Unique Features of
High Heat Flux Testing with E-Beams
for Aerospace Applications

- **Sandia fusion activities**
  - *introduction*
  - *high heat flux testing equipment*
- **Research: issues and highlights**
  from our experience testing and modeling
  - *preference for e-beams as test platform*
  - *gas cooling*
  - *modeling of heat transfer*
  - *temperature measurement*

Richard Nygren
& Dennis Youchison*
Sandia National Laboratories
****now at Oak Ridge National Laboratory***

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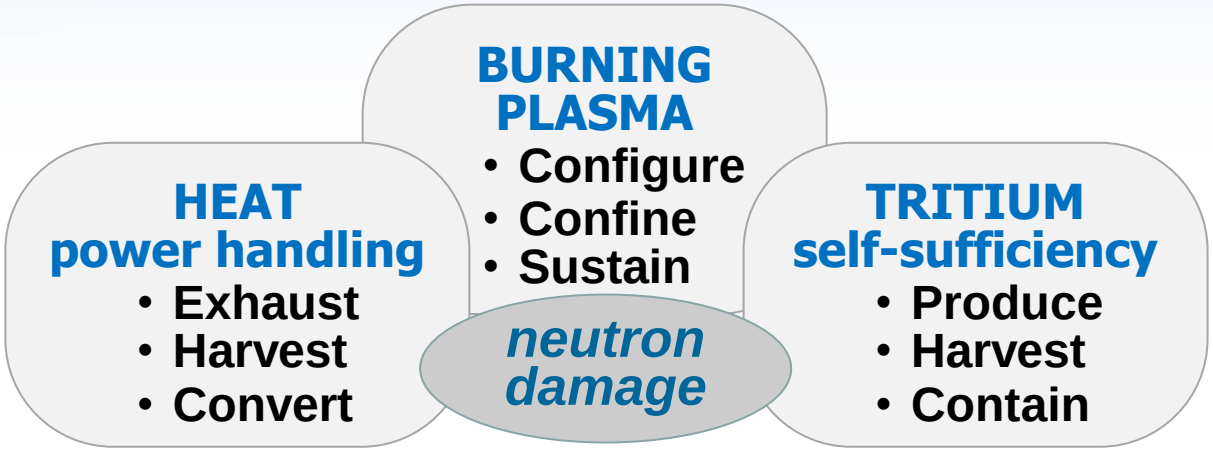
Basic requirements in fusion systems



HANDLE/HARVEST HEAT **and** ***BREED/PROCESS/TRACK TRITIUM***

PROTECT the PLASMA

ROBUST PLASMA FACING COMPONENTS

- **Mitigate ion & radiation damage**
- **Develop suitable materials**
- **Develop workable cooling systems**
- **Understand/predict system behavior including plasma-wall interactions**

VIABLE BREEDING BLANKETs

- **Demonstrated tritium breeding**
- **Develop suitable materials**
- **Viable integrated systems**
- **Understand/predict system behavior including tritium migration/retention**

HEAT power handling | **BURNING PLASMA** | **TRITIUM** self-sufficiency

Plasma Edge

HANDLE HEAT

PROTECT PLASMA

Heat & Particles

- Surface temperature
- One-sided heating
- Gradients: temp/stress

ion damage

- Impurity source
- Erosion
- Melting/solidification

Morphology evolves!

Surface heat causes:

- Ablation
- Melting
- Micro-cracking
- Deformation
- Emission

Volumetric heat:

- Deflections/stress
- Expansion
- Permeation
- Re-crystallization
- Reactions
  - precipitation
  - intermetallics
  - corrosion
- Cross-sections

P F C

developing PFC armor:

- *heat transfer/HHF testing -segregation*
- *MHD, melting*
- *particle emission*
- *roughening, micro-cracks*
- *experiments in plasma devices*

developing heat sinks:

- *fluid flow physics, CFD*
- *heat transfer*
- *thermal stresses*
- *high heat flux testing*
- *corrosion/permeation*

For W PFCs and solid FWs, flow instabilities in He at high T & P are a potential problem.

