

Plasma Materials Test Facility (PMTF) and R&D on He-cooled PFCs

Richard Nygren
Manager Fusion Technologies Department

- Sandia MFE Fusion Technology Program
- Overview of PMTF and He-loop
- Some examples of HHF testing of He-cooled PFCs

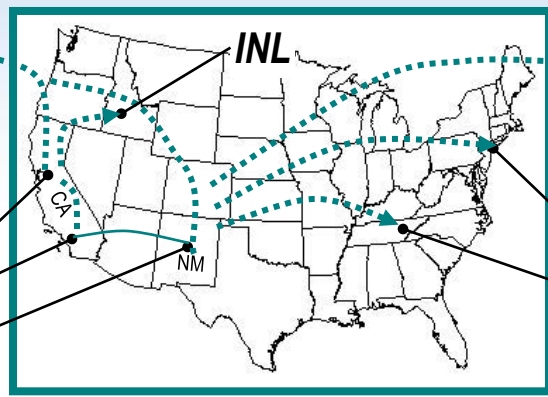


Sandia National Laboratories is a multi program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



(Magnetic) Fusion at Sandia

Collaborations with Japan, China, Korea, India



IPO, CEA France
Other EU collaborations

Livermore
La Jolla
Albuquerque

NSTX, PPPL
IP-ORNL

Sandia National Laboratories

California Lab.

Science & Technology

Physical & Eng. Sci.

Phys., Chem. & Nano Sci.

Pulsed Power Center
"Z" machine ICF



Analytical Mat. Sci.

- PSI experiments and collaborations with TPE (INL)
- DiMES collaborations
- joining metallurgy

Dean Buchenauer, Rob Kolasinski

Rad.-Solid Int.

- PSI experiments
- PSI collaborations

Barney Doyle, Bill Wampler

Fusion Technology

- ITER FW R&D/Design
- NSTX Liquid Li Divertor
- W armor, He-cooled PFCs

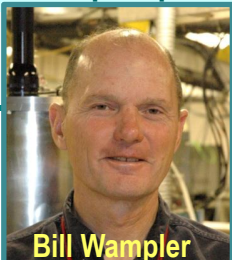
Dennis Youchison, Mike Ulrickson

DIII-D Edge Probes,
Jon Watkins

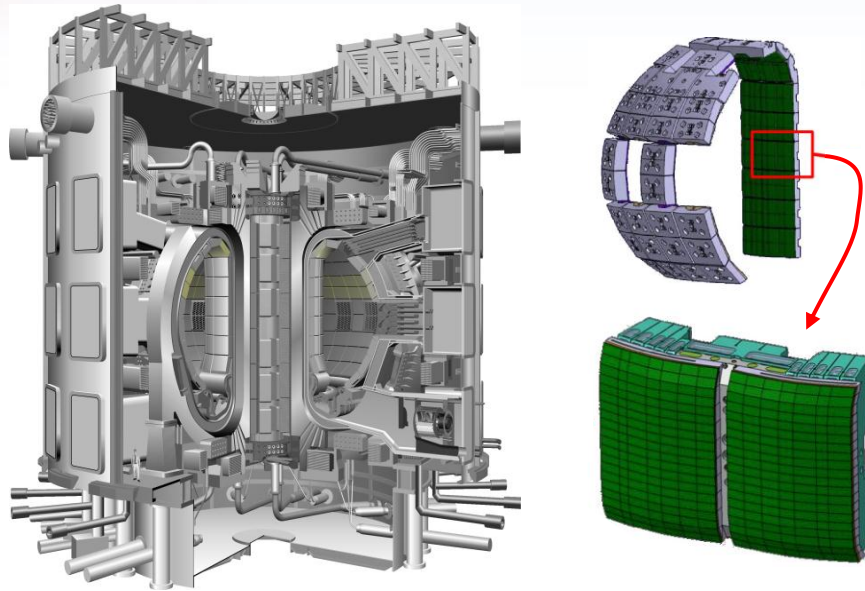
Albuquerque, New Mexico

La Jolla, CA

Livermore, CA



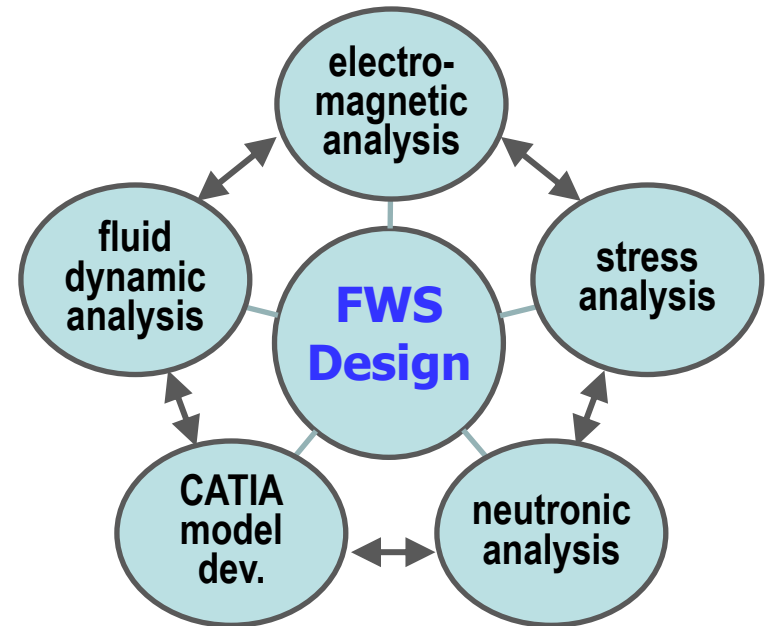
ITER Design and R&D



Mike Ulrickson (Sandia) leads the US technical team for FW design and coordinates the international Blanket Integrated Product Team.

Interdisciplinary Design Process

We draw upon expertise at Sandia, the nation's strongest engineering lab, and other organizations.



The US ITER FW Team includes: Sandia, ORNL, UCLA, U Wisconsin, Purdue U, U Toronto, Acoustic Ideas Inc.

Sandia has a unique set of capabilities that support our PFC research.

Surface analysis for Plasma Surface Interactions

- Plasma sources for tritium PSI studies: Deuterium Plasma Experiment (DEP) and TPE, now at INL in Idaho.
- Low-energy ion beam probes for LEIS, DRS & SIMS
- MeV ion beam analysis of surface modification and T trapping.
- Traditional surface analysis (Auger, Raman AFM, and XPS).

High Heat Flux Testing (Plasma Materials Test Facility)

- Electron beams: EB60 & EB1200
- Coolants: high temp & press water, helium, liquid metal
- Diagnostics: IR, pyrometers, thermocouples, calorimetry
- Beryllium handling facility
- Large sample SEM
- Codes: steady and transient magnetic fields, thermal & stress distributions, computational fluid dynamics

Part 2. PSI R&D at Sandia

Part 1. HHF Testing at Sandia

PMTF (Plasma Materials Test Facility)



EB1200
1.2 MW



Jimmie McDonald
retired



Lab Staff
Tom Lutz
lab mgr



Sean Simpson
DACs eng.

