Comparing the Exposure Experiments

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Introduction

- HAPL has three major exposure experiments
  - RHEPP – ions
  - XAPPER – soft x-rays
  - Dragonfire – laser
- …and two additional ion experiments
  - UNC beamline
  - UW IEC

Hypothesis

- Damage in HAPL chamber walls will be thermomechanical in nature
- Since surface is totally constrained, stress and strain depend only on temperature rise, all 3 experiments should lead to similar damage for similar temperature rise
- If this is proven, then these results will allow us to predict behavior under IFE conditions

Experimental Approach

- Baseline case:
  - Start at 600 C
  - Select input power such that peak temperature is 2400 C
- Run other cases, varying start temperature and rise
- Compare surface effects
- Then assess potential differences

FACILITY	Initial temp °C	Peak temp °C	ΔT °C	Shots	Description
RHEPP	20	1400	1380	2000	No change in surface roughness for 2000 shots = 0.02 μm RMS
	20	1690 (2280 peak)	1670	2000	Roughness increases to 2 μm RMS in 450 shots, constant after
	520	2280 (2830 peak)	1760	2000	Roughness increases to 2 μm RMS in 450 shots, constant after
	20	3100	3080	2000	Roughness increases to 4 μm RMS in 400 pulses, constant after
	600	3575	2975	1000	Roughness increases to 4 μm RMS in 400 pulses, constant after
DRAGONFIRE	100	1800	1700	10^5	In all cases see surface roughening. RMS has not been quantified yet. Any given degree of roughening occurs faster with higher ΔT, independent of initial temp
	600	2300	1700		
	100	2500	2400		
	100	2000	1900		
	100	1500	1400		
XAPPER	600	1800	1200	50,000	No roughening
	600	2500	1900	50,000	Roughening

Indications

- RHEPP data is consistent with theory of thermomechanical damage
- So are Dragonfire and XAPPER data (qualitatively)
- RHEPP data indicate 1400 C is clearly OK; saturation seen in other runs may allow peak temperatures well over 2000 C

