Bonding Tungsten to Low Activation Ferritic Steel

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Fabrication and Characterization
Tungsten Armored Low Activation Ferritic Steel

Objective: Evaluate methods for bonding tungsten to F82H Steel and assess the integrity of these coatings under IFE relevant thermal fatigue conditions.

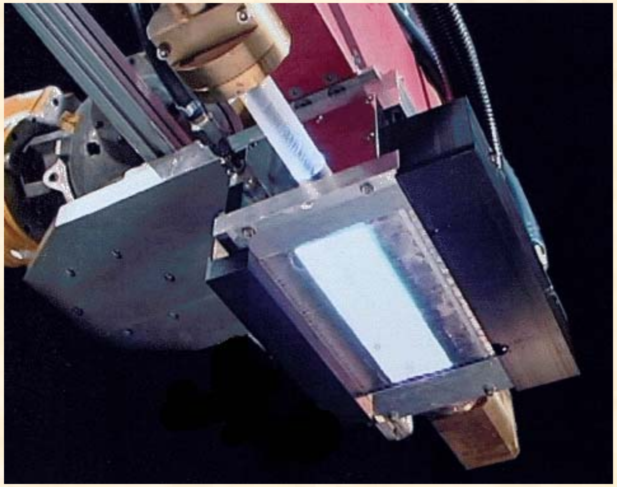
Approach: Focus on achieving mechanical and thermal similitude at the W-Steel interface.

Tungsten Clad LAF
Potential Damage - Failure Modes

a. **Spallation – Stain mismatch**
b. **LCF – Excursions to Ambient**
c. **DBTT in Tungsten – Impurity Issue**
d. **HCF Failure – through thickness and interface cracking**
e. **Thermochemical** and irradiation **stability of F82H at W-LAF interface.**
f. He evolution and spallation
g. Thermomechanical performance of LAF
   Creep and Creep-Fatigue

IR Thermal Fatigue Capability

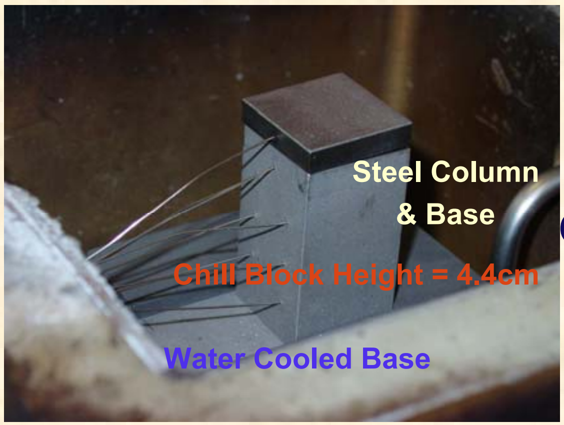
200 MW/m² upgrade just completed



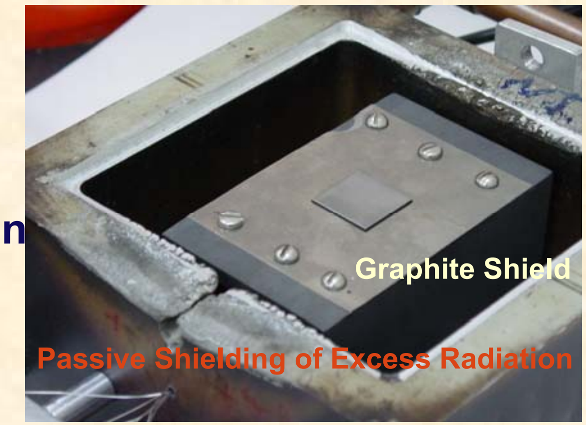
Plasma Arc Lamp Specifications

	Heat Source	Max Energy @ Min Pulse Width (MJ/m^2)	Min Pulse Width (ms)	Max Heat Flux (MW/m^2)	Frequency (Hz)
	IFE f(radius)	~0.1	0.01	10^4	5 to 10
Currently Used ►	1x10 cm Plasma Lamp Standard Power Supply	~0.7	20	35	≤10
	1x10 cm Plasma Lamp Capacitor Power Supply	~0.4	2	200	Undetermined
	10x30 cm Plasma Lamp Standard Power Supply	~0.1	20	5	≤10

