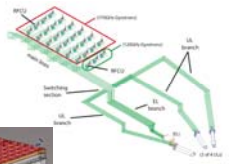
7 Central solenoid windings
8% of TF conductor

Steady-state
power supplies

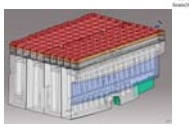
15% of port-based
diagnostic packages

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

ITER Project Support — *procurement package R&D and design*

- The 13-T, 277-V·s central solenoid magnet assembly and toroidal field conductor that utilizes the highest Nb_3Sn superconducting wire available.
- The feed system for the 20-MW IC heating and current drive antenna which will require the development of actively cooled coaxial transmission lines operating at up to 5 MW each.
- Low loss EC transmission lines and mode control units that supply the 24-MW electron cyclotron heating and current drive launchers at up to 1-2MW/ line.
- A gas gun based DT pellet fueling system that continuously supplies 5-mm diameter cryogenic DT pellets at mass throughput requirements significantly beyond present-day designs.
- Twenty percent of the actively cooled Be-clad first wall armor panel and shield block module assemblies that must withstand the combined effects of ~0.5 MW/m^2 surface heat loads from the plasma, erosion and nuclear heating levels of ~10 MW/m^3.
- The exhaust gas processing system that separates hydrogen isotopes from water, methane and inert gases from the exhaust stream of 400- to 3000-s-long tokamak pulses at high throughput and with very high decontamination factors.

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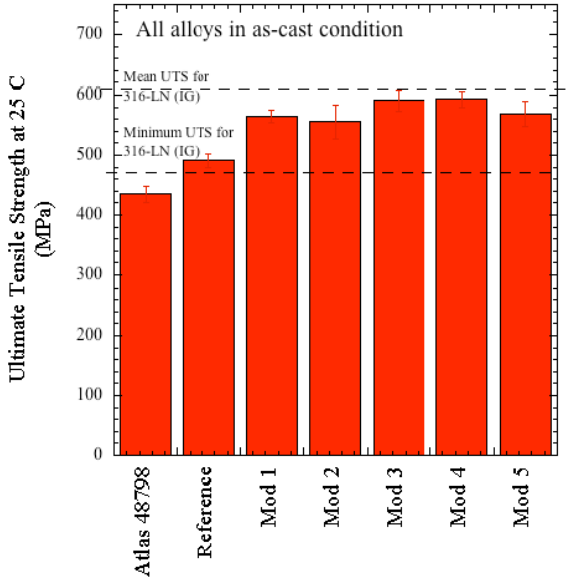
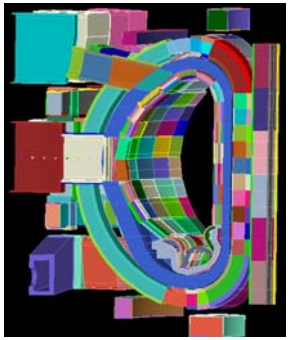
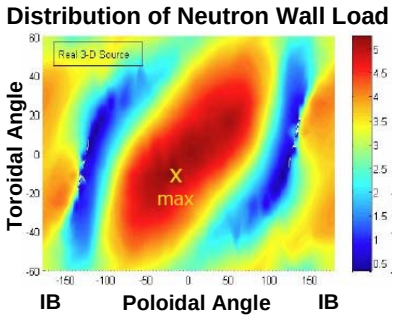
ITER Project cross-cutting activities

- Development and evaluation of cast stainless steel alloys as a lower cost shield block fabrication option
- 3-D CAD based high fidelity neutronics modeling
- 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.