Basis for current designs may be wrong.

Understanding of fluid physics, and testing at high T & P are needed to benchmark models.

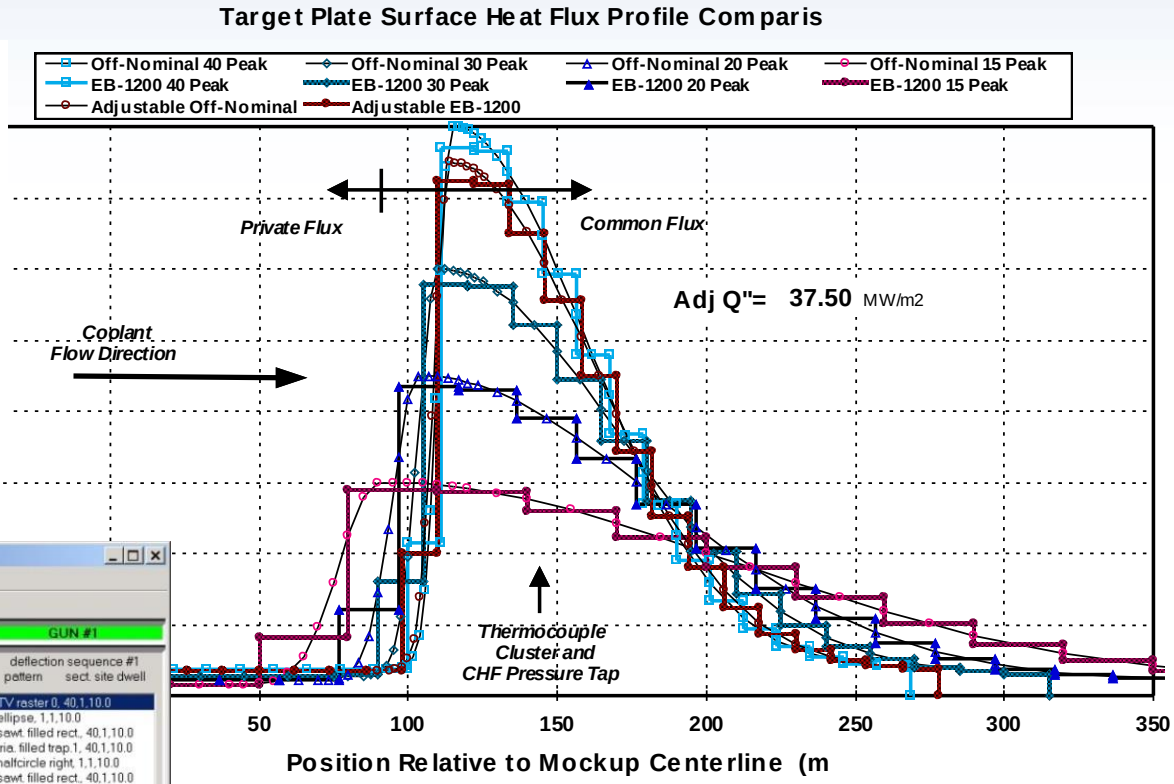
HEAT power handling

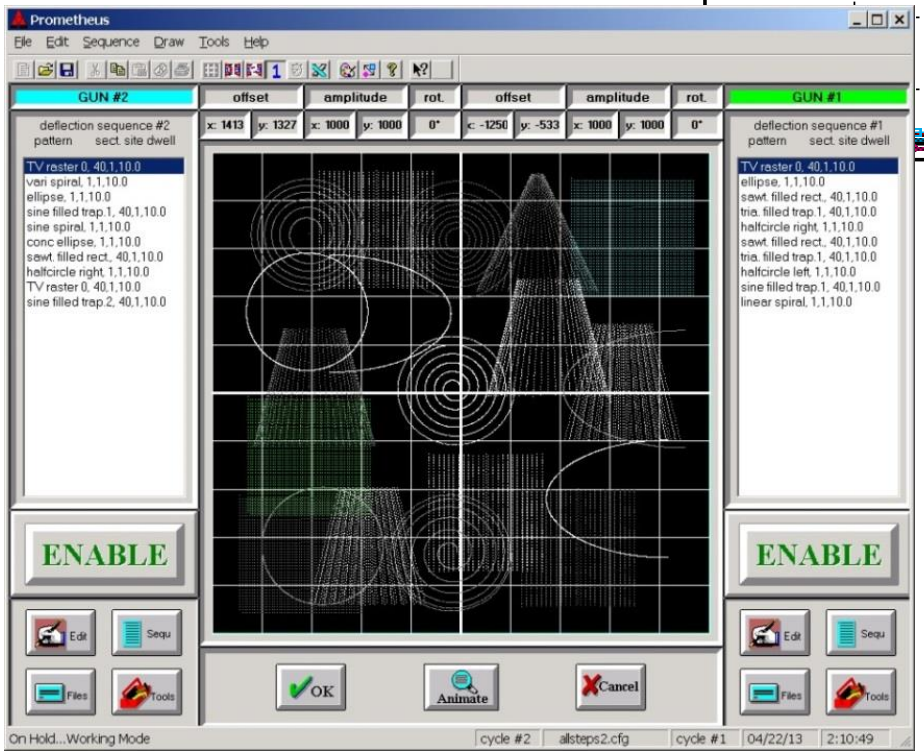
E-beams can tailor heat loads in time and space.

- PMTF had digital raster
- exotic patterns (below)
- EB1200 - large targets

Diagnostics are key.

PMTF- heavily instrumented.





