Fracture of Tungsten in a HAPL Chamber

Jake Blanchard

HAPL MWG

Fusion Technology Institute

University of Wisconsin

September 2003

Outline

- Latest results for crack propagation in tungsten-coated steel walls
- Thoughts on how to measure mass loss in samples

Introduction

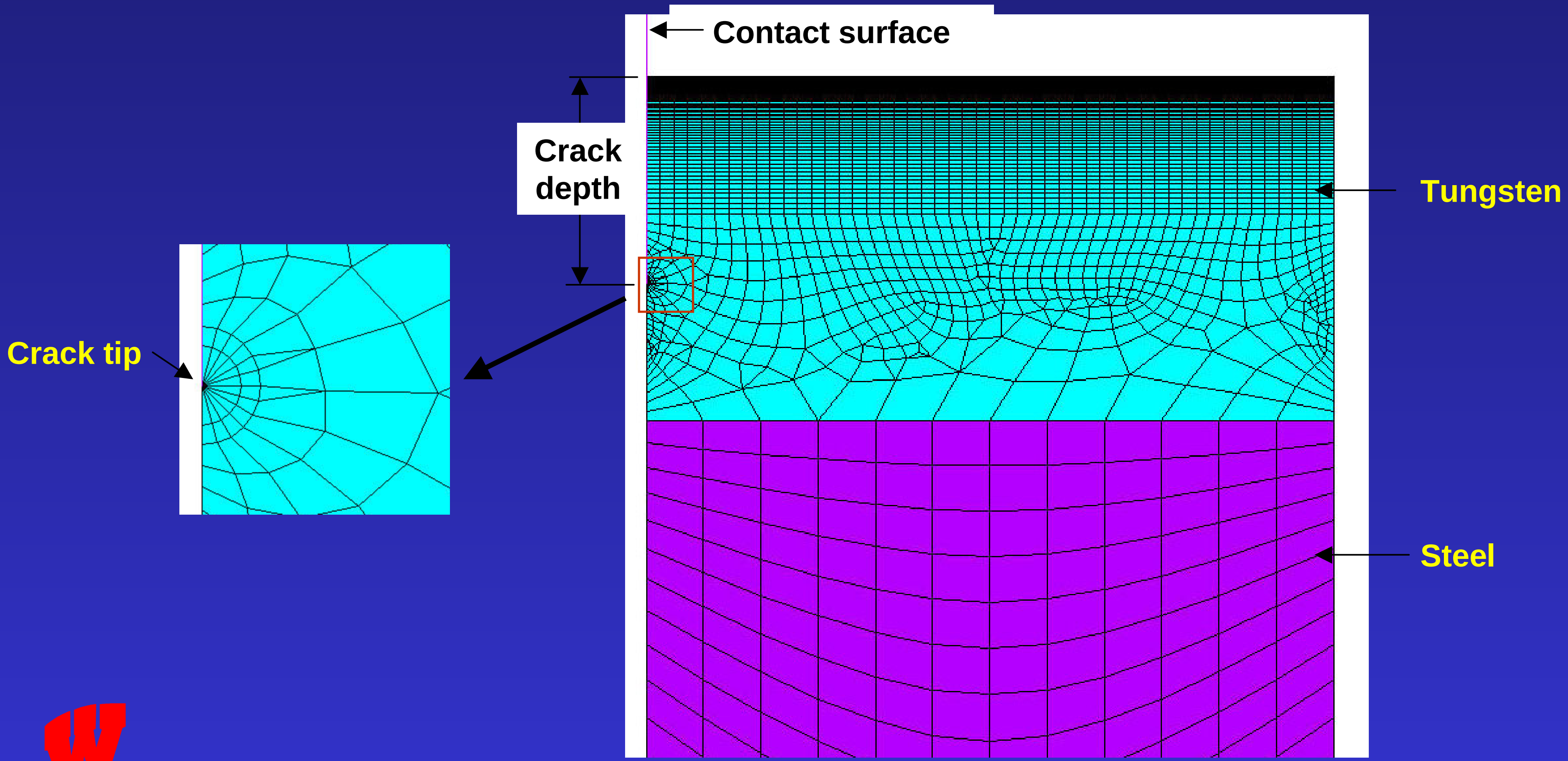
- In Albuquerque, I presented a fatigue analysis for a tungsten-coated, steel HAPL wall
- This analysis indicated that surface cracking can be expected within the first hour of operation
- This does not tell us whether cracks will reach the steel (this requires fracture mechanics)