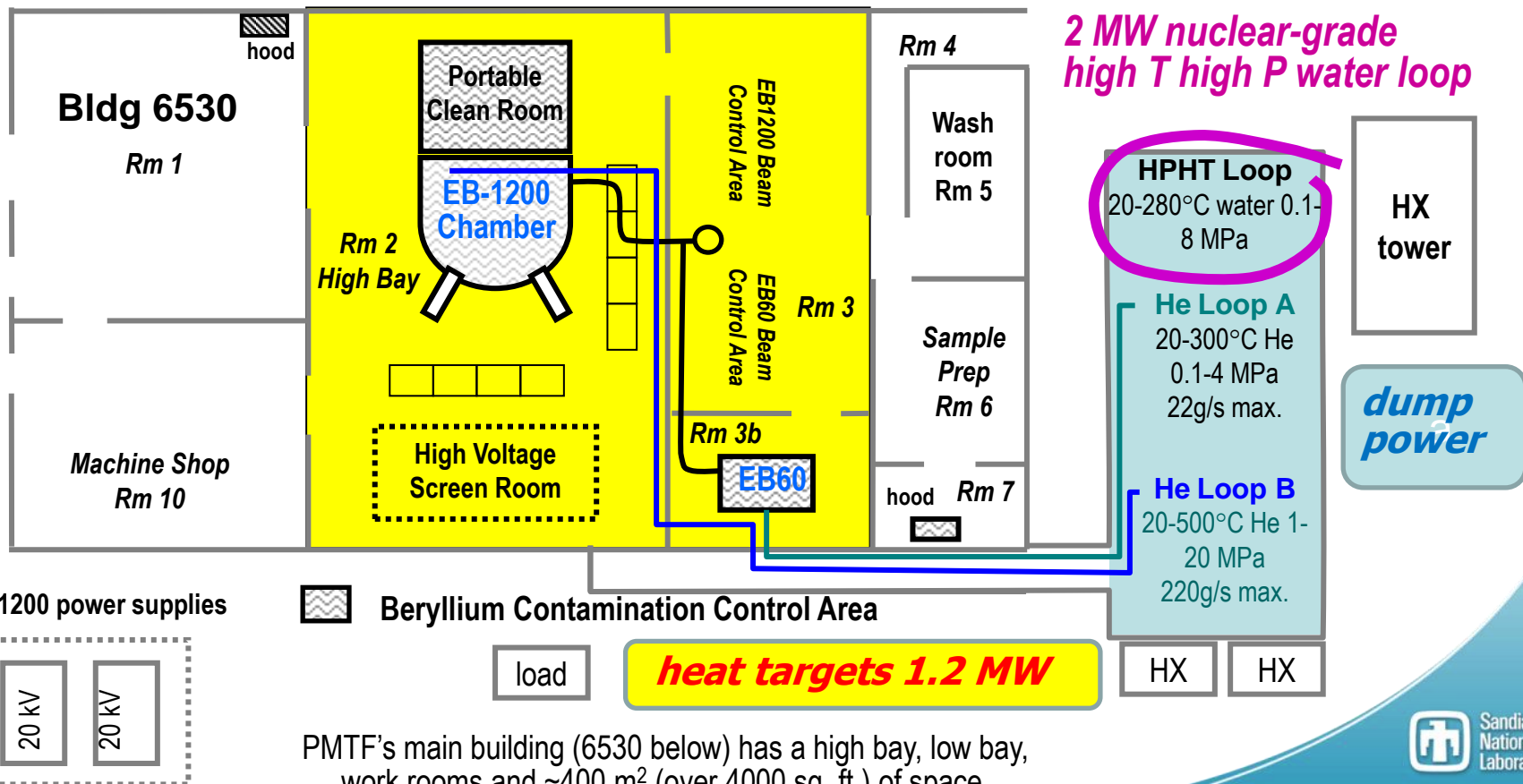


Fred Bauer
tech.



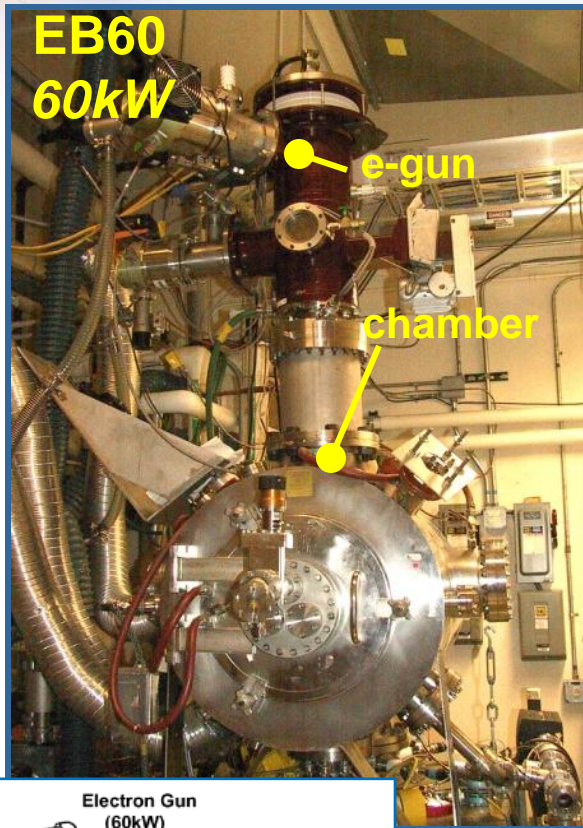
Jay Taylor
tech.

EB60
60kW



PMTF's main building (6530 below) has a high bay, low bay, work rooms and ~400 m² (over 4000 sq. ft.) of space.

EB60 has vertically mounted e-gun

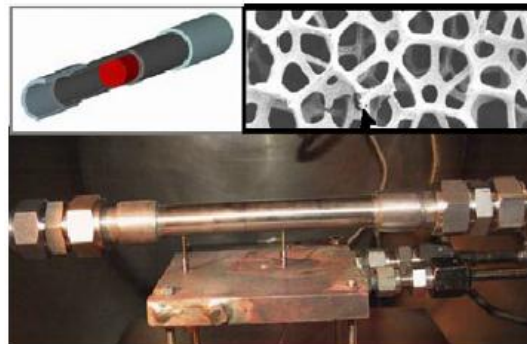
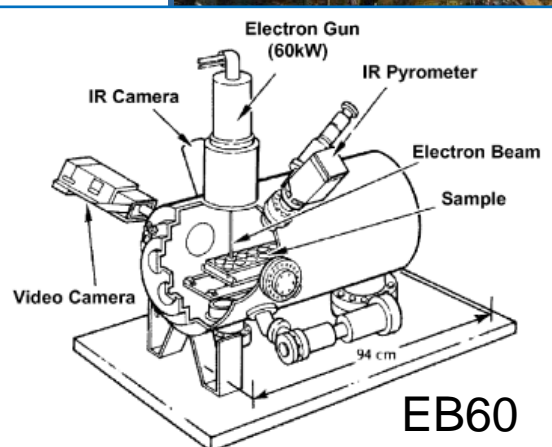


EB60 operating parameters

Beam power	60,000 W (60 kW)
Accelerating voltage	20,000 V (20 kV)
Beam current	3 A
Beam spot	2 mm FWHM at target plane
Target area	0.1–10,000 mm ²
Pulse length	From 2 ms to continuous
Chamber pressure	~6 × 10 ⁻⁴ Pa, cold-trapped diffusion pump
Gun pressure	~1 × 10 ⁻⁶ Pa, turbopump

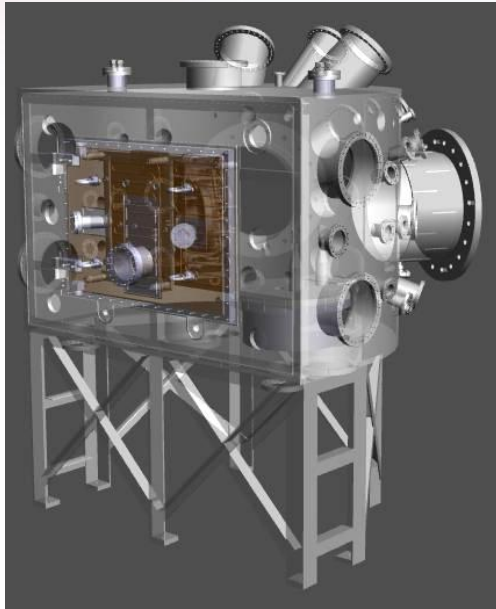
EB60 and EB1200 diagnostics

Diagnostic (EB60, EB1200)	Purpose
Pyrometers (2, 4)	Local surface temperature
Infrared Camera & Digitizer	Surface temp. profiles
TV monitoring system	Visual records
Thermocouple channels (16, 48)	Bulk temperatures
Strain gauges	Bulk response
Pressure taps, other sensors (0, 16 channels)	Coolant pressure, displacement, etc.
Residual gas analyzer	Partial pressures
Water calorimetry	Absorbed power
Bore scopes (3/1)	<i>In situ</i> surface views
E-gun current, voltage	Applied power



He-cooled tungsten tube with porous tungsten internal structure mounted for testing in EB60

EB1200 is a dual e-beam system

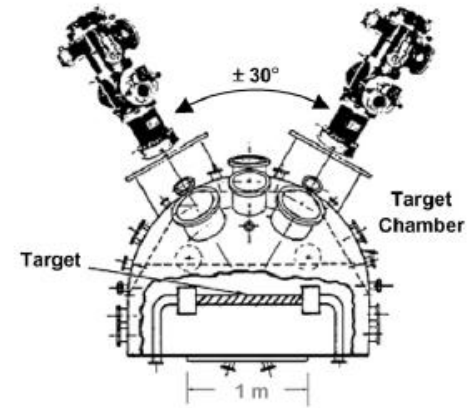


View of EB1200 D-chamber from side with door visible

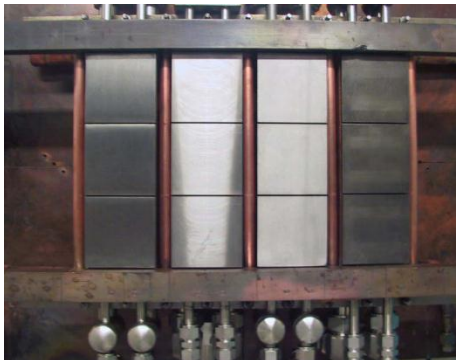
Door is mounted on trolley and pulled back from chamber to install and remove targets.