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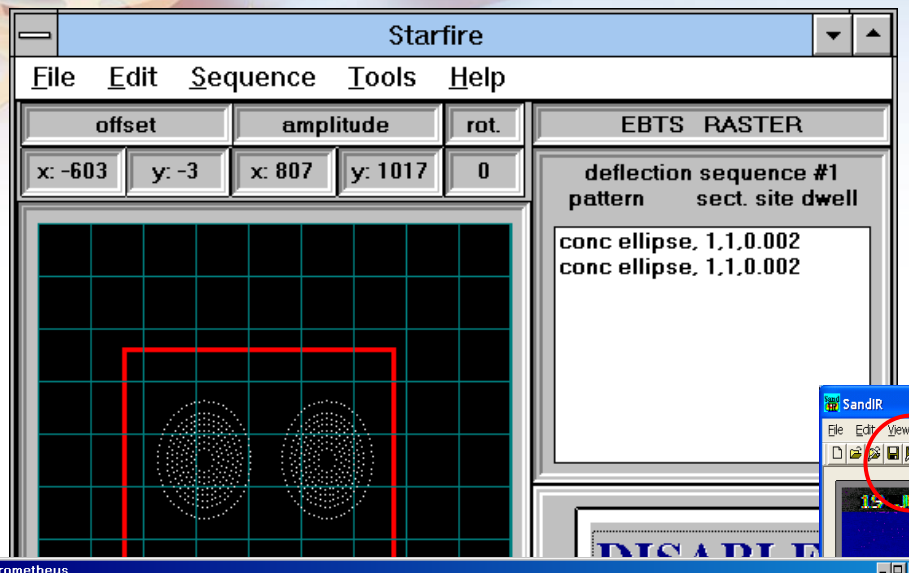
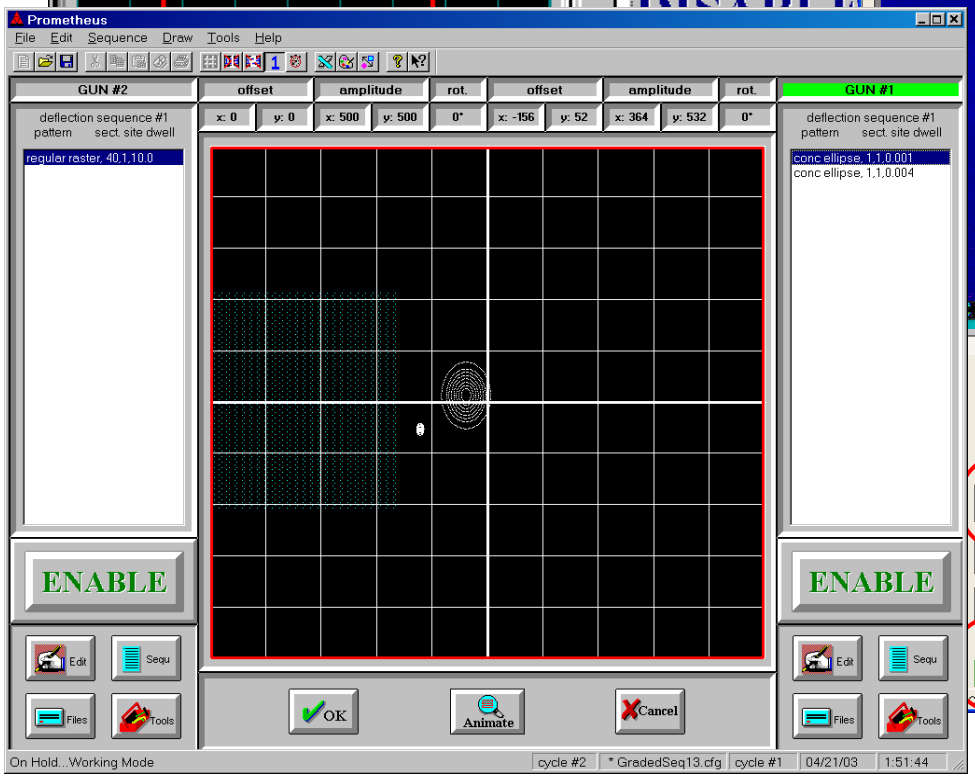