Approach

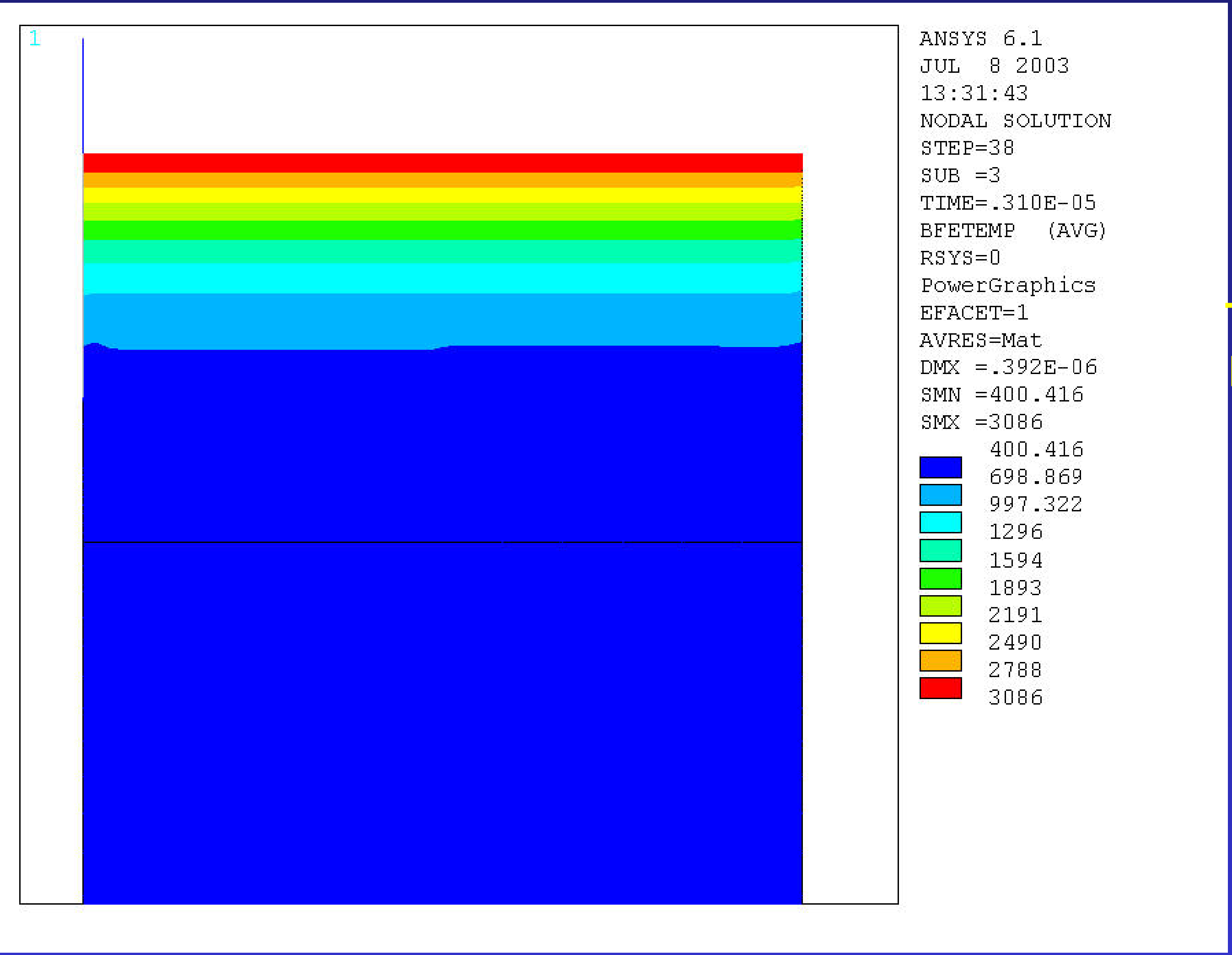
- Place crack into structural model and calculate stress intensity factor for several crack depths
- If stress intensity goes to 0, cracks will stop
- Otherwise, the stress intensity determines the crack growth rate (per cycle)
- Unfortunately, no crack growth data for tungsten has been found