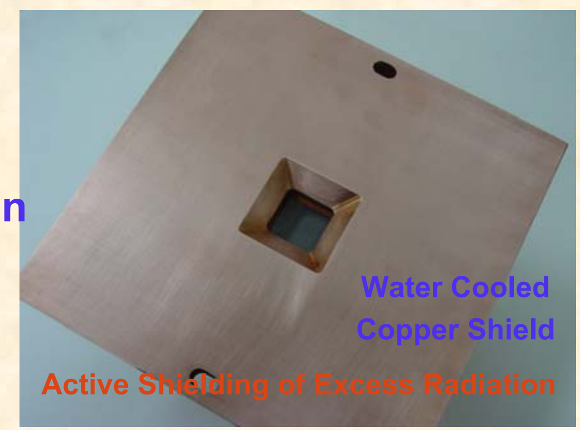
The IR thermal fatigue test has been re-configured to achieve steeper temperature gradients and manage excess incident radiation.



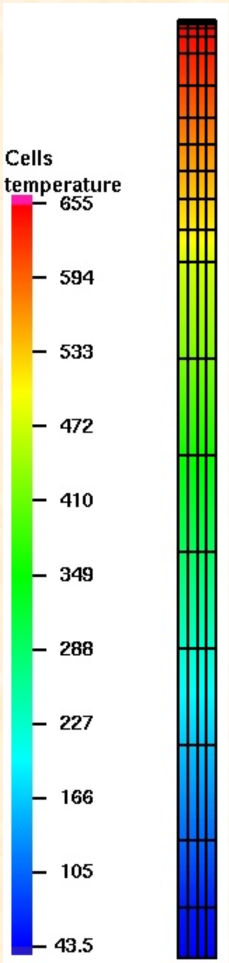
Old Configuration



New Configuration



A Finite Element Model was developed to simulate thermal gradients in the IR fatigue test for W-clad F82H steel specimens measuring 25mm x 25mm x 5 mm.