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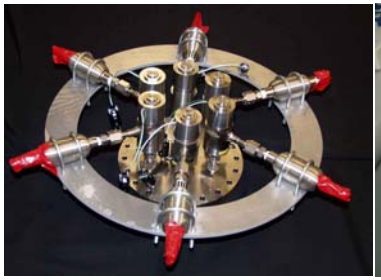
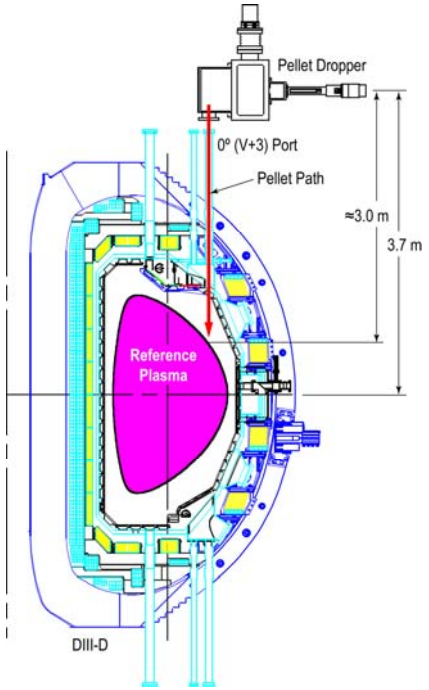
In it's R&D program, the VLT is also addressing high priority issues for ITER — *disruptions, ELMs*

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

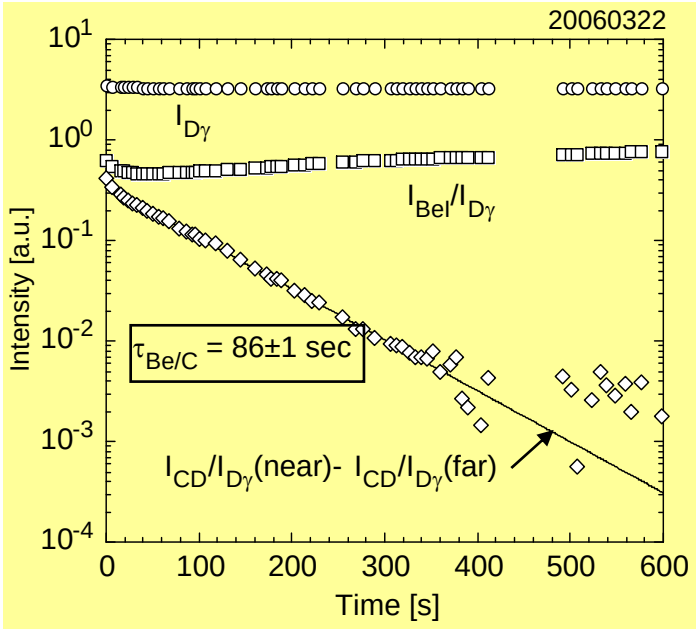




In it's R&D program, the VLT is also addressing high priority issues for ITER — *tritium retention and PFC choice*

- 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



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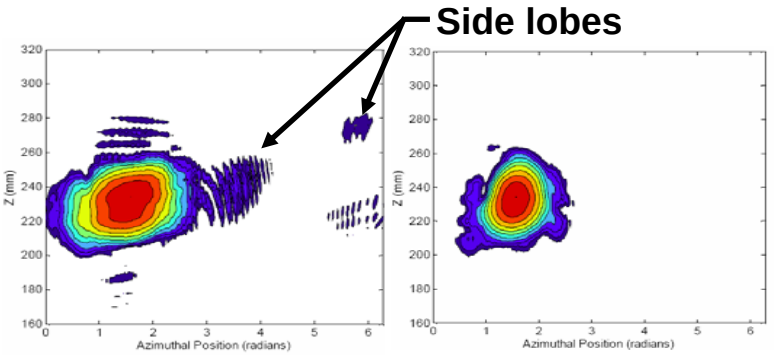
The VLT is also conducting research to improve the performance of plasma control tools on ITER — *heating and current drive*

- 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.