Fracture Mechanics Analysis of Tungsten Coating

Crack tip stress intensities during thermal cycling calculated using ANSYS J-integral fracture mechanics algorithm



Thermal Response of Structure

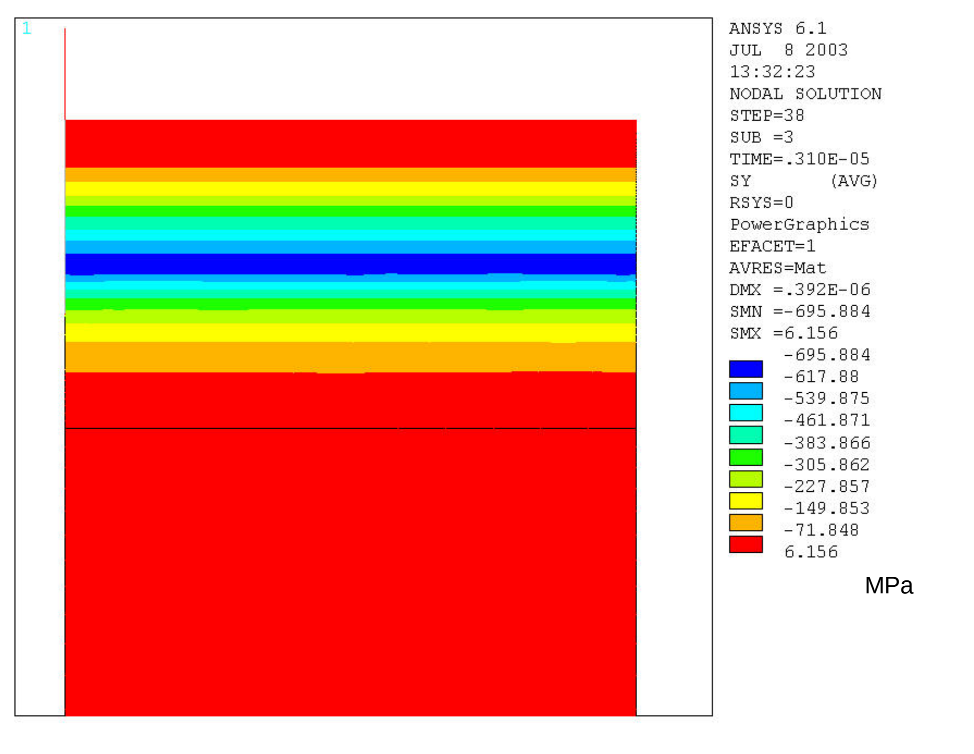


Temperature Contours Near Surface at end of Pulse

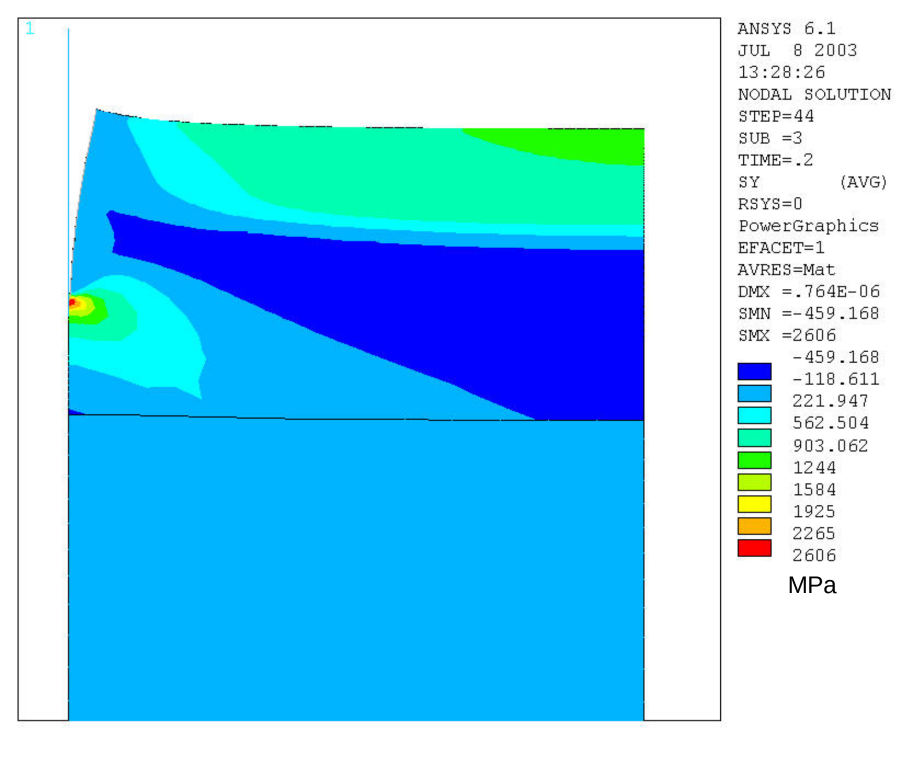
6.5 m chamber
154 MJ target
No gas
50 microns W

