A Fusion Development Facility to Test Divertor and PFC Solutions for DEMO

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GENERAL ATOMICS

Significant Gaps from ITER to DEMO for PFC Solutions

- **Erosion and material migration**
  - Higher power density and higher duty cycle
  - More aggressive heat flux control required
  - Tons of PFC material will be eroded and redeposited
- **Tritium fuel cycle**
  - DEMO must breed its own tritium
  - Only small fraction of injected tritium fuel can remain in device
- **High temperature**
  - Blanket temperature ≥ 600 °C required for efficient electricity generation
  - PFC characteristics fundamentally change at high temperature
- **Off normal events**
  - Disruptions must be eliminated, or substantially mitigated
  - ELMs must be essentially eliminated

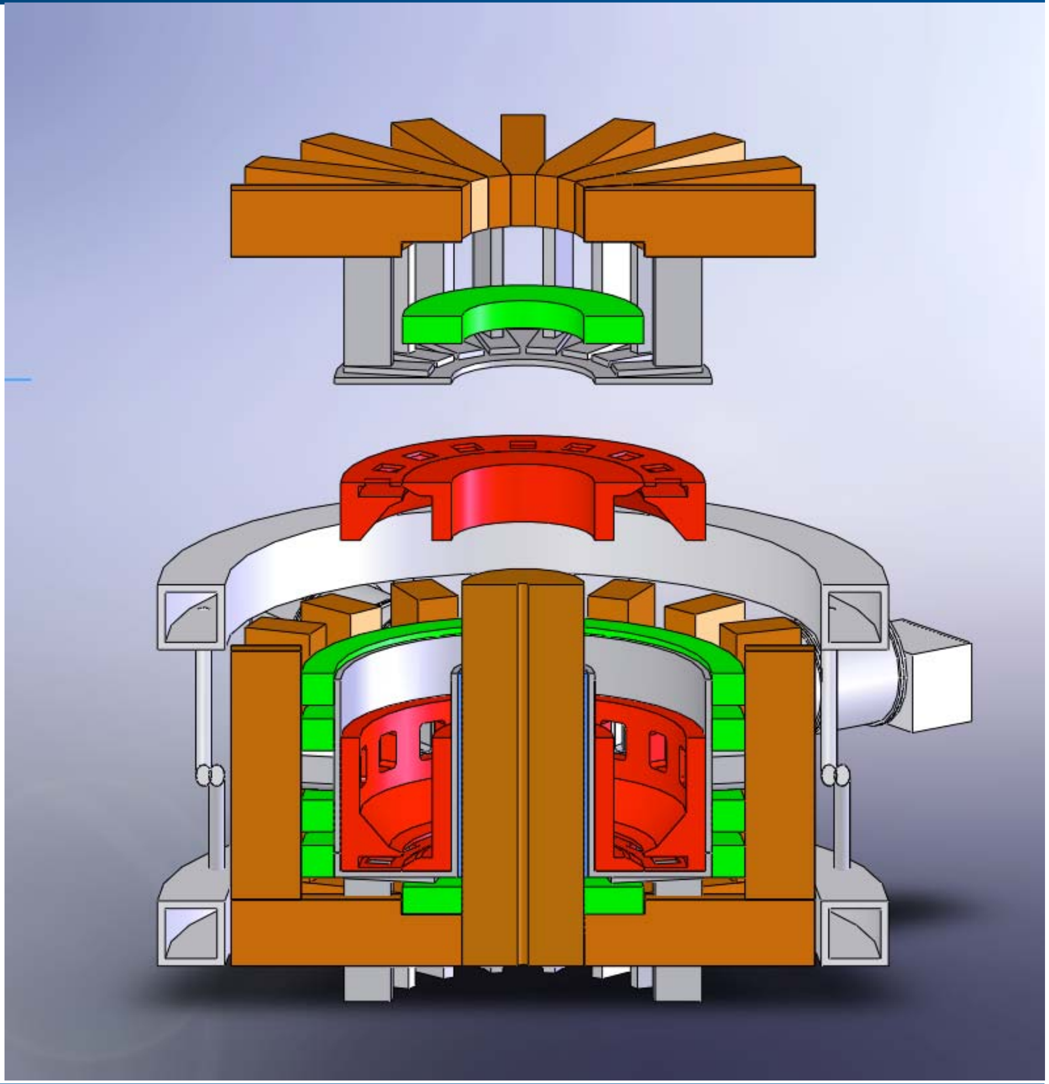
A RESEARCH Facility for PFC Development is Needed to Bridge the Gaps to DEMO