EB1200 has two 600 kW e-guns mounted horizontally at 30° from center.



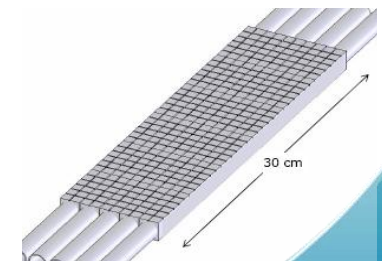
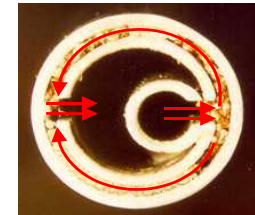
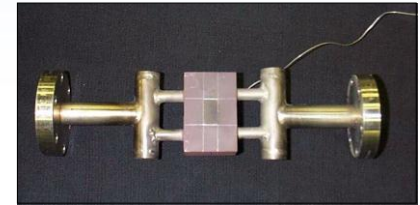
Be-armored ITER FW mockups from Japan, China, Korea and US mounted on EB1200 door. (IR image later)



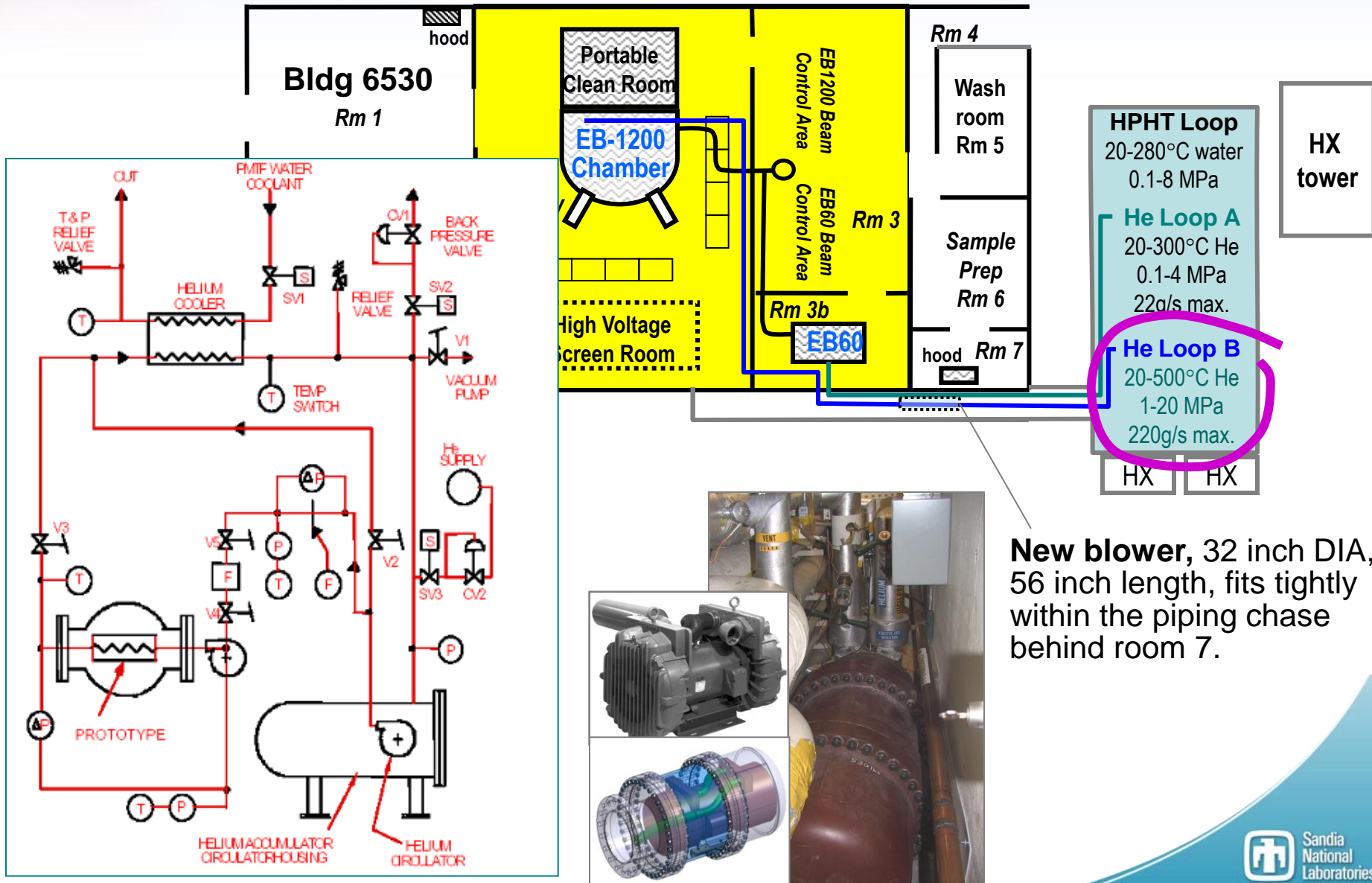
Beam power	0-1.2 MW (cw)
Accelerating voltage	0-40,000 V (40 kV)
Beam current	15 A each gun
Angle of beam incidence	0-90°
Cathode lifetime	>200 h
Magnetic lenses	2 coils
Spot diameter at 600 kW, 1.5 m	35 mm
Magnetic deflection	2 yokes (orthogonal)
Max. raster frequency	10,000 Hz (10 kHz)
Max. angle, beam deflection	±7°, 10 kHz; ±30°, <200 Hz
Max. heat flux (unrastered)	>1000 MW/m ²
Max. heated area at 10 kHz	370 mm × 370 mm at 1.5 m
Heat flux at maximum area	8.7 MW/m ²
Max. pressure in chamber	<3 Pa
Cooling water consumption	2.2 m ³ /h

He-cooled modules tested at Sandia

<u>year</u>	<u>Type of Test Article</u>	<u>fabricator</u>
1993	Cu Micro-channel HX (~100 μ channel size) Cu Divertor mockup A (0.46mm channels) Cu Porous (40%) metal HX (0.43mm dia.)	Create, Inc. General Atomics Thermacore, Inc.
1994	Cu Dual channel porous metal HX Cu Div. mockup A retest, higher heat loads	Thermacore, Inc. General Atomics
1996	Cu Phase-II porous metal HX Vanadium spiral-tube HX	Create, Inc. General Atomic
1997	Cu Faraday shield A Cu Divertor mockup B	Thermacore, Inc. Thermacore, Inc.
1998	Cu Faraday 2 nd shield B Cu Divertor 2 nd mockup C	Thermacore, Inc. Thermacore, Inc.
1999	Div. mockup B retest, added diagnostics	Thermacore, Inc.
2000	W tubes with W foam	Ultramet, Inc.
2000	W FW module with W porous medium	Thermacore, Inc.
2001	VPS W tube with VPS porous medium	Plasma Processes
2006	W tube with W foam in axial flow	Ultramet, Inc.
2008	Sq. Mo w/ Mo foam, circumferential flow	Ultramet, Inc.
2009	4-Channel, Larger Area Mo panel	Ultramet, Inc
2009	W T-tube Jet impingement	Plasma Processes



PMTF Target Coolant Loops - Helium



New blower, 32 inch DIA, 56 inch length, fits tightly within the piping chase behind room 7.