Stresses Resulting from Thermal Cycle

Stresses at Maximum Temperature



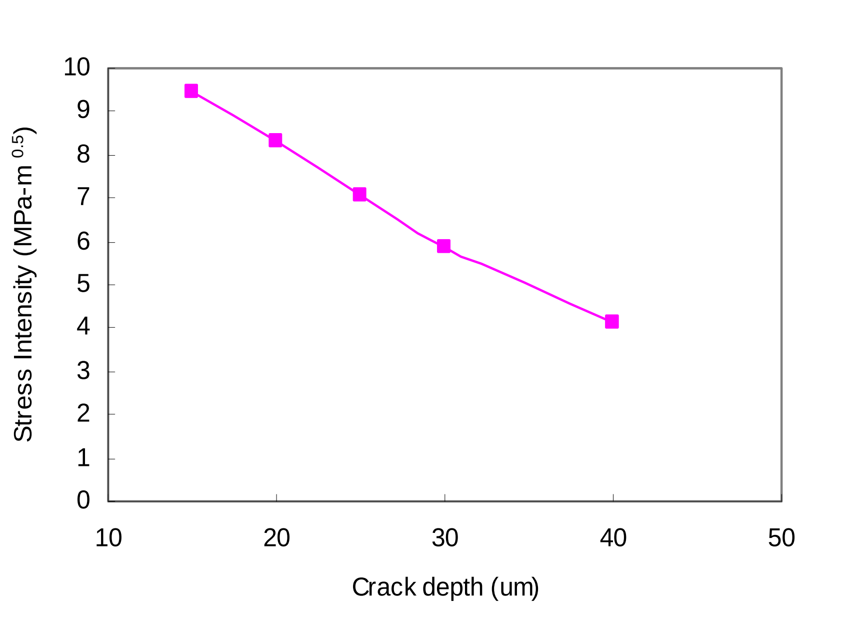
Stresses After Cool Down



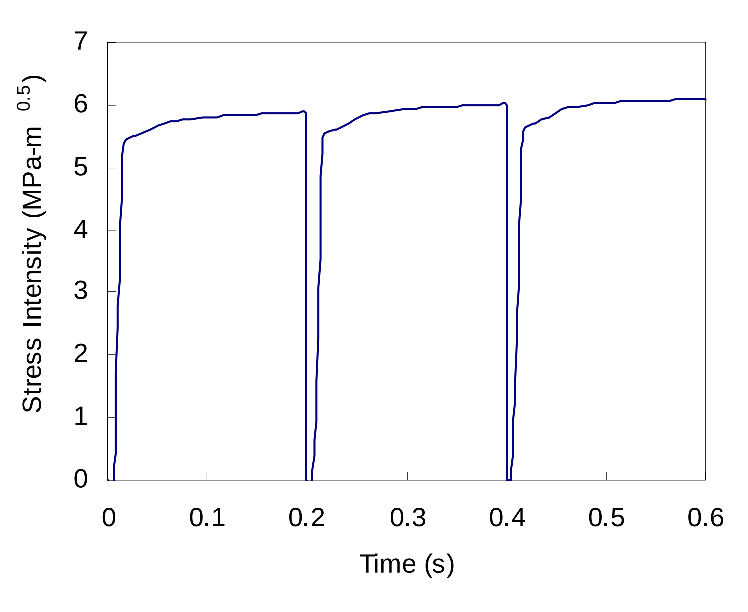
Fracture Mechanics Analysis Results

- **Maximum stress intensities occur at end of cycle (when structure is cool).**
- **Stress intensity decreases with increasing crack depth**

Stress Intensity vs. Crack Depth After One Thermal Cycle



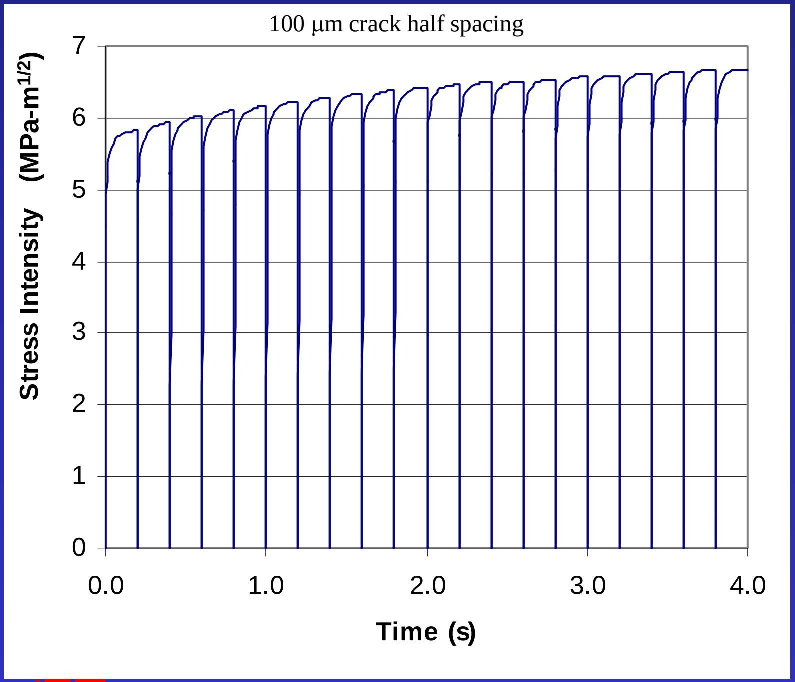
Transient Stress Intensity (30 μm Crack Depth)