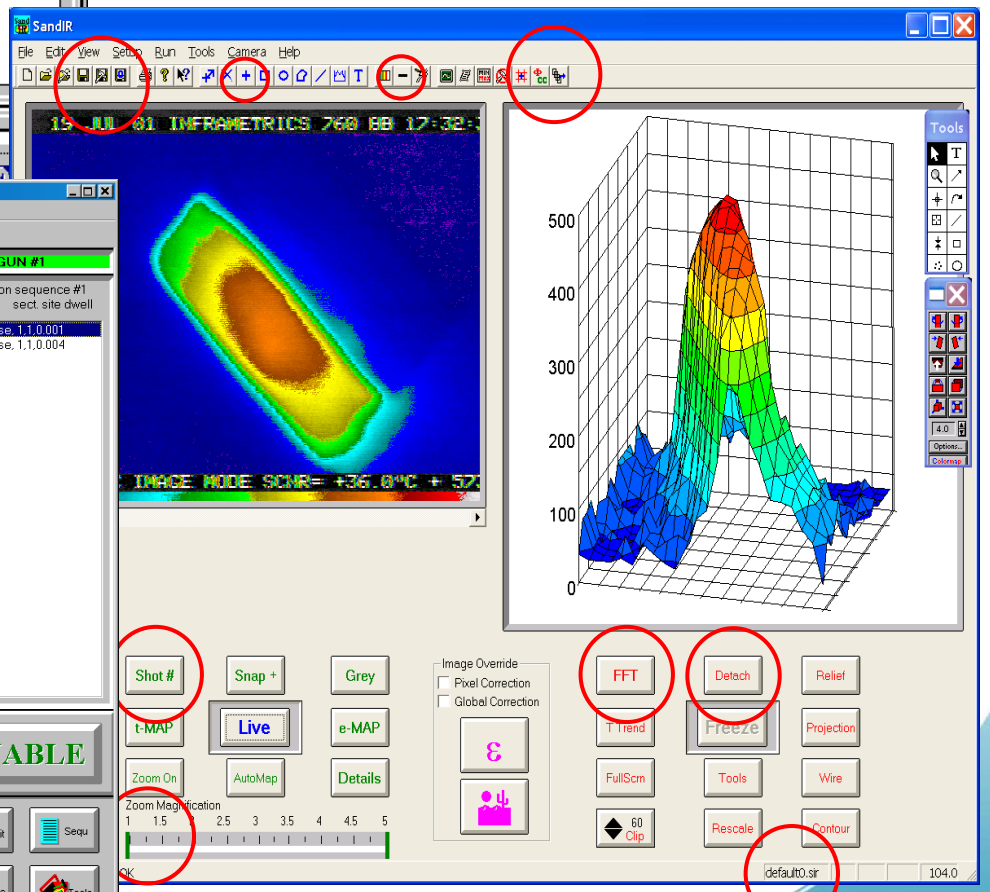
EB-60 equipped with digital raster control, IR analysis, real-time calorimetry, flow diagnostics and TC array.