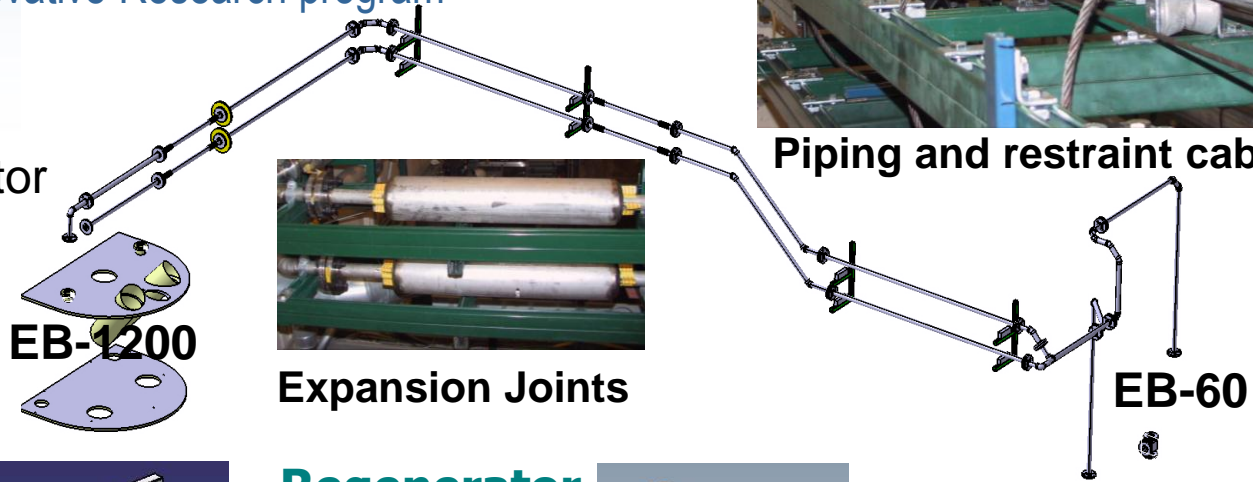
He Loop Upgrade*

*Enabled by Phase II grant to Ultramet, Inc. from the US Dept. of Energy's Small Business Innovative Research program

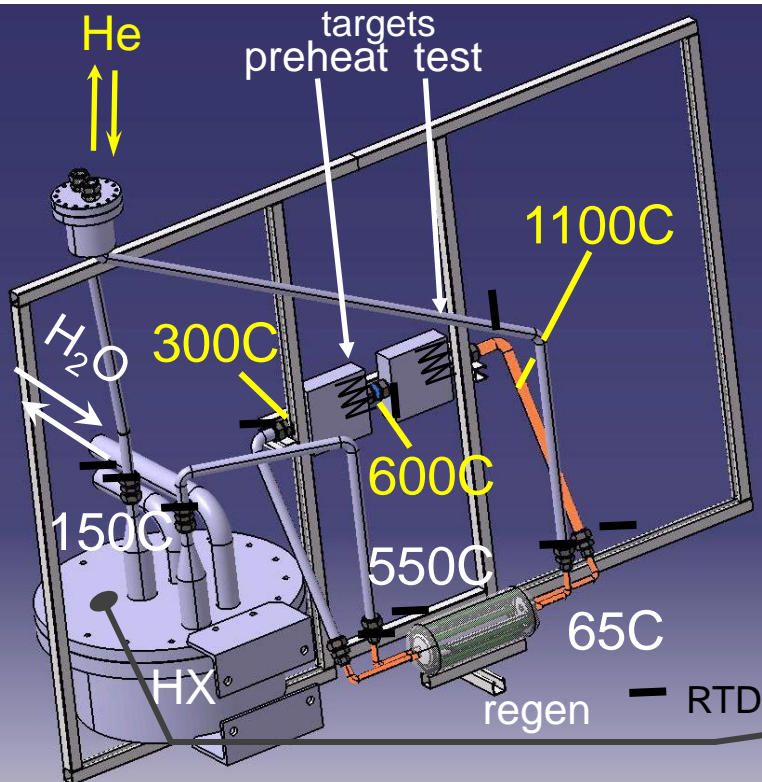
Our plan is to install a preheater and a regenerator that will enable high temperatures in a short leg of the loop inside EB1200.



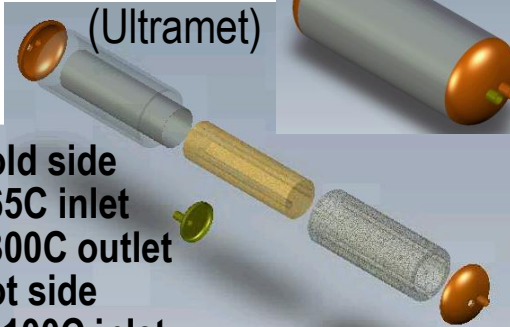
Piping and restraint cables



Expansion Joints



Regenerator



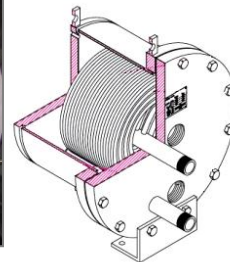
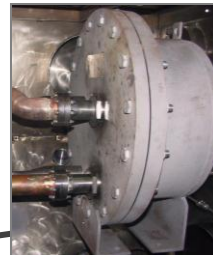
(Ultramet)

Cold side
65C inlet
300C outlet

Hot side
1100C inlet
550C outlet

The early targets that we hoped would serve as preheaters failed during testing. We need further development.