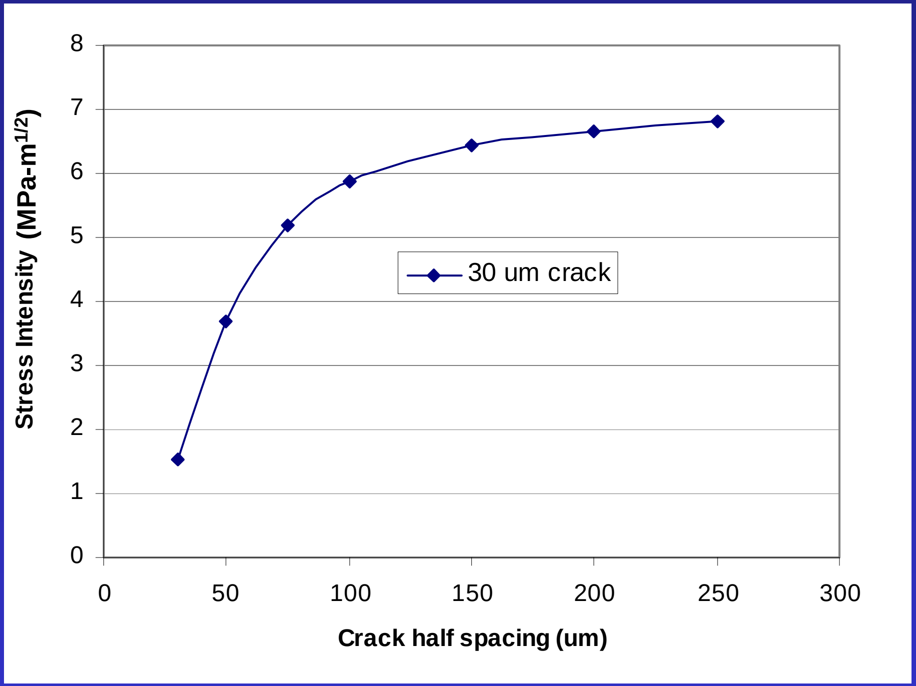
Crack Tip Stress Intensity Variation with Time and Crack Spacing

Stress intensity for a 30 μm crack in a 50 μm thick tungsten layer

