PMI & PFC R&D in a FNS Program

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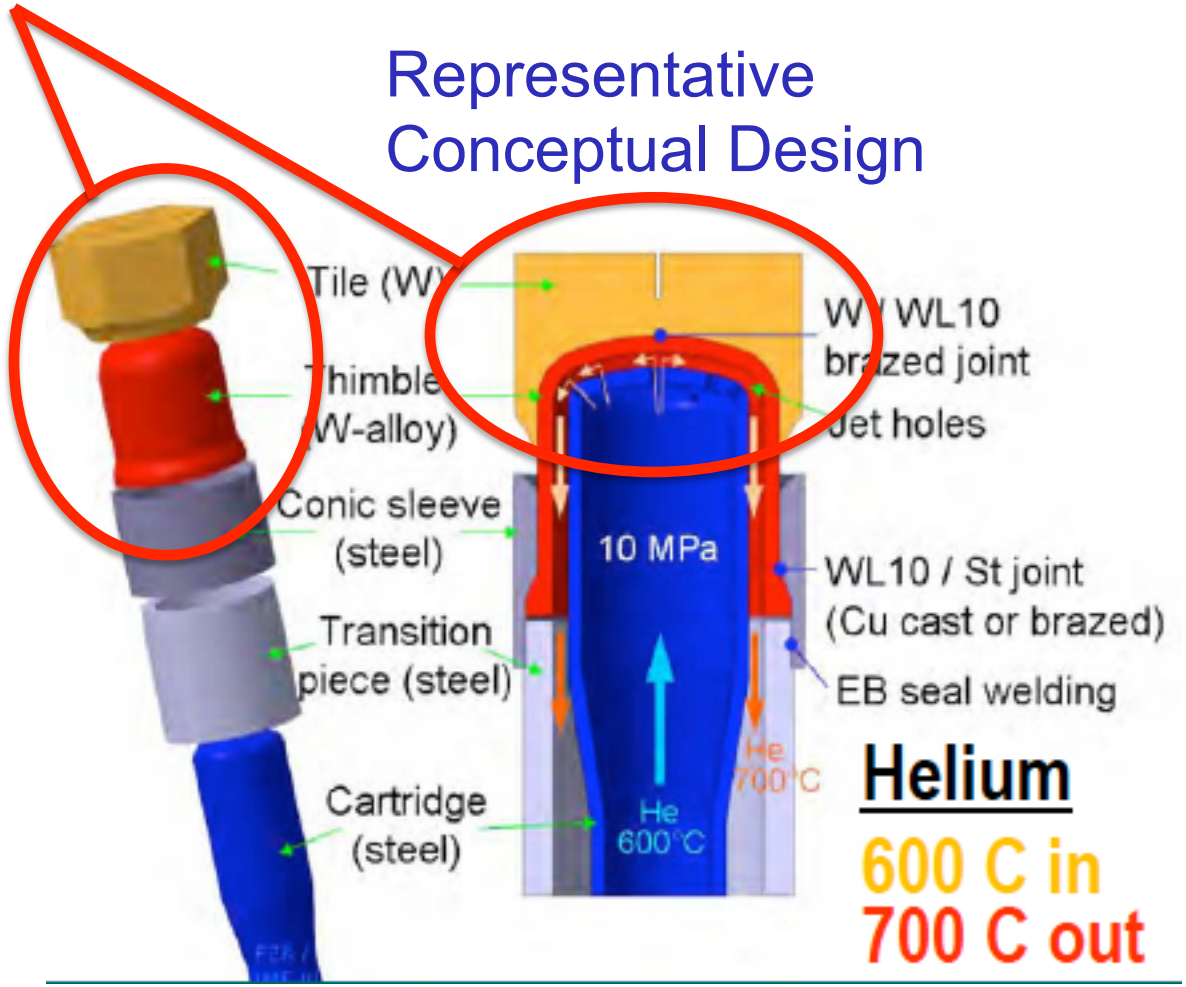
PFC Region of Interest

- Plasma Facing **Surface**
  - Ion Penetration Depth ~10's-100's nm
- **Diffusion Zone** (~1-10 microns)
- **Bulk:** Permeation & Strong Temperature, Stress Gradient Region to Coolant Channel



Norajitra et al, FED 83 (7-9) (2008) 893-902

Underlying Issues

- **Surface:** Mixed material formation & evolution:
  - Composition, morphology & thermo-mech. Properties of near-surface region formed by erosion/redep processes
- **Bulk:** Neutron damage
  - Damage cascade effects on D/T/He retention, diffusion, transport & trapping which can lead to bulk thermo-mech. Property evolution
- **Bulk:** Transient & gradient effects
  - Temperature, D/T/He concentration gradients lead to differential stresses b/w surface, bulk, joining region & coolant channels