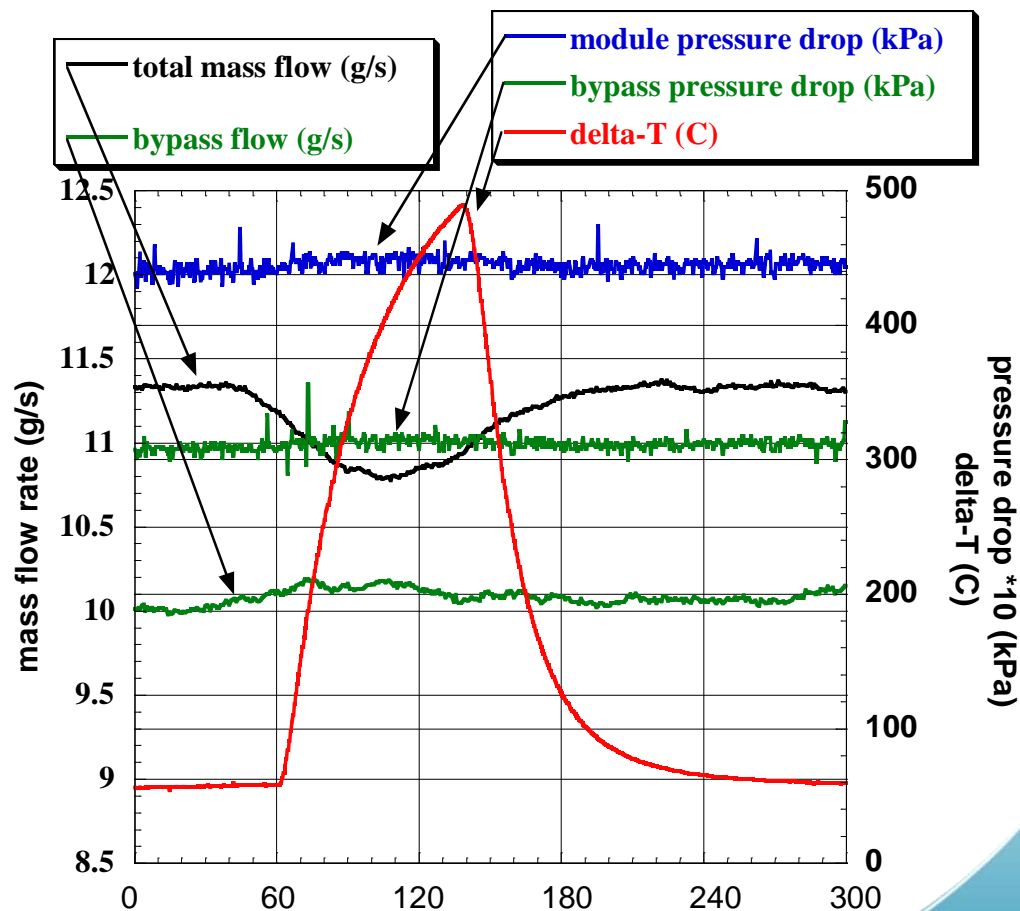
He/H₂O Heat Exchanger



Power= 242 kW,
828,000 Btu/hr
Tin=550C
Tout=150C

PFC He-cooled modules - examples

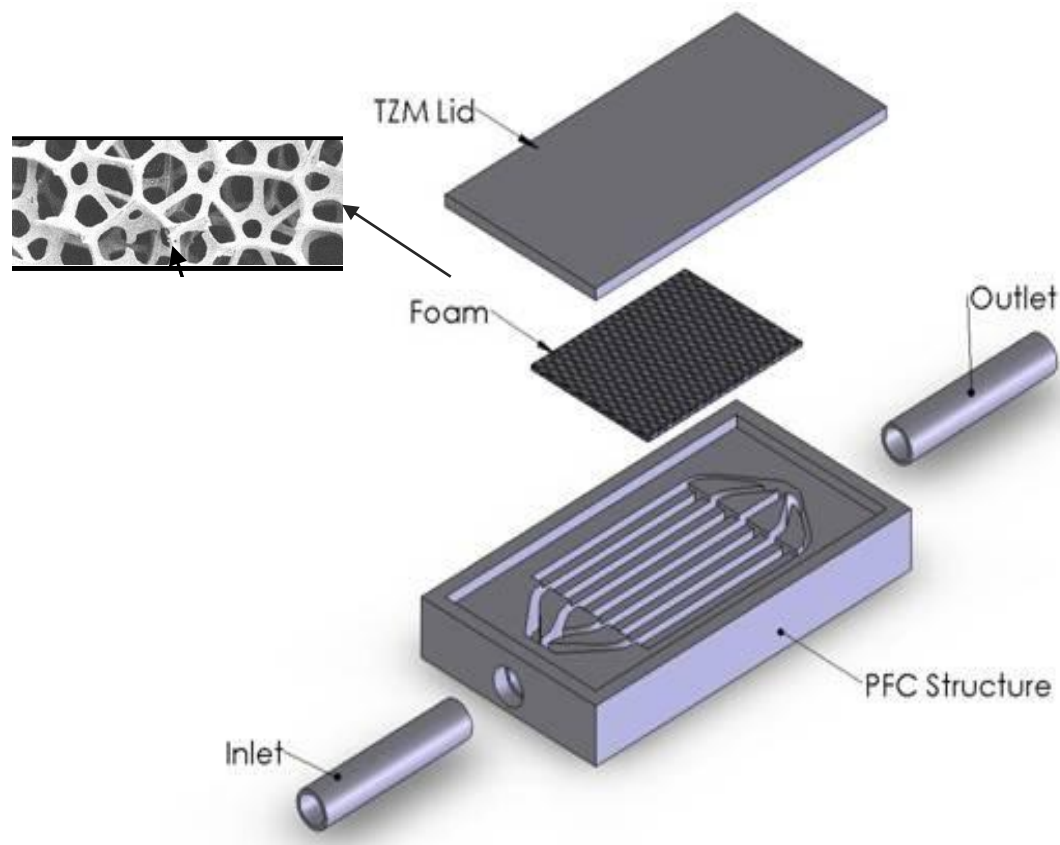
Experiment had balanced parallel flow through heated target and bypass flow channel. Parallel flow instability, i.e., decrease in mass flow in heated section, seen only in worst case scenario.



Test enabled by grant to Thermacore, Inc. from the US Dept. of Energy's Small Business Innovative Research program

PFC He-cooled modules - examples

Preliminary test panels - Ultramet to deliver larger panels for phase-II testing in spring 2010.



- Multiple channel (4)
- Flat surface
- All refractory
- Short flow paths
- 600 C inlet temps

Investigate:

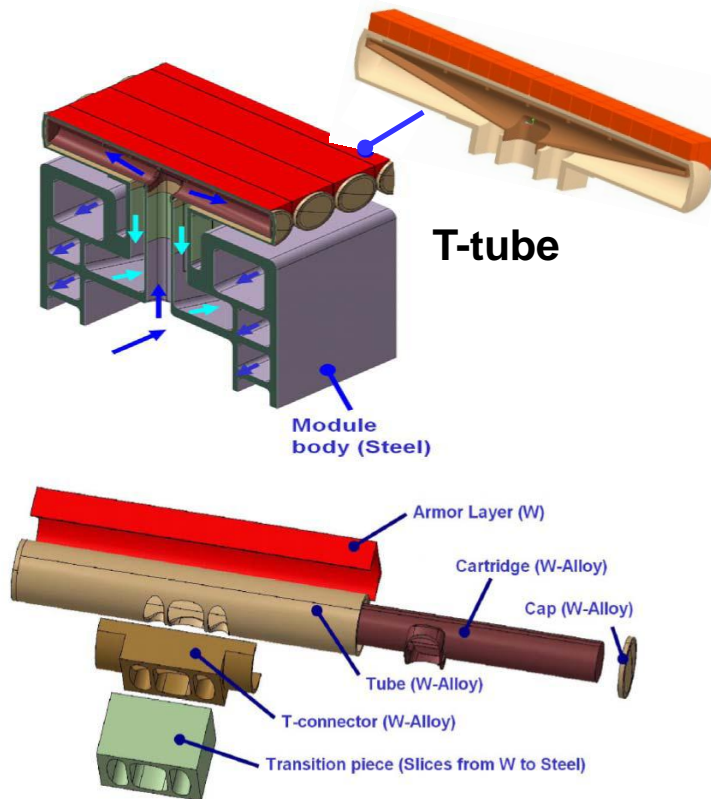
- Larger heated areas
- Flow instabilities

Panels in preliminary tests had faulty design of joint and failed at edges of panel.

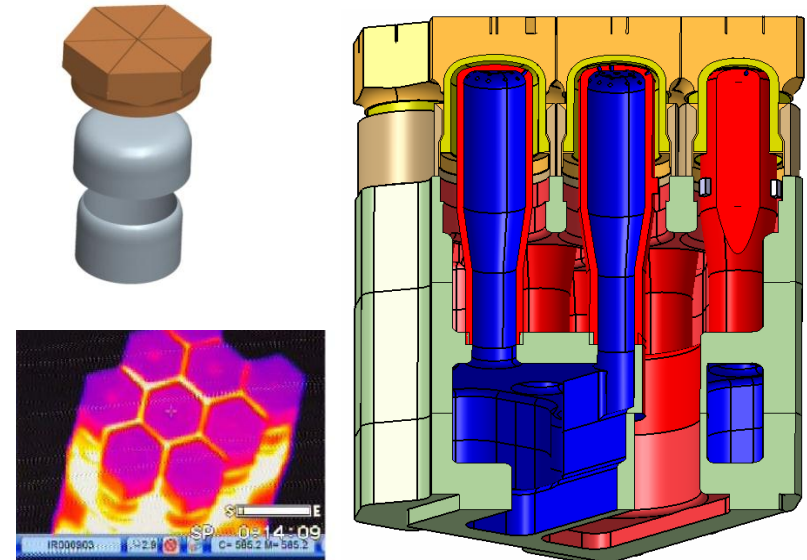
PFC He-cooled modules – examples

Testing in PMTF planned for latter half of 2012

T-tube* - developed and evaluated by Plasma Processes, Georgia Institute of Technology and the ARIES Team.



HEMJ W Module - developed and evaluated by KFK (Norajitra et al) and tested in the Russian Federation.



*Infra-red image during high heat flux testing
P. Norijitra et al., FZK*

*Test enabled by grant to Plasma Processes, Inc. from the US Dept. of Energy's Small Business Innovative Research program

“Breakthrough analysis” of flow in porous media for fusion applications

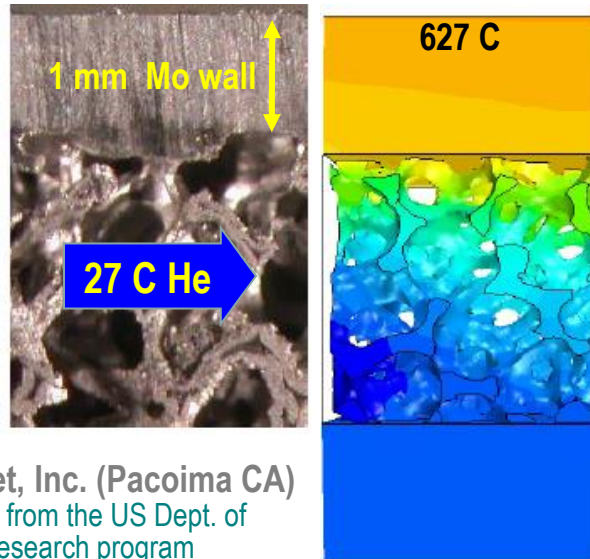
Dennis Youchison

Presentation at ICENES2100
2.2.6 Evaluation of Heat Transfer in
High-Temp. Refractory Foam HXs
using CFD

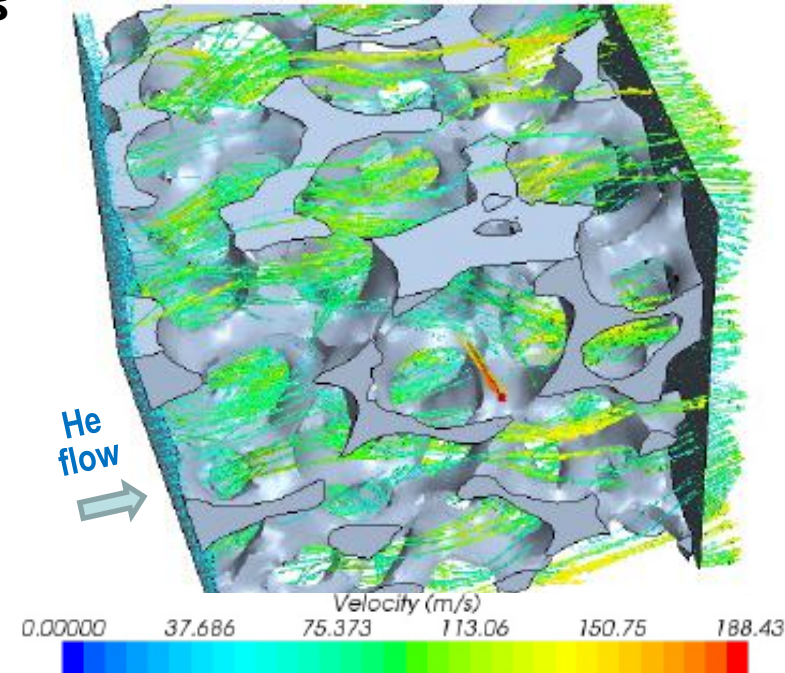


Early work for helium-cooled fusion heat sinks used correlations (Ergun equation) to predict heat transfer in porous media.