Variation of Stress Intensity for a 30 μm Crack over 20 Thermal Cycles



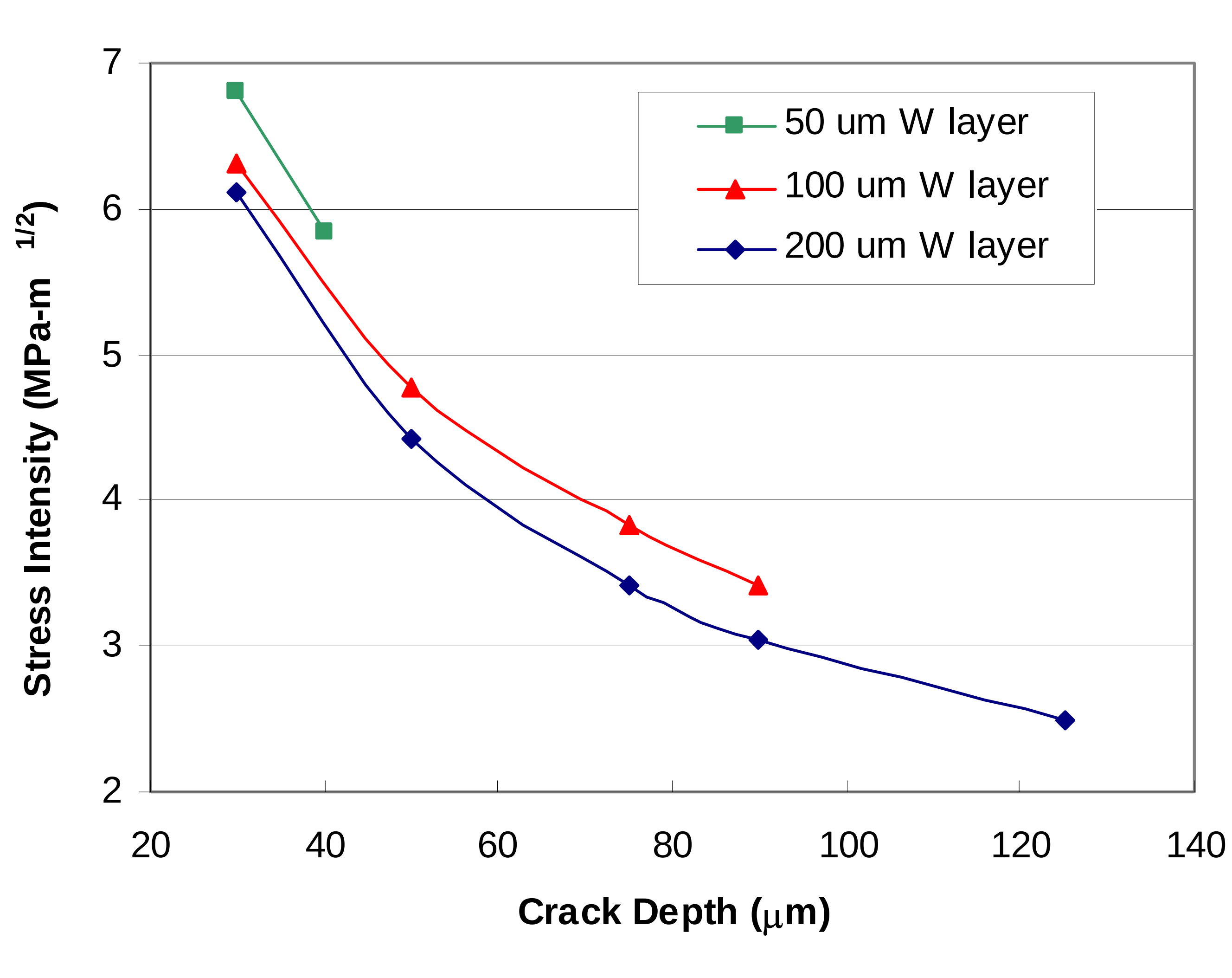
Variation of Stress Intensity with Crack Spacing for a 30 μm Crack (Single Cycle)