T1

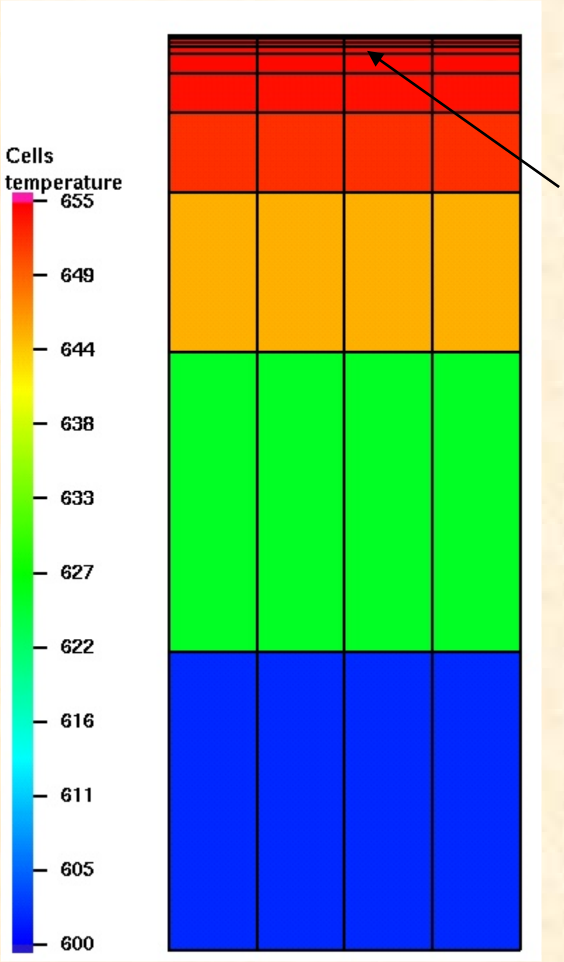
T2

T3

T4

T5

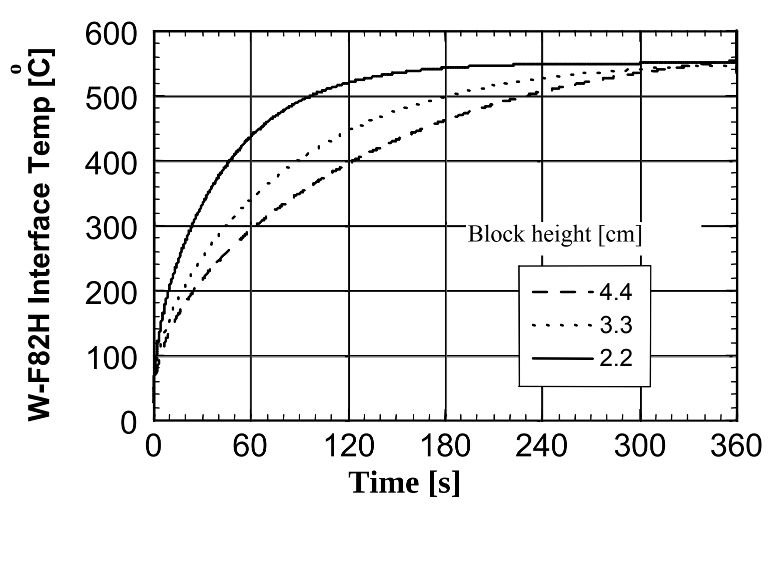
Thermocouples

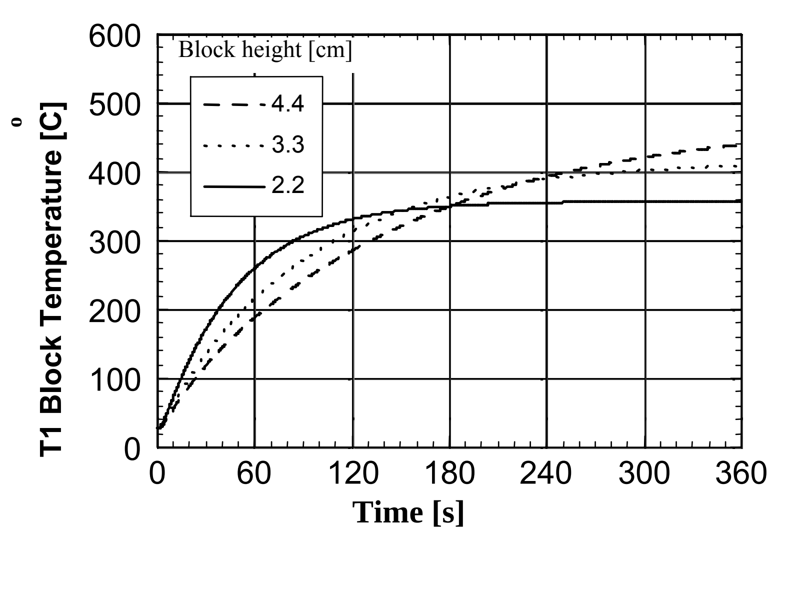


W-F28H interface

◄ T-F82H @ 2.5 mm

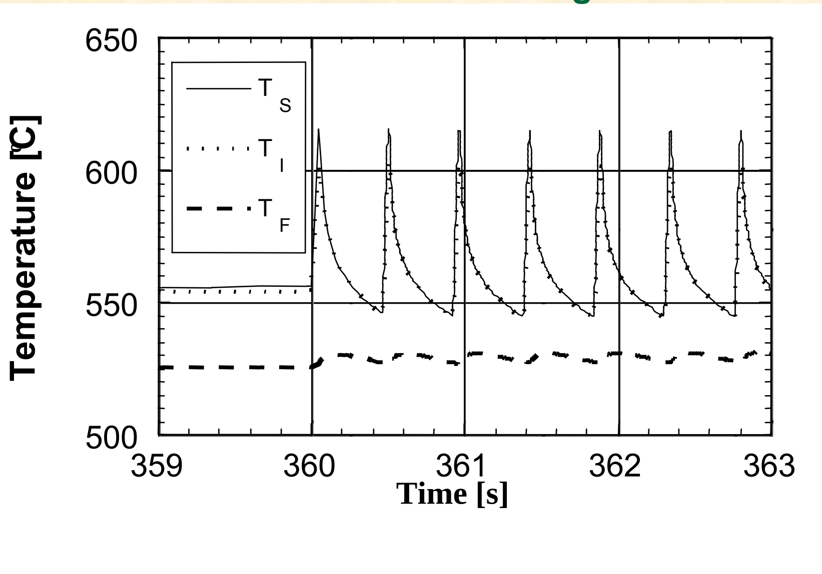
New thermal fatigue configuration enables rapid equilibration