SandIR







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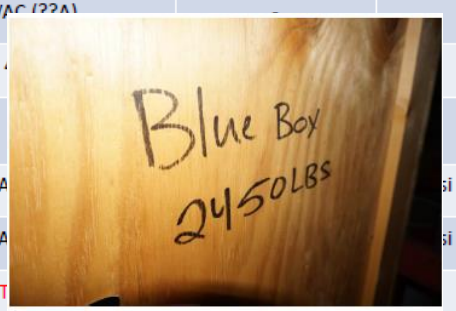
Sandia was (finally) able to transfer PMTF equipment to ORNL and the Applied Research Lab (ARL) at Penn State.

We hope the equipment can be operated for other users and also be available for HHF fusion tests. ARL is unpacking the small e-beam system this week.

(Thank you to Dennis Youchison whose dedication and persistence achieved this.)

Equipment	Input Voltage	Input Water	Input Air	Dimension
Air Dryer	125VAC (??A)		??	48" x 48" x 53"
Blue Box	400A		-	
Chamber			-	
Stand	120VAC, 30A		si (solenoids)	
Large Vacuum chamber	120VAC, 30A		si (solenoids)	
Rack#1	T		-	
Rack#2	TBD		-	



Blue box (250 KW EB PS), box 13 of 24 (1)


Blue box (250 KW EB PS), box 13 of 24 (3)


EB-60 Chamber, box 7 of 24 (2)


Guns (two), box 18 of 24 (8)

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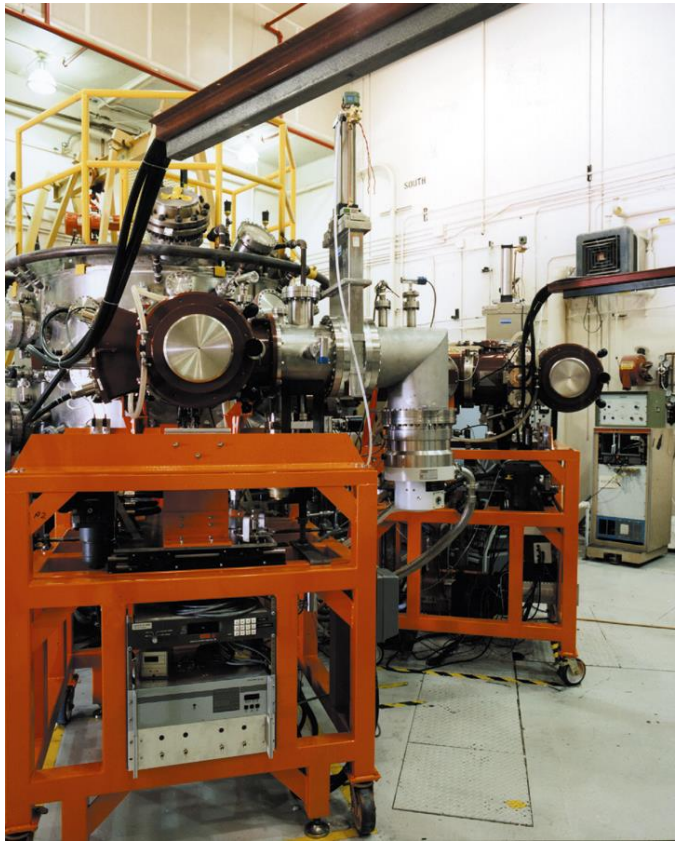
Thanks