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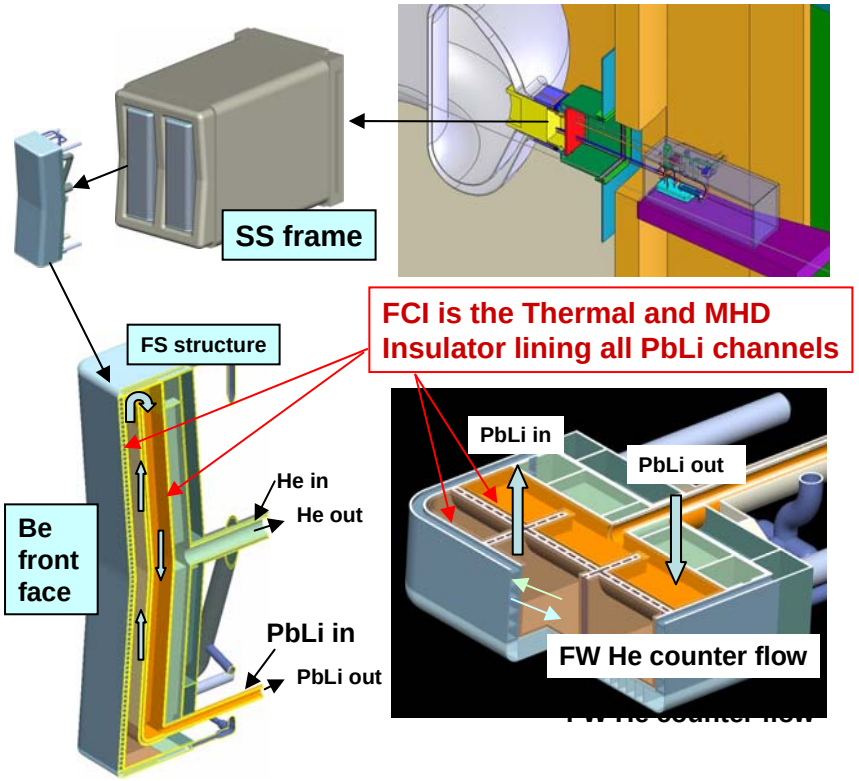
Utilizing ITER as a test bed — *tritium breeding and heat extraction*

- Testing of tritium breeding and heat extraction blanket concepts in special ports is one of the principal 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 focused activity integrates the efforts of several program elements of the VLT (chamber systems, materials science, neutronics, PFC/PMI, and safety and tritium)
- The Parities are working to resolve technical and legal issues with respect to participation in an eventual test blanket program.

US DCLL TBM module



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VLT engagement in ITER is pervasive.

	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	D. Petti – INL
√	Materials	R. Kurtz - PNNL
	NSO/FIRE	TBD
	ARIES	F. Najmabadi - UCSD
	Socio-Economic	L. Grisham - PPPL

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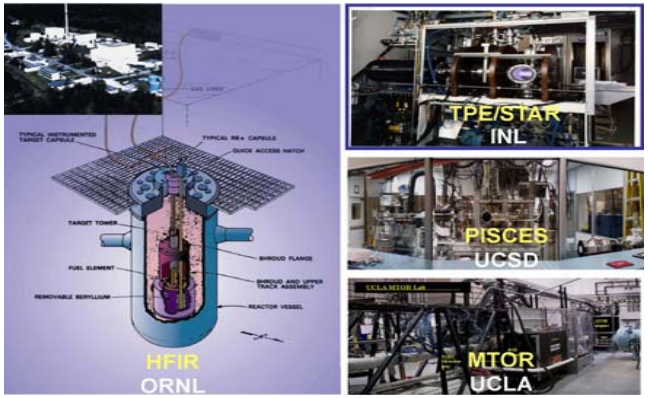
ITER and beyond — *materials and fusion nuclear science and technology*

- 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
  - 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