of a steady state heat flux during preheat and thermal cycling. Preliminary measurements have confirmed this result.



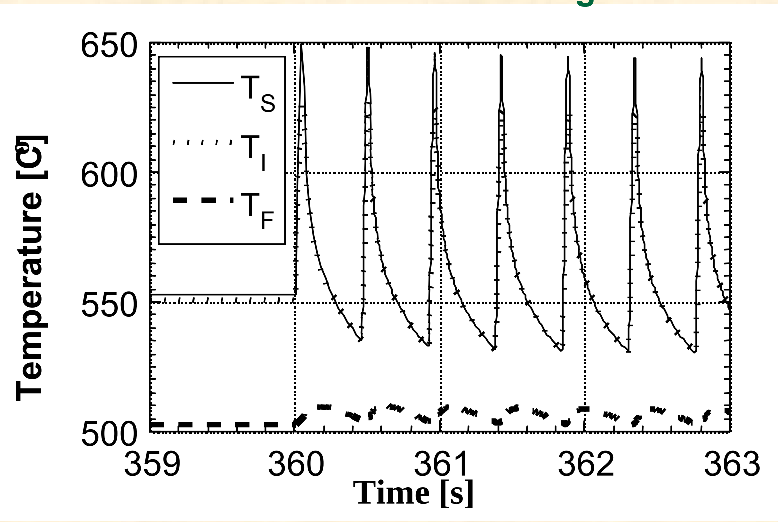


A decrease in the chill block height resulted in greater calculated temperature swing, ΔT, at the interface.

Chill Block = 4.4 cm height