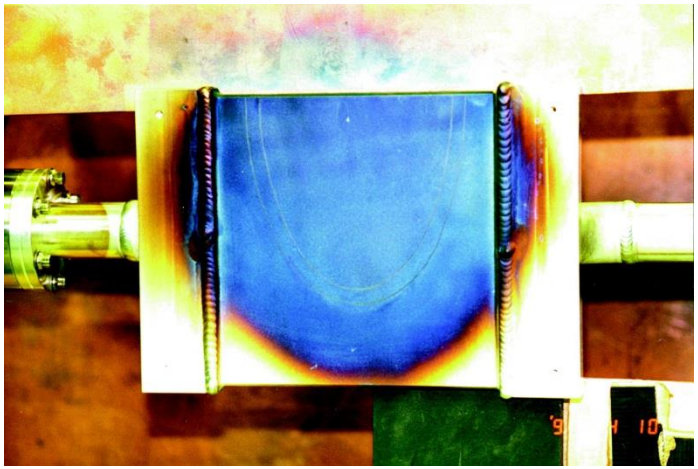
Other slides:

- *Complexity of setups*
- *Large size mockup or full size (non-fusion) component testing*
- *Many SBIR/CRADA tests supporting fusion He cooling and other applications*
- *Extensive diagnostics*

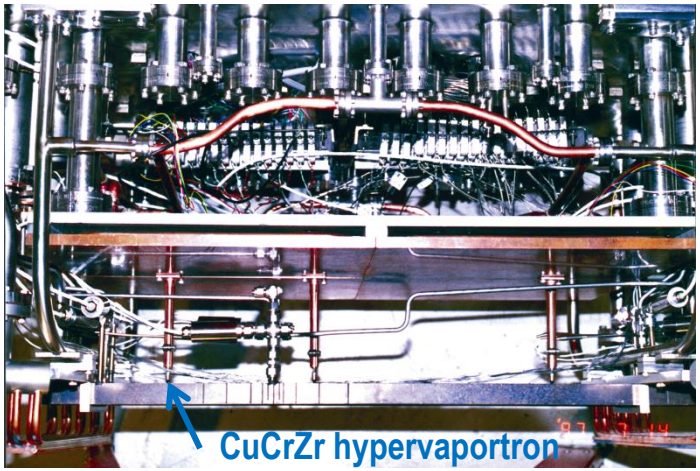
Sandia's Related PFC Research

The EB-1200 can test full-scale components.