New approach combines accurate and irregular geometry and full fluid physics of boundary layers and turbulence to model fluid flow and heat transfer.

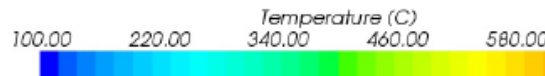


Use computerized X-ray microtomography to image foam* and then translate data to format for solid models.



2x2 mm volume from model
65 ppi, 10% dense Mo foam

Analysis reveals turbulent mixing and fin effect created by foam.





END

PSI Research at Sandia, Livermore

Analytical Mat. Sci.

- PSI experiments
- joining metallurgy
- DiMES collaborations



edge physics, fueling
(compact toroids)

H/D/T in metals,
lab plasma
experiments



TPE – Tritium Plasma Experiment

(1982-92 Sandia, 1992-2002 LANL, 2002-- STAR Facility, INL)



TPE has H/D/T plasmas with the intense ion fluxes onto targets. We measure plasma driven permeation and retention in metals and graphites.



Research Personnel:

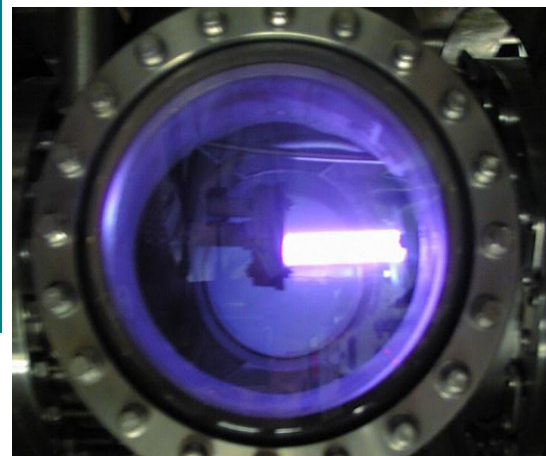
M. Shimada (INL)

R. Pawelko (INL)

B. Denny (INL)

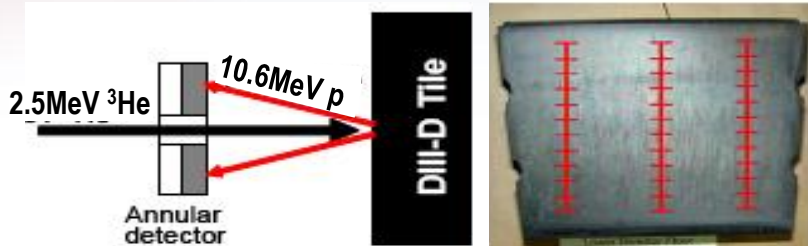
R. D. Kolasinski (SNL)

Retired: Bob Bastasz, Rion Causey

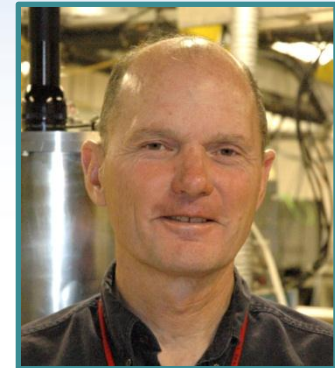


DPE (above) is an H/D linear plasma device for PSI studies.

Working in PSI on plasma edge



Bill Wampler (Albuquerque) uses our Ion Beam Lab to measure H/D/He and metals in surfaces and collaborates with fusion projects worldwide.



ITER – assess impacts on tritium inventory

- Influence of displacement damage on DT retention (e.g., W) and its impact of neutron damage. *(with UCSD)*
- Characterize erosion, redeposition and codeposition on main chamber wall (using the Chinese superconducting tokamak EAST). *(with ITER IO, ASIPP, UTIAS)*

The influence of displacement damage on deuterium retention in tungsten exposed to plasma - Wampler & Doerner, NF 49 (2009)

DIII-D – characterize erosion and impurity transport in the plasma edge

- Continue to study *a) with GA and b) with GA & UTIAS)*
 - a)* erosion & D retention using divertor & midplane probes & tiles, and
 - b)* impurity ionization, transport & deposition, e.g., ^{13}C methane injection experiments.
- Explore methods for tritium removal, e.g., in-vessel oxygen bake. *(with GA)*

Transport and deposition of ^{13}C from methane injection into partially detached H-mode plasmas in DIII-D - Wampler et. al. *JNM 363-365 (2007) 72*, also *19th PSI Conference* May 2010.

NSTX – characterize deposition of lithium around the divertor and wall

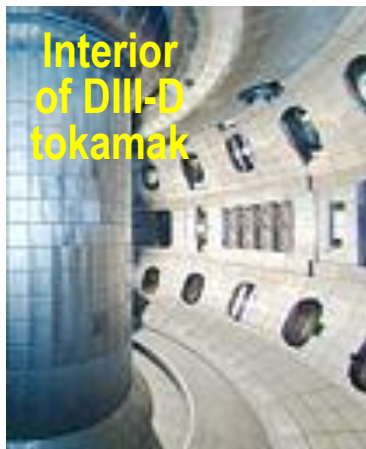
- Measure Li deposition (from LITER and LLD); assess its impact on retention of D from the plasma. *(with PPPL)*

Working on plasma edge

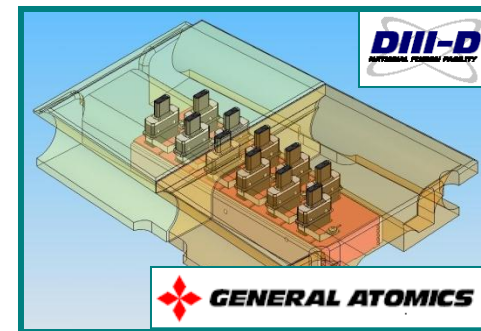
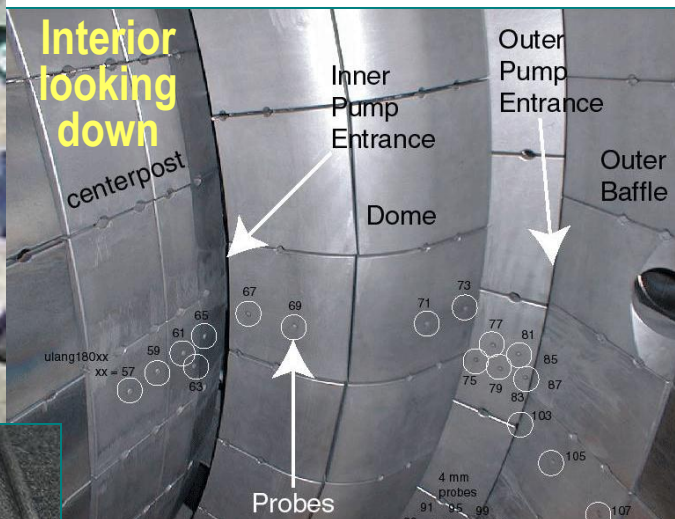
Jon Watkins



Plasma Edge Physicist DIII-D (La Jolla, CA) designs, builds and operates plasma edge probes in DIII-D and collaborates with scientists worldwide to interpret plasma edge conditions.



Interior of DIII-D tokamak



Particle, heat, and sheath power transmission factor profiles during ELM suppression experiments on DIII-D –[Watkins](#), Evans, ... [JNM 390-391, 839 \(2009\)](#)

High heat flux Langmuir probe array for the DIII-D divertor plates –[Watkins](#), Taussig, ... [RSI 79,10F125 \(2008\)](#)

Target Plate Conditions During ELM-Suppressed Operation on DIII-D - [Watkins](#), Evans, ... [JNM 363-365, 708 \(2007\)](#)



Senior Staff, Fusion Technologies Dept.