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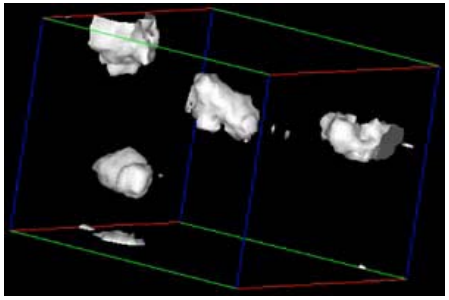
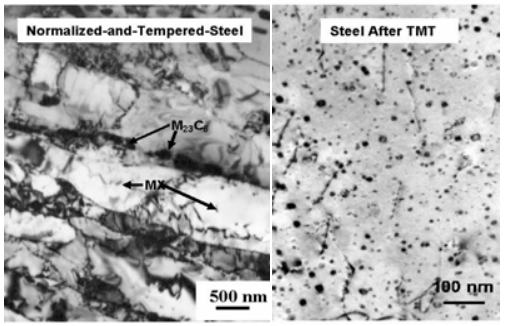
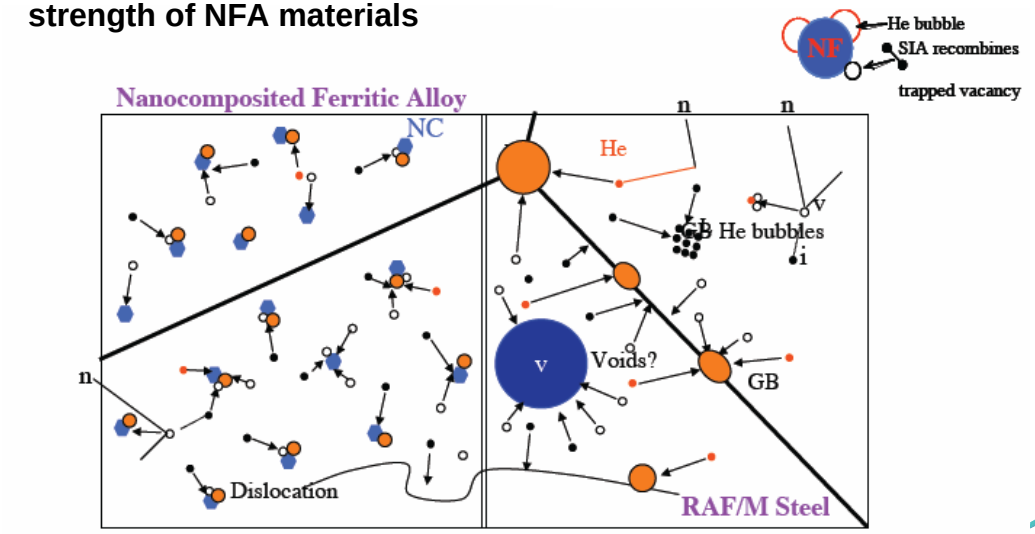
In the JAEA collaboration a science based approach is being applied to develop materials with radiation resistant tough microstructures



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



9Cr-1Mo before and after Thermo-Mechanical Treatment



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The future is looking fusion engineering science

How Initiatives Could Address Gaps

Legend

Major Contribution	3
Significant Contribution	2
Minor Contribution	1
No Important Contribution	

	G-1 Plasma Predictive capability	G-2 Integrated plasma demonstration	G-3 Nuclear-capable Diagnostics	G-4 Control near limits with minimal power	G-5 Avoidance of Large-scale Off-normal events in tokamaks	G-6 Developments for concepts free of off-normal plasma events	G-7 Reactor capable RF launching structures	G-8 High-Performance Magnets	G-9 Plasma Wall Interactions	G-10 Plasma Facing Components	G-11 Fuel cycle	G-12 Heat removal	G-13 Low activation materials	G-14 Safety	G-15 Maintainability
I-1. Predictive plasma modeling and validation initiative	3	2		2	2	3	1		2						
I-2. ITER – AT extensions	3	3	3	3	3		2		2	2	1	1		1	1
I-3. Integrated advanced physics demonstration (DT)	3	3	3	3	3	1	3	2	3	2	1	1	1	1	1
I-4. Integrated PWI/PFC experiment (DD)	2	1		1	2		2	1	3	3	1	1		1	1
I-5. Disruption-free experiments	2	1		2	1	3		1	1	1					
I-6. Engineering and materials science modeling and experimental validation initiative							1	3	1	3	2	3	3	2	1
I-7. Materials qualification facility							1			3	2	1	3	3	
I-8. Component development and testing			1				2	1		3	3	3	2	2	2
I-9. Component qualification facility	1	1	2	1	2		3	2	2	3	3	3	3	3	3

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The future as seen by an engineer.

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I-3. Integrated advanced physics demonstration (DT)	3	3	3	3	3	1	3	2	3	3	1	1	1	1	1
I-4. Integrated PWI/PFC experiment (DD)	2	1		1	2		2	1	3	3	1	1		1	1
I-5. Disruption-free experiments	2	1		2	1	3		1	1	1					
I-6. Engineering and materials science modeling and experimental validation initiative							1	3	1	3	2	3	3	2	1
I-7. Materials qualification facility							1			3	2	1	3	3	
I-8. Component development and testing			1				2	1		3	3	3	2	2	2
I-9. Component qualification facility	1	1	2	1	2		3	2	2	3	3	3	3	3	3

Legend

Major Contribution	3
Significant Contribution	2
Minor Contribution	1
No Important Contribution	

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