Chill Block = 2.2 cm height

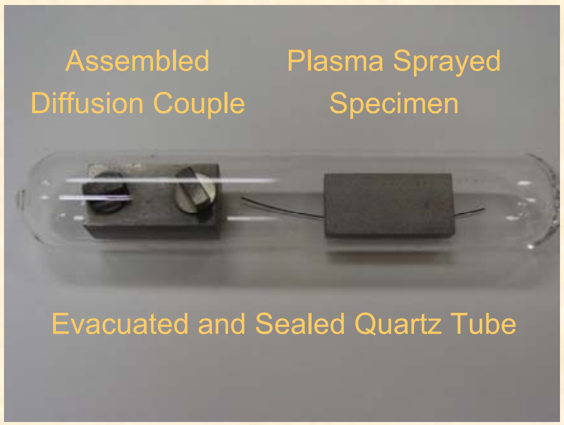


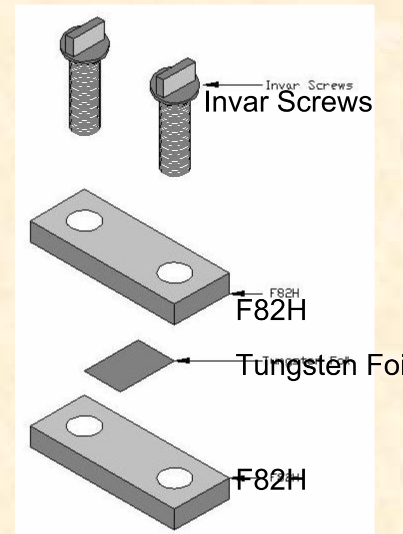
ΔT = 55ºC

ΔT = 100ºC

TI = Interface Temperature

Isothermal aging experiments are underway to systematically characterize the thermochemical stability of tungsten/LAF coating system.