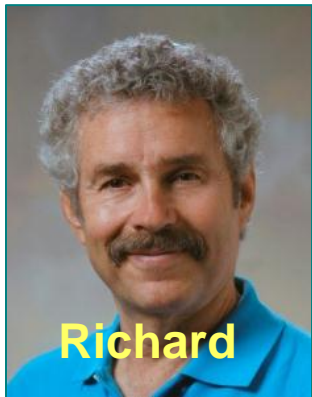
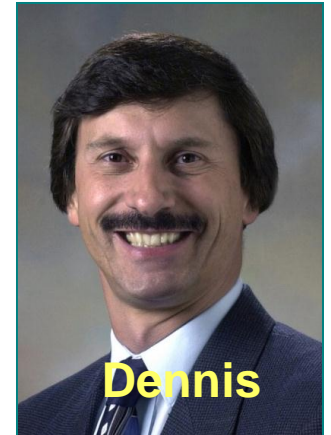


Mike Ulrickson

US Technical Leader for ITER PFCs,
ITER Coordinator for Blanket Integrated Product Team,
US Burning Plasma Organization Advisory Committee,
PFC Group Steering Committee,
past: ReNeW leader (1 of 5), FESAC subtask,
Fusion Technology Editor, SOFE Tech Chair

Dennis Youchison

US ITER Team,
Chair IEEE Fusion Technology Committee,
field coordinator for DOE SBIR Program on PFCs,
PFC Group Steering Committee,
chair IEA Annex II PFCs Subtask,
past: SOFE General Chair, ReNew task group



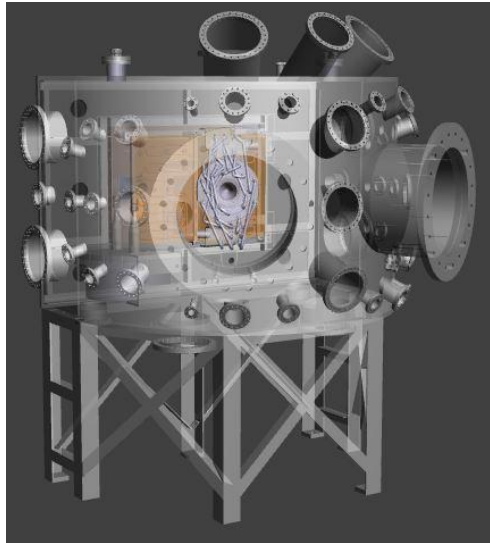
Richard Nygren

Deputy Dir. Virtual Lab for Technology
Fusion Nuclear Science Pathways Assessment Team,
US BPO Research Committee, BPO Topical Group Co-chair
past: ReNew task group, ISFNT9 & ICFRM14 Tech Program,

Also, on contract to Sandia is

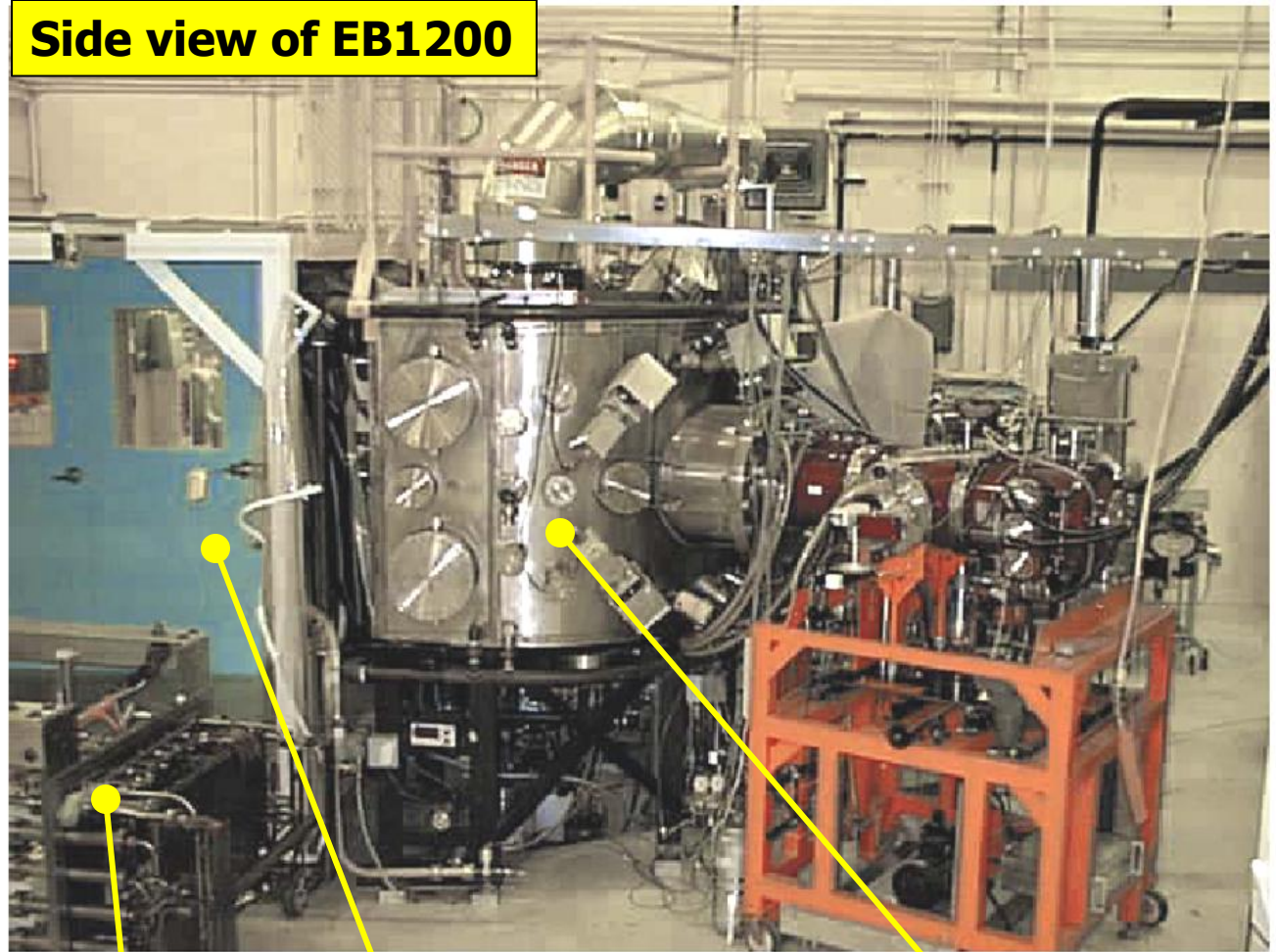
Charlie Baker (retired) – NAS IFE Panel, LANL PAC, FED Editor,
past: ITER MAC, FESAC, US ITER Team

EB1200 is a dual e-beam system



EB1200 chamber - view along one beam line port

Side view of EB1200



Door

Door has been moved from target handling area with crane.