Experimental Approaches

- Single Issues Studies
  - E.g. Ion beam studies of physical sputtering, e-beam thermal loading studies, etc…
- Multi-issue Studies
  - E.g. erosion & redeposition in plasma devices, plasma-induced morphology changes & impact on retention, …
- Highly integrated issues
  - Impact of FNS-relevant wall on core plasma performance, material migration in steady-state tokamak, …

Off-line Facilities & DEMO Conditions

		Linear Divertor Plasma Simulators						Reactor
		PISCES-B	NAGDIS-II	PISCES-A / TPE*	PSI-II	PILOT	MAGNUM	DEMO
Discharge		Refl. Arc	Pen.	Refl. Arc	Pen.	Arc Casc.	Arc Casc.	Divertor
Power	(kW)	5–15	10.5	5–10	6.5	45	270	
p_{target}	(Pa)	0.01–1	0.1–4	0.01–1	0.01–0.1	1–10	< 10	
T_i	(eV)	10–300	50	10–200	< 15	0.1–5	0.1–10	**<100**
T_e	(eV)	3–50	10	3–20	< 30	0.1–5	0.1–10	< 100
n	(m^{-3})	10^{17}–$2\cdot10^{19}$	$6\cdot10^{19}$	10^{17}–10^{19}	10^{19}	$4\cdot10^{21}$	10^{20}	**~ 10^{20}**
Ion flux	($m^{-2}s^{-1}$)	10^{21}–$2\cdot10^{23}$	10^{22}	10^{21}–$3\cdot10^{22}$	10^{22}	$5\cdot10^{24}$	10^{24}	**10^{23}–10^{24}**
Energy flux	($MW\cdot m^{-2}$)	1–10	0.01	2	0.1	30	10	10
B	(T)	0.04	0.25	0.1	0.1	1.6	3	**10**
Beam dia.	(cm)	5	2	5	6–15	1.5	10	
Length		1.5	2.8	1	2.5	0.5–1		
Heating	(kW)	< 3 dc	~50 rf	< 1 dc	5	10 dc	50 dc + rf	Thermal
		PMI capabilities						
Gas species		D, He	D, He	D, T*, He	D, He	D, He	D, He	D, T, He
Targets		Be, C, W	W, C	Be*, W, C	W, C	W, C	W, C	**W**
Pulse length	(s)	steady	steady	steady	steady	10	steady	steady
Impurity PMI		Be, C						**W**
Transients		YAG	YAG					ELM
Damage								Neutron
Fluence (/ day)	(m^{-2})	~10^{27}	~10^{26}	~10^{26}	~10^{26}	~10^{26}	~10^{28}	**>10^{28}**

In service | Not operational | Near condition | Meets condition | Below condition

KEY NEW PMI-PFC Issue in FNS Program

- Self-consistent evolution of high heat flux surface under plasma bombardment
  - Morphology, Retention, Yield, Nucleation, Diffusion & Permeation, Thermomechanical Properties ***ALL*** Coupled & Linked to T_{surf}

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» NOTE k=k (T)!

KEY NEW PMI-PFC Issue in FNS Program

- Self-consistent evolution of PMI in radiation-damaged materials
  - Morphology, Retention, Yield, Nucleation, Diffusion & Permeation, Thermomechanical Properties ***ALL*** Coupled & Linked to Radiation Damage

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» NOTE k=k (dpa)!

Key High-level Questions

- To what state does the PFC ***surface***, ***diffusion region***, and ***bulk region*** evolve under simultaneous plasma exposure with high heat flux & with radiation damage?
- What is the lifetime of PFCs in this state?
- How does this state affect the core plasma?
- Can conventional solid materials be engineered to provide acceptable performance?

Outline or Sketch of an R&D Program

- Understand SOL transport, flows & impact on material migration
- D/T/He retention & microstructure evolution in ion-beam damaged surfaces
- Bulk permeation in plasma-exposed actively cooled high heat flux components
- Thermo-mechanical performance of radiation damaged high heat flux components
- Integrated PFC Performance

Likely Required New Capabilities

- Multi-scaled plasma & materials modeling
- High heat flux plasma simulators
- Ion beam facilities
- Neutron irradiation
- Plasma simulators handling activated sampled
- (Possibly) Integrated plasma & neutron irradiation
- + Focused Expt's on Tokamaks