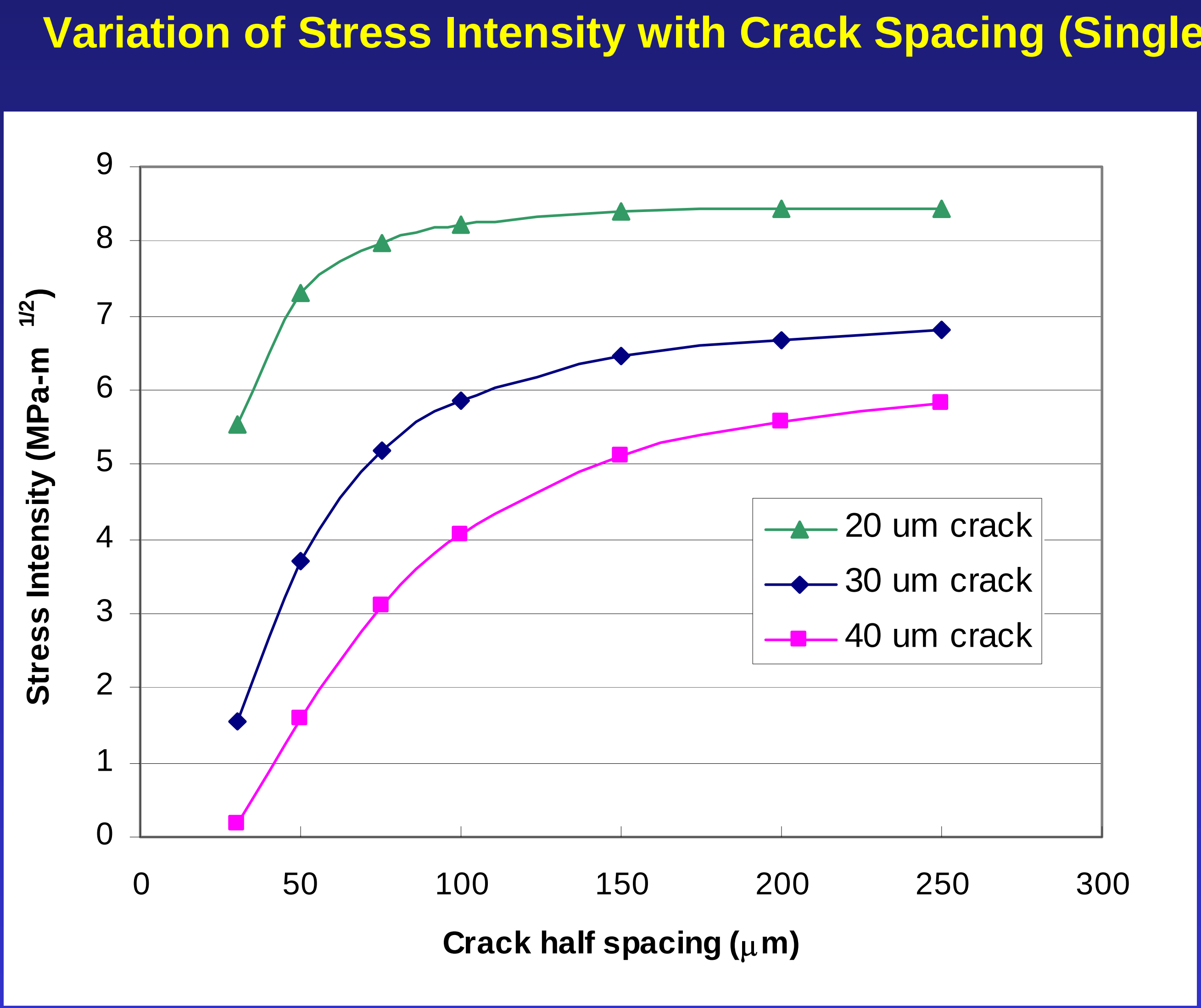
Stress Intensity Variation with Crack Depth