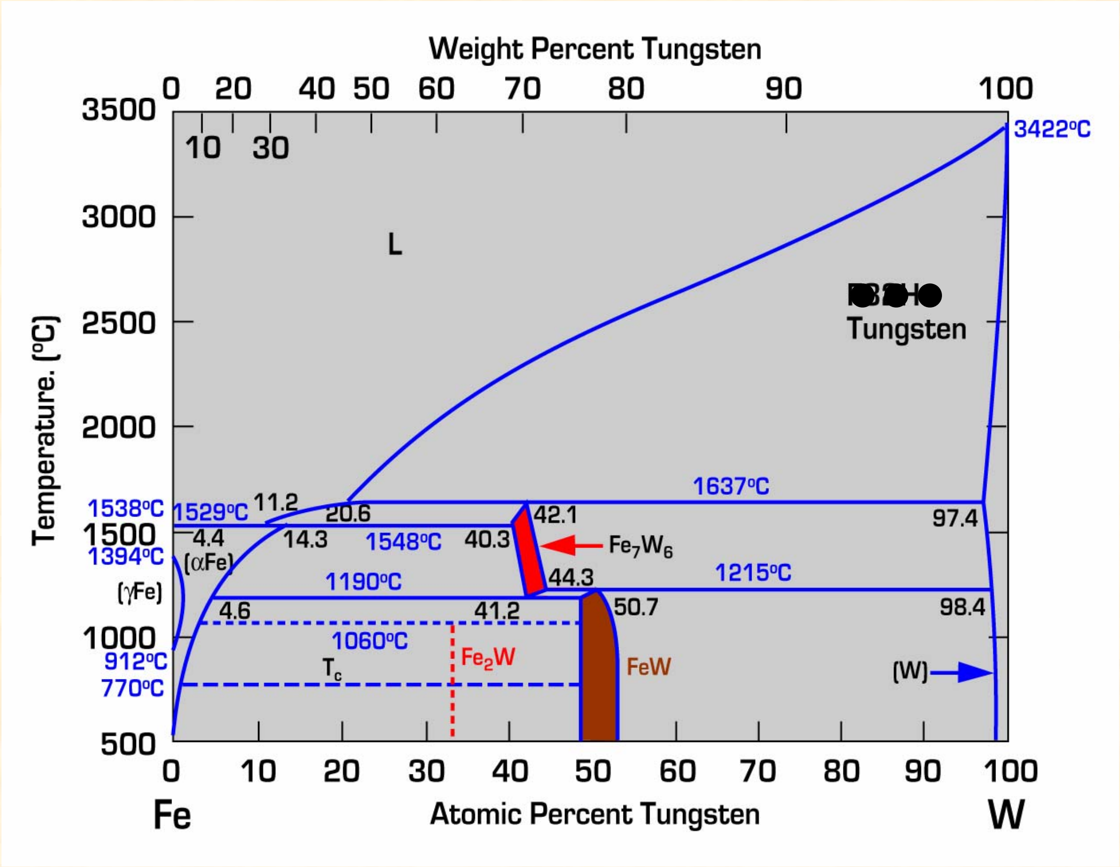




Diffusion Couple

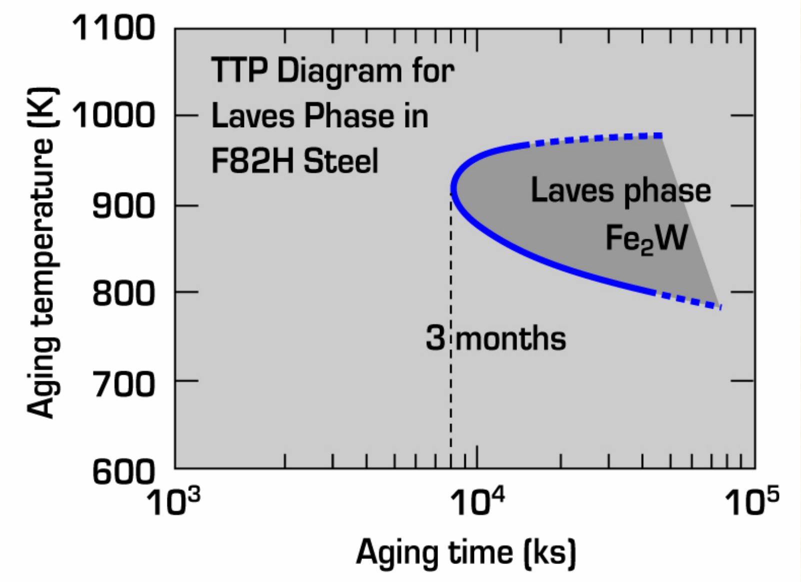
- **Tungsten/LAF diffusion couples are being aged at 500C to 900C for times ranging from 100h to 4,000h.**
- **Post aging analysis of samples will includes:**
  - **Microchemistry profiles in the steel, interface and coating**
  - **Phase identification by XRD**
  - **Phase equilibrium analysis**
- **Solid state diffusion model will be developed to extrapolate results to longer times**

Fe-W binary phase diagram indicates the potential formation of several intermetallic phases.



Numerous intermetallic and carbide phases form in F82H Steel during long term aging at elevated temperatures.

Precipitate Phases	Composition
$M_{23}C_6$	$(Cr_{16}FeW)C_6$
MX	(CrV)N
M_2X	W_2C
Z-phase	(CrVTa)N
η - carbide	M_6C
Laves	Fe_2W
Chi	$M_{18}C$ or $Fe_{35}Cr_{12}W_{10}C$
Other Carbides	$(CrFe)_7C_3$ $(FeCr)_3C$ $(FeCr)_4C$ Fe_6W_6C Fe_3W_3C
Other Intermetallics	Fe_7W_6 and FeW