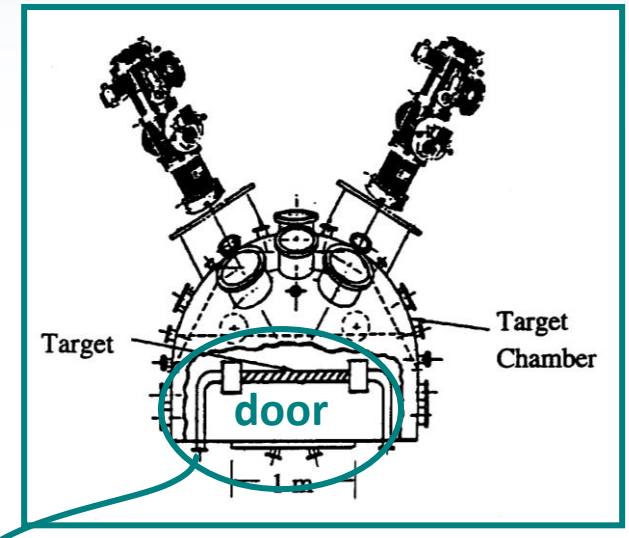
Aluminum BNCT target

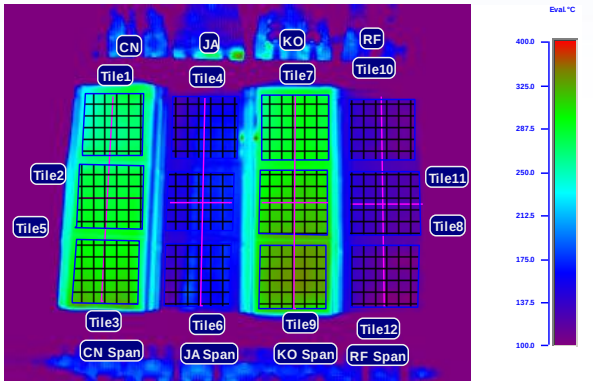


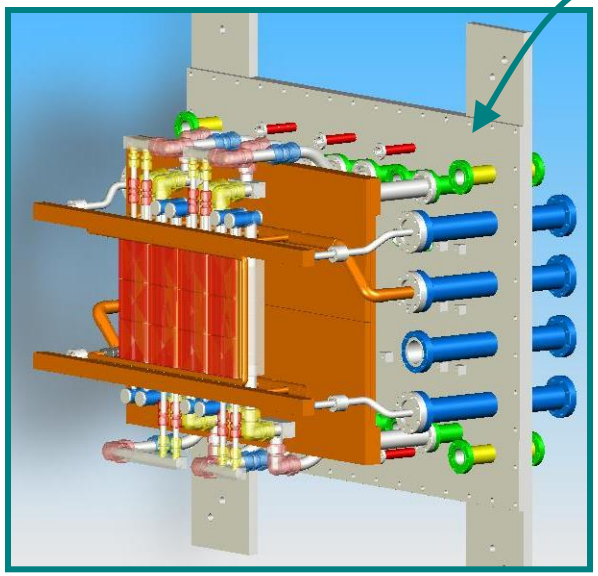
Top view of chamber door

FWQM Tests in EB1200

- We can test four FWQ mockups at one time using two e-guns and have tested mockups from the US, EU, KO, JA, CH and RU.
- 2 IR cameras
- Reduced coolant velocity simulates neutron heating.







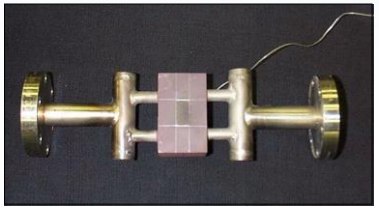
Heat flux (absorbed)	0.7 MW/m^2
$P_{absorbed}$/cycle	13.4 kW
Water	100 C 1 m/s
Water T_{out}-T_{in}	~20C
Number of cycles	12,000
Full cycle (on/off)	96 s

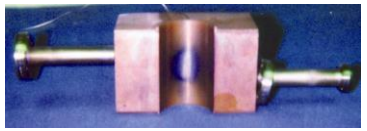
EB1200 Electron Beam

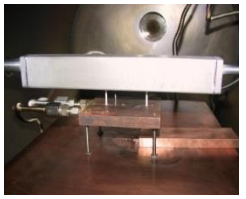
- 1.2 MW beam power
- Digital beam raster
- Extensive diagnostics *IR, pyrometers, RGA, water calorimetry, beam power, etc.*
- High T, High P water
- He loop in 2008

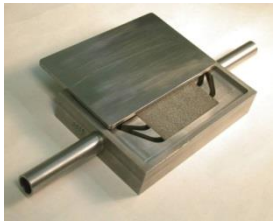
SBIR/WFO testing has produced continuing significant contributions.