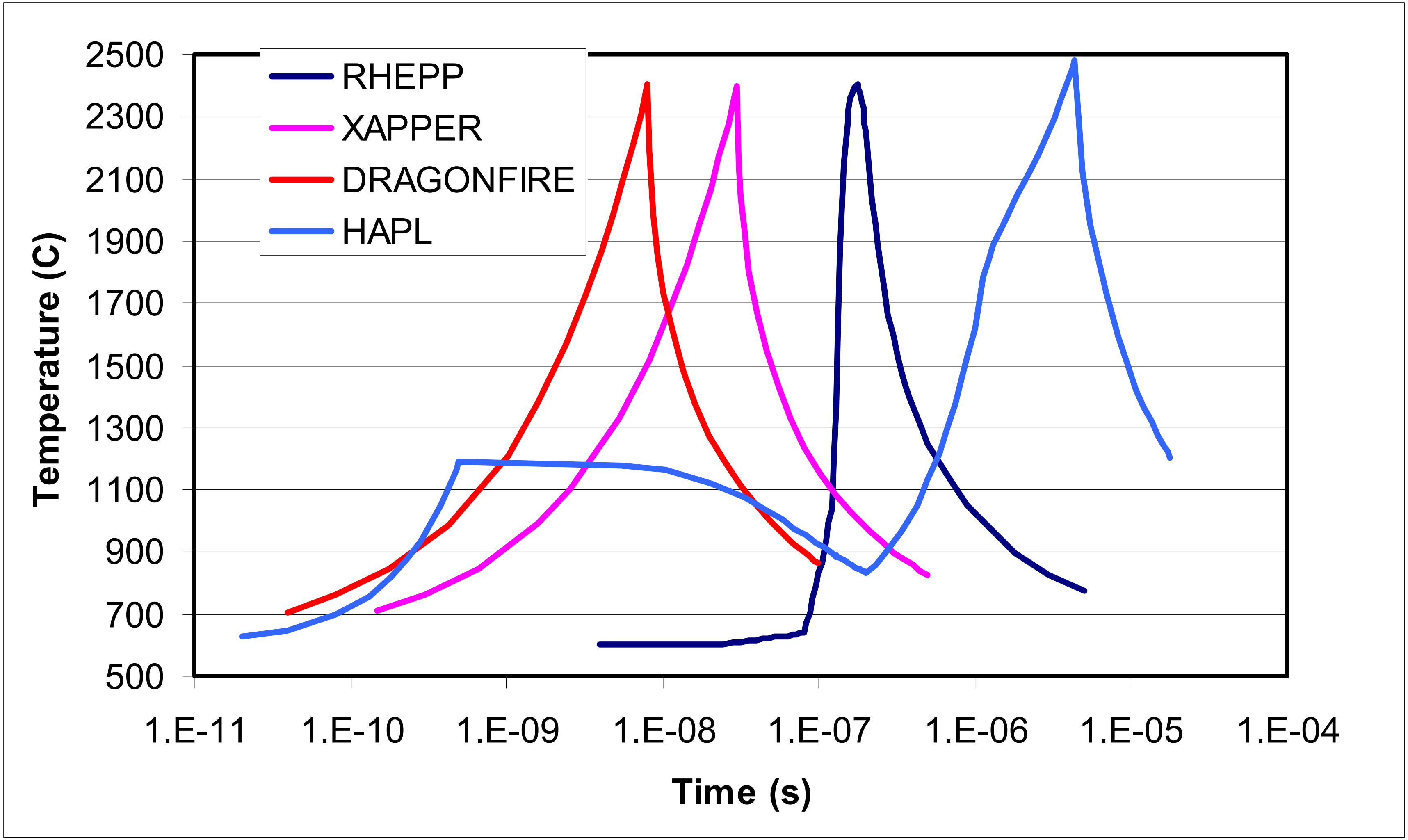
Possible Explanations for Differences

- Real Effect
  - Time-at-temperature differences (recrystallization, defect diffusion, etc.)
  - Ion damage (enhanced diffusion, property changes)
  - Elastic waves (more severe for shorter pulses)
  - Strain gradients are different (affected volumes differ)
- Experimental
  - Inconsistent characterization
  - Inconsistent vacuum
  - Contamination
  - Overheating

Parameters

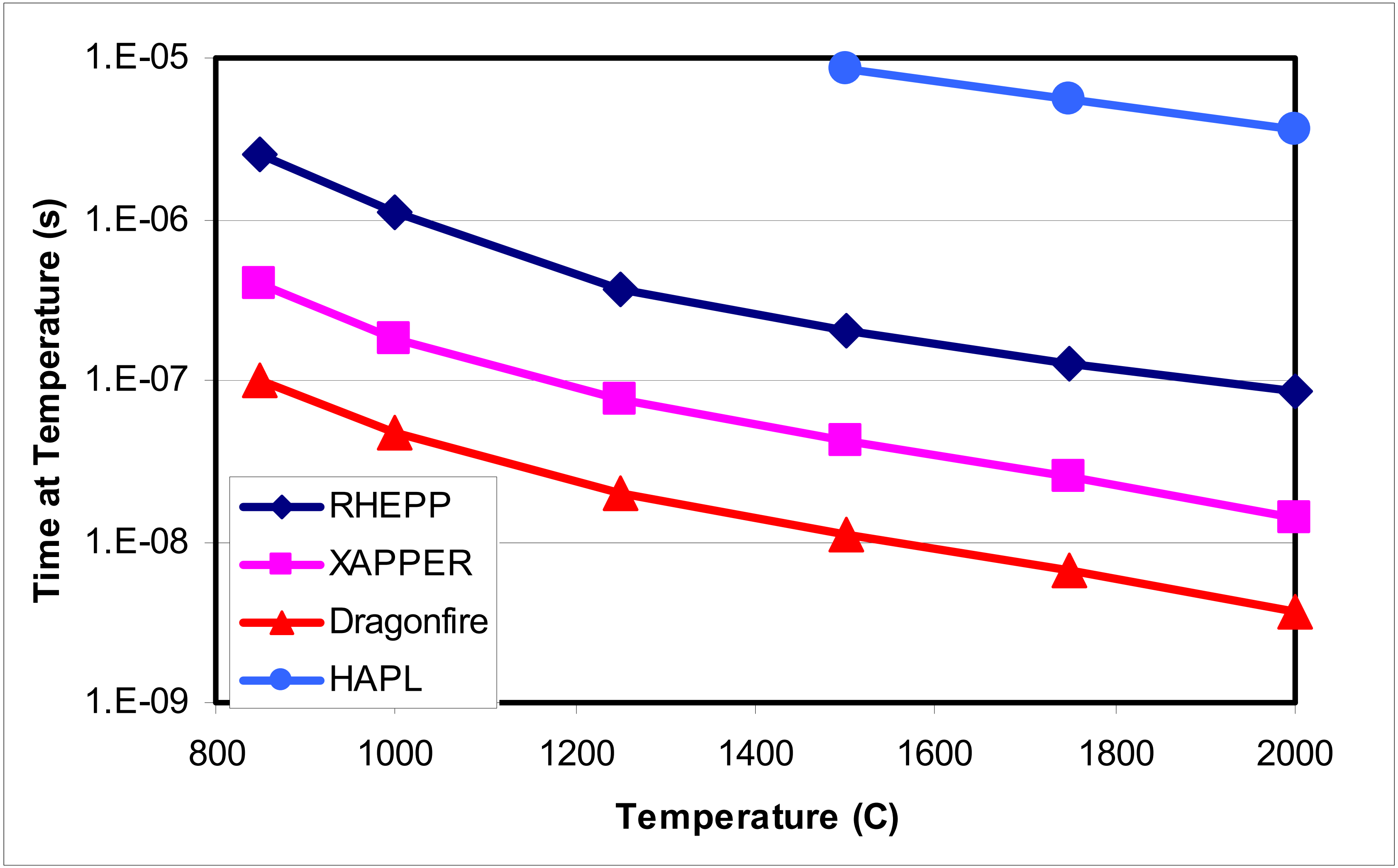
Experiment	Type	Pulse width (ns)	Energy (keV)	Spot Size (mm)	Rep Rate (Hz)
RHEPP	Ions	~100	500-850	10x60	<0.1
XAPPER	X-Rays	~40	<1	0.5 dia.	10
Dragonfire	Laser	~8	1 micron YAG	7 dia.	10