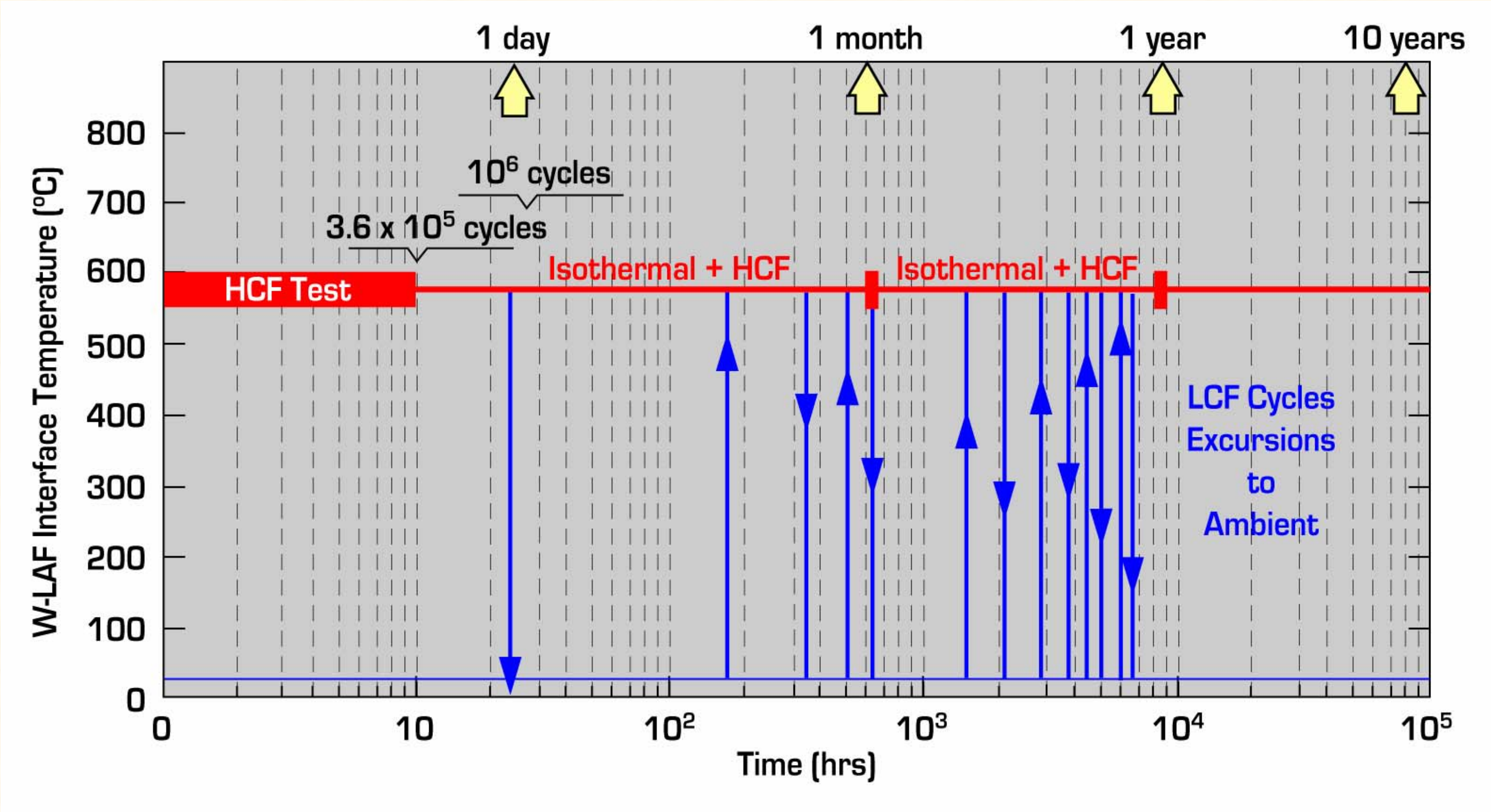
F82H Steel and debris ions are a potential source of carbon that may react at the W surface or the W-F82H interface.

Isothermal Aging of W-F82H Samples
Iron-Tungsten Carbides Formed at Interface

(More relevant interface temperatures were added to the test matrix.)

Temp. (ºC)	Aging Time (hrs)				
	100 (Completed)	1000 (Completed)	2000 (August '05)	3000 (August '05)	4000 (Dec. '05)
550	Temperature Added				
600	No Reaction	No Reaction			
650	Temperature Added				
700	No Reaction	No Reaction			
750	Temperature Added				
800	Fe_{3W3C}	Fe_{3W3C} Fe_{6W6C}	Temperature Discontinued		
900	Fe_{3W3C} Fe_{6W6C}	Fe_{3W3C} Fe_{6W6C}	Temperature Discontinued		

The durability assessment of W-clad LAF steel must address HCF, LCF, DBTT of W and long term thermochemical stability of the interface.



Current Status

- Vacuum plasma sprayed W on F82H Steel is the principal material candidate. Additional materials, including W-Re alloys, will be provided by Plasma Processes Inc. Samples are being prepared for interfacial strength measurements by UCLA.

- The thermal fatigue test has been reconfigured to result in a steeper and better controlled temperature gradient across the W-F82H interface. Fatigue tests for durations of 1 million cycles are planned.

- Low cycle fatigue tests will be performed with encapsulated samples in a box oven (100ºC to 700ºC to 100ºC) at a 4 cycle/day frequency.

- Long-term stability of the interface is required. Isothermal aging experiments are underway to assess the thermochemical stability of the interface for times as long as 4000 hours.