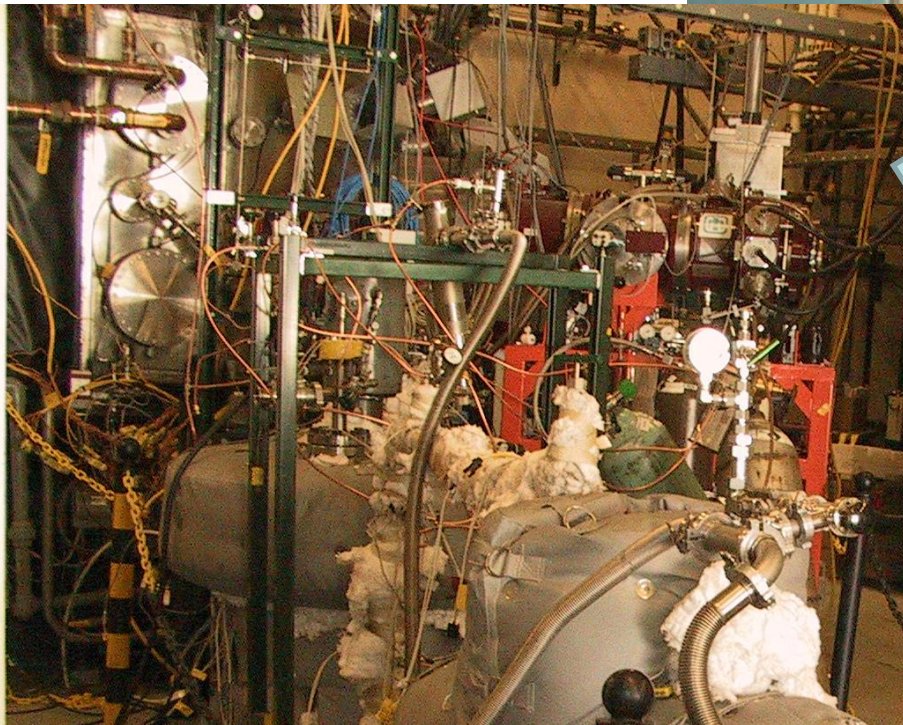
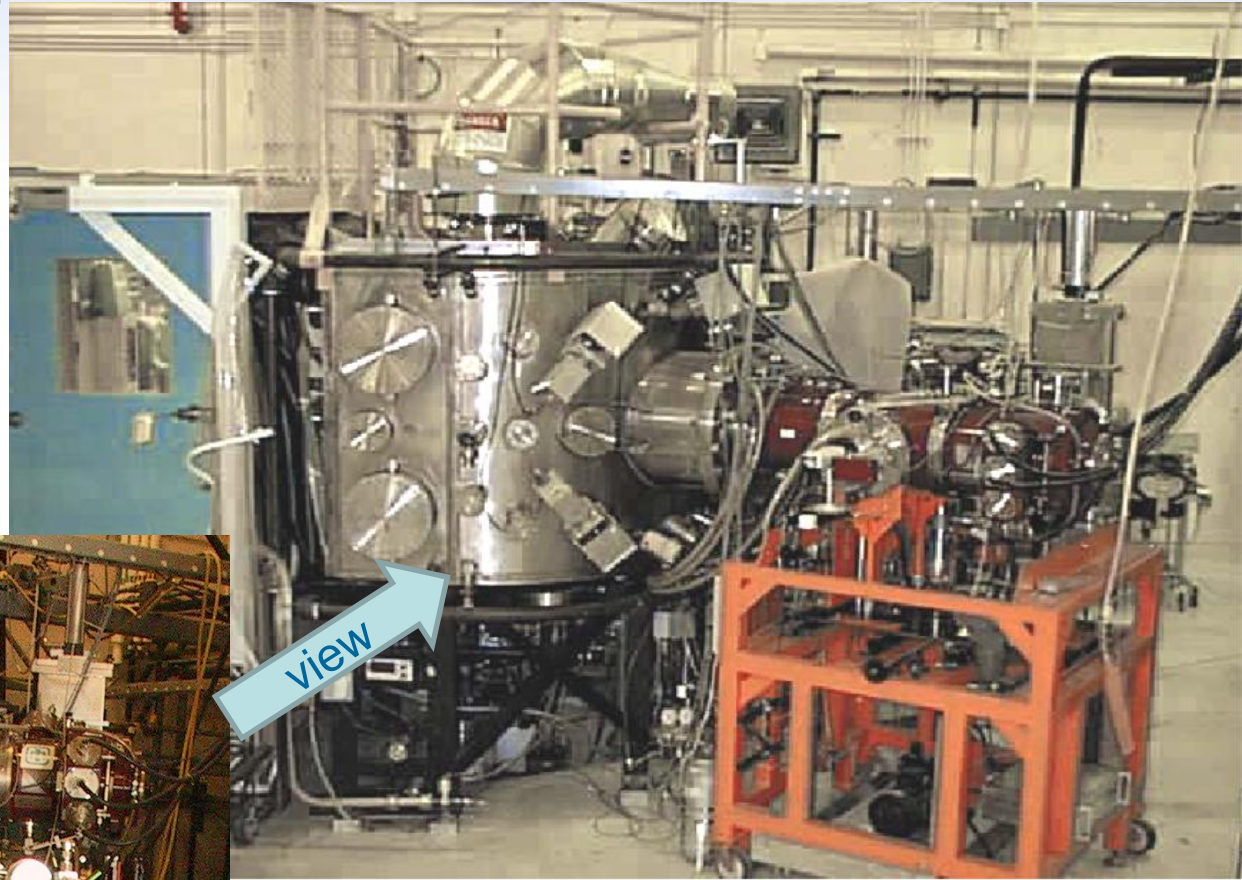
Target handling area

Door mounted on trolley is pulled back into this area to install and remove targets. In tests with Be targets, this is a beryllium handling area.

D-chamber

EB1200 Chamber & Beam Line 2 (right)

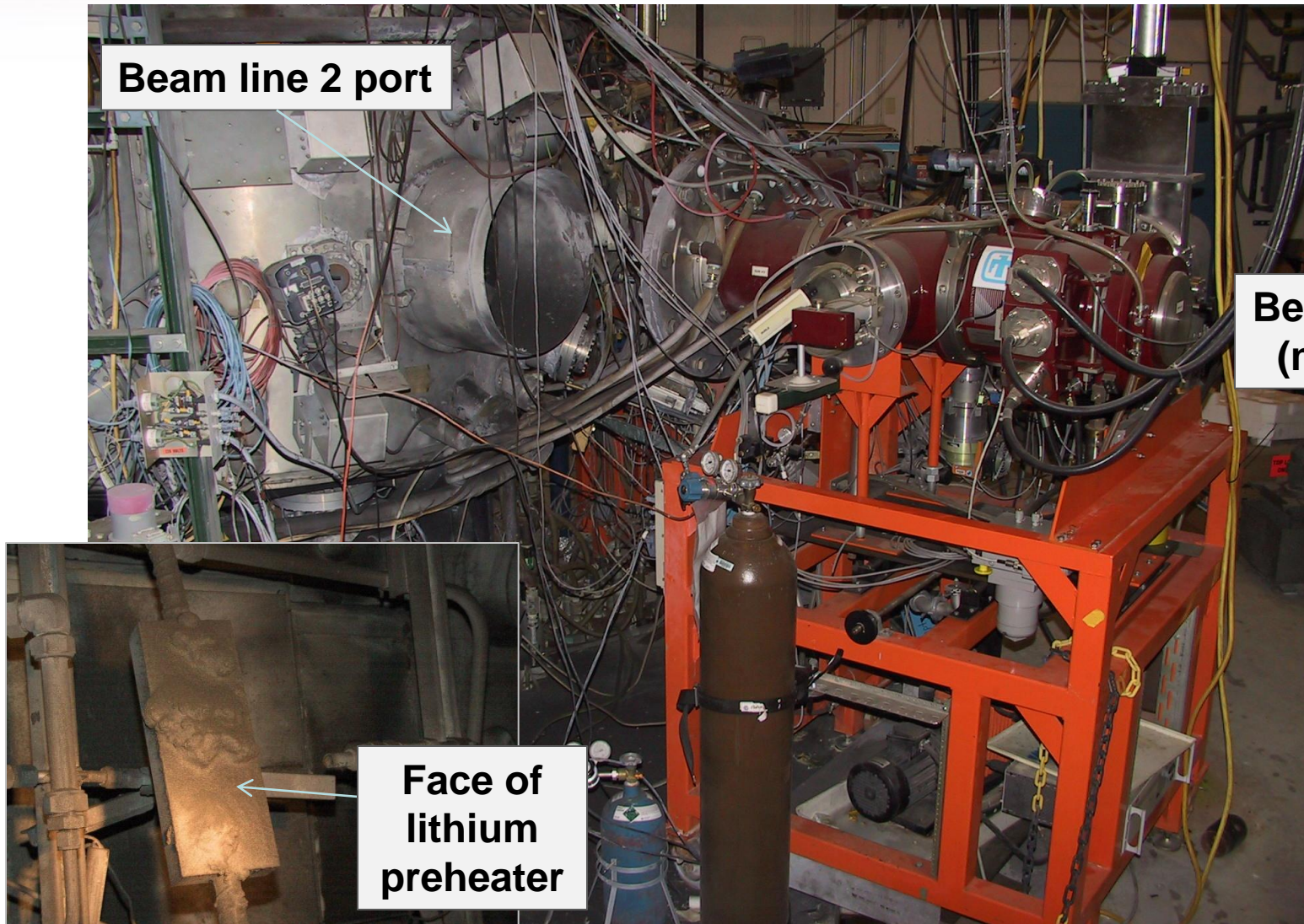
*setup with LIMITS
(below)*



View over LIMITS
with chamber (left)
and beam line 2 in
background

Beam Line 2 Displaced After Fire

Flange separated from port wall.



Beam line 2 port

Beam line 2
(maroon)

Face of
lithium
preheater