A PFC research facility should encompass:

- **Tritium breeding**
  - PFC issues are central to obtaining TBR >1; Thin PFCs for neutron flux to blankets, tritium retention and permeation in PFCs
- **High power density and duty cycle**
  - Tests of heat flux control solutions compatible with high core confinement
  - Test designs to handle large levels of gross and net erosion and redeposition
  - Develop diagnostics for monitoring PFC erosion and integrity
- **High temperature**
  - Tritium retention and permeation change drastically at high temperature
  - PFC surface properties, reworked by the plasma and neutron, may change at high temperature
- **High neutron fluence**
  - Capability to test PFC designs, material and surface properties to > 20 dpa
- **Flexibility**
  - Ability to change out and test alternative PFC materials and designs

FDF is an research facility to address the PFC gaps to DEMO

- **Compact**
  - Utilize AT physics for a high power density device at modest size, ~1.3 x DIII-D
- **Helium cooled PFCs**
  - Optimize vessel and PFC temperatures
  - Other options possible
- **Steady state**
  - 2 week discharges, 30% duty cycle over a year
- **High density**
  - Enhanced radiative dissipation
- **Flexibility with removable TF**
  - PFCs assembled outside vessel
  - Divertor and other PFCs can be changed in timely manner

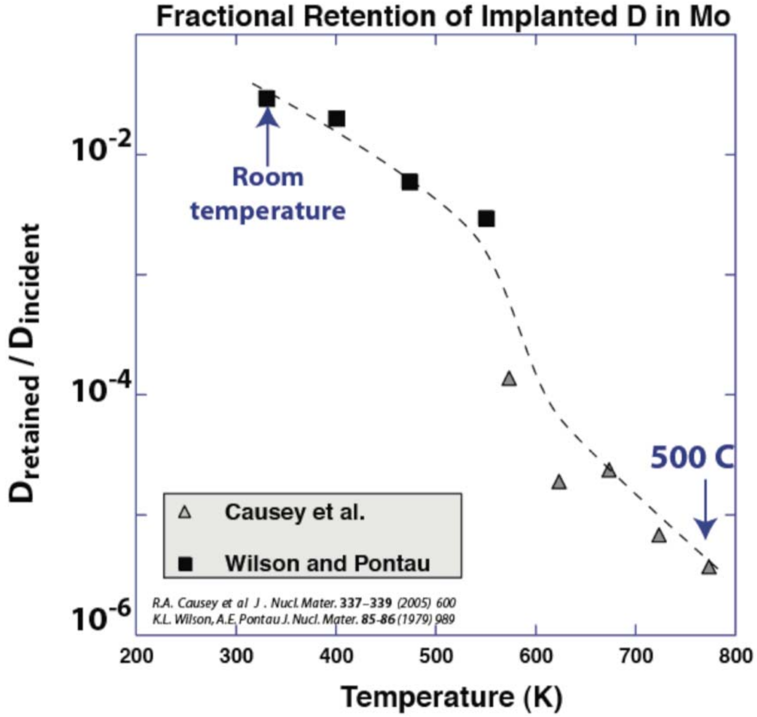


FDF Can Conduct a Broad and Flexible Research Program

- **Test a variety of PFC materials**
  - Possible carbon PFCs for initial operation and discharge optimization; Oxygen bake for periodic cleanup
  - All potential materials can be installed and tested W, Mo, RAFM, engineered BW, flow through C
  - Large volume of PFC material will be eroded and redeposited with unknown characteristics
  - Complete surface inspection, and possible replacement at regular intervals
- **A number of PFC designs can be tested**
  - Swirl tubes and hypervapatrons for heat removal
  - Joining of PFCs to heat sink; Brazing, mechanical clamping, etc.
- **Heat flux solutions**
  - High density for radiative heat flux dissipation
  - Compatibility of radiative divertors with optimized core confinement
  - Precision divertor alignment to maximize use of flux expansion
  - Innovative divertor configurations for increased flux expansion; Super-X

FDF Research Capability (cont.)