Gyrotrons	Thermacore and Varian (2)
RF Mirrors	PPPL
Magnetrons/CFAs	Jaycor and CPI (2)
Klystron Source	Thermacore
Porous metal HX	Thermacore (3)
RF Faraday Shield (He)	Thermacore (3)
Divertor Module (dual) (He)	Thermacore (2)
Vanadium He-cooled HX	General Atomics
Tungsten Divertor (dual)	Thermacore
Tungsten Foam HX	Ultramet
Micro-channel He-cooled HX	General Atomics (2)
Normal Flow He-cooled HX	Creare (2)
BNCT photon beam stop	Lawrence Berkeley
BNCT target	Linac Systems (2)
PEP-II photon beam stop	Stanford Linear Accelerator Center
Beryllium windows	General Electric (3)
EUV Plasma source electrodes	Thermacore (3)
C-C Heatpipe Space Radiator	AllComp
Hypervapotron Divertors	ITER (3), Boeing (3)
1-channel He-cooled Mo HX	Ultramet (3)
Multichannel He-cooled W HXs	Ultramet (3)









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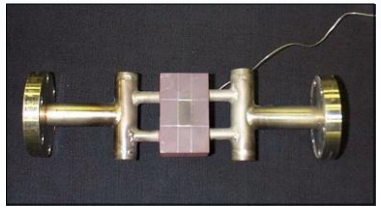
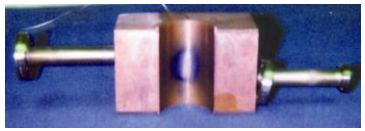
PPPL
Javcor and CPI (2)

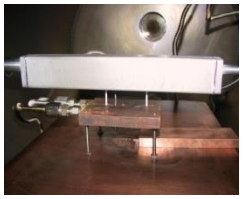


Let's not take time to read the list.

The point is that Sandia has

a) provided versatile HHF testing and
b) testing for innovative ideas and involvement of industry (SBIR/CRADA),
c) satisfied a steady stream of customers,
d) delivered significant output for fusion.





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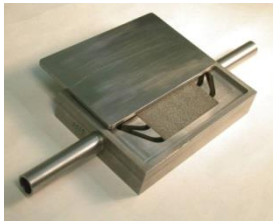

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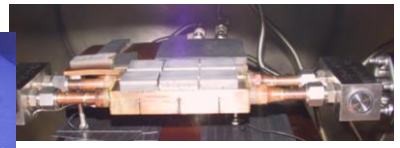
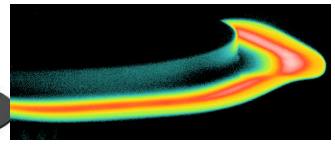
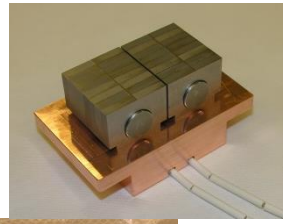
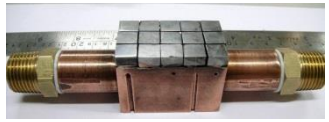
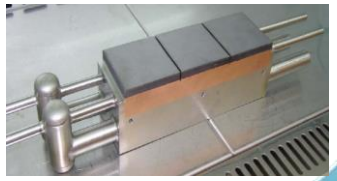
PFC Health Monitoring	Luna
Phased-Array Ultrasound NDE	Acoustic Ideas
Lithium-cooled Refractories	PPI (2)
Helium-cooled PS Refractories	PPI
DIII-D Graphite Tiles	GA (5)
W Lamellae Tiles	MIT (2)
TPX & Kstar CFC Tiles	PPPL (2)
NSTX CFC Tiles	PPPL
FRIB Accelerator Targets	MSU (2)
Nanowire Enhanced HXs	Technova (2)
He/He Refractory Regenerator	Ultramet
Li/He Refractory HX	Ultramet
Be Armored Heatsinks	NGK
PS Be Armored Heatsinks	LANL (2)
Be ITER FWQ Mock-ups	ITER (6)
W-coated Graphite Mock-ups	NIFS (2)
Swirl Tube or Finned Heatsinks	JAEA (8)
Swirl Tube Divertor Heatsinks	CEA (2)
W and CFC Armored Divertors	IPR (2)
Lithium jets	ALPS/APEX (4)
Lithium Emissivity	ALPS/APEX (2)
Molten Salt (FLiBe and FLiNaBe)	ALPS/APEX (2)





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