50, 100, and 200 μm Tungsten coating thicknesses

500 μm crack half spacing – single thermal cycle



Crack Tip Stress Intensity Variation with Crack Spacing



50 μm thick tungsten layer

Next Step

- What if crack reaches steel?

Stresses in Steel

- As long as we avoid yielding in the steel, the stress will always be compressive
- Hence, fatigue is not an issue and we can just compare the steel stress to the allowable stress (factoring in yielding, creep, etc.)

Allowable Stresses

Temperature (C)	Allowable Stress (MPa)
500	268
650	133
700	111

Latest Results

Chamber radius (m)	Xe Pressure (mTorr)	Target Yield (MJ)	W Thickness (micron)	Peak W Temp in 4 cycles (C)	Peak Steel Temp in 4 cycles (C)	Steel Temp Swing (C)	Peak Steel Stress (MPa)	Steel Stress Swing (MPa)
6.5	10	154	100	2510	550	130	-438	410
6.5	10	154	167	2510	510	85	-300	270
6.5	10	154	250	2510	480	59	-210	180
7.5	10	154	100	1840	520	100	-330	310
7.5	10	154	167	1840	480	65	-230	210
7.5	10	154	250	1840	460	45	-160	140
7.5	10	154	500	1840	440	18	-80	55
7.5	10	300	500	3190	470	35	-150	110
8.5	10	300	167	2410	520	96	-340	310
8.5	10	300	250	2410	490	65	-240	100
9.5	0	300	167	2480	510	88	-310	280
9.5	0	300	250	2480	480	59	-212	180
9.5	10	300	167	1890	500	78	-270	250
9.5	10	300	250	1890	480	53	-190	160

Designs That Work

150 MJ	6.5 meter radius 10 mTorr Xe 250 microns W
300 MJ	8.5 meter radius 10 mTorr Xe 250 microns W

Conclusions

- Tungsten will crack and cracks may well reach the steel (results are inconclusive)
- Modeling a crack which has reached the steel may not be of any benefit
- Experiments will be the key
- Steel stress requirements lead us to tungsten thicknesses on the order of 250 microns

How to Measure Mass Loss

- Weigh Samples before and after
- Measure Remaining Thickness of Armor (Profilometry, Auger, RBS)
- Measure What Comes Off (Spectrometry/RGA)
- Measure velocity of vapor cloud (shadowgraphy or similar)
- Put layer of trace element at fixed depth