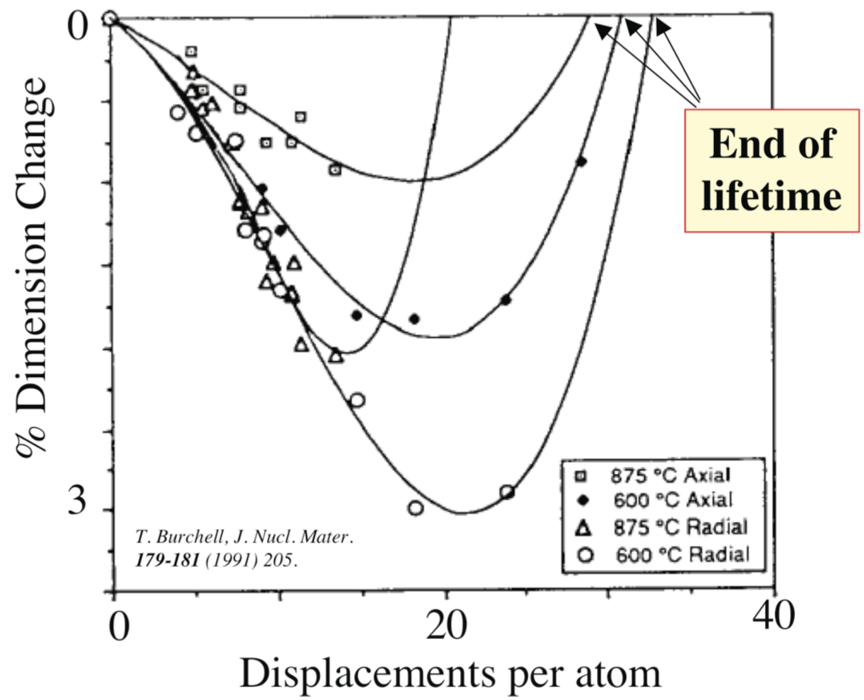
- **Tritium retention**
  - Tritium retention decreases significantly at higher temperature
  - Tritium diffusion, permeation, in high Z metals increases at high temperature
  - Surface properties at high temperature may limit flux of tritium into bulk
  - Optimal operating temperature for tritium control very uncertain
- **Tritium breeding**
  - Credible PFC designs for net tritium breeding can be tested



FDF Research Capability (cont.)

- **Component lifetime tests**
  - 20-40 dpa in a 5 year operating period can test material integrity of PFC materials
  - Effects of neutrons on eroded and redeposited PFC material can be examined
- **RAMI**
  - High duty cycle over years required high reliability and availability
  - Maintenance techniques can be developed
  - Diagnostics important for evaluating erosion, tritium retention and PFC integrity

Neutron induced shrink/swell in N3M graphite



Staged Schedule for Experimental Approach

- **Startup phase; 4 years**
  - Shorter pulses for system checkout
  - Optimize performance with PFCs forgiving to off normal events
- **1st experimental phase; 5 years, 12 dpa**
  - Begin steady state operation
  - Convervative PFC and blanket design for initial evaluation
- **Maintenance; 2 years**
  - Install DEMO relavent PFC, divertor and blanket systems
- **2nd operation phase; 5 years, 25 dpa**
  - Test performance of DEMO relevant PFC designs
- **Maintenance; 2 years**
  - Install optimized PFC designs
- **3rd operation phase; 5 years, 40 dpa**
  - Final testing of PFC, divertor and blanket designs for DEMO

A Staged Research Plan for Increasingly Optimized Operation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	←START UP→						FIRST MAIN BLANKET							SECOND MAIN BLANKET							THIRD MAIN BLANKET		
	H	D		DT																			
Fusion Power (MW)	0	0		125	125				250			250				250			250				400
P_N/A_{WALL} (MW/m^2)				1	1				2			2				2			2				3.2
Pulse Length (Min)	1			10	SS				SS			SS				SS			SS				SS
Duty Factor	0.01			0.04	0.1				0.2			0.2				0.3			0.3				0.3
T Burned/Year (kG)				0.28	0.7				2.8			2.8				4.2			4.2				5
Net Produced/Year (kG)					–0.14				0.56			0.56				0.84			0.84				1
Main Blanket					He Cooled Solid Breeder Ferritic Steel									Dual Coolant Pb-Li Ferritic Steel							Best of TBMs RAFS?		
TBR					0.8				1.2			1.2				1.2			1.2				1.2
Test Blankets							1,2						3,4		5,6					7,8		9,10	
Accumulated Fluence ($MW\text{-}yr/m^2$)				0.06					1.2							3.7						7.6	