Peak Temp with IFE

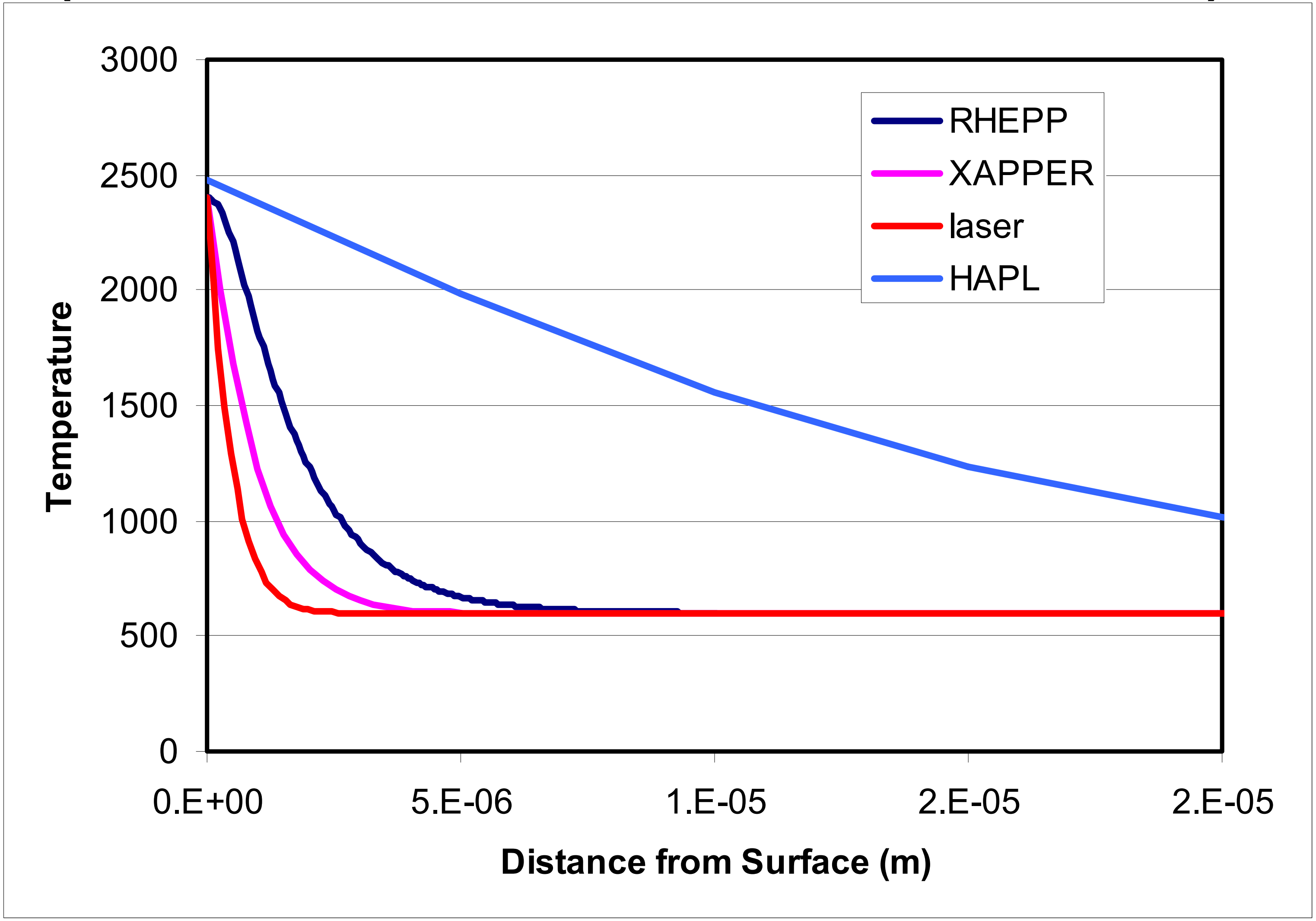


HAPL conditions are 350 MJ yield, 10.5 m chamber, no gas

Time at Temperature (single cycle)



Temperatire Profiles (at time of peak temperature)



Data Needs

- Mass loss measurements
- Quantitative roughening measurements from Dragonfire
- Temperature measurements from XAPPER and RHEPP
- Longer pulses
- Shorter pulses
- More pulses

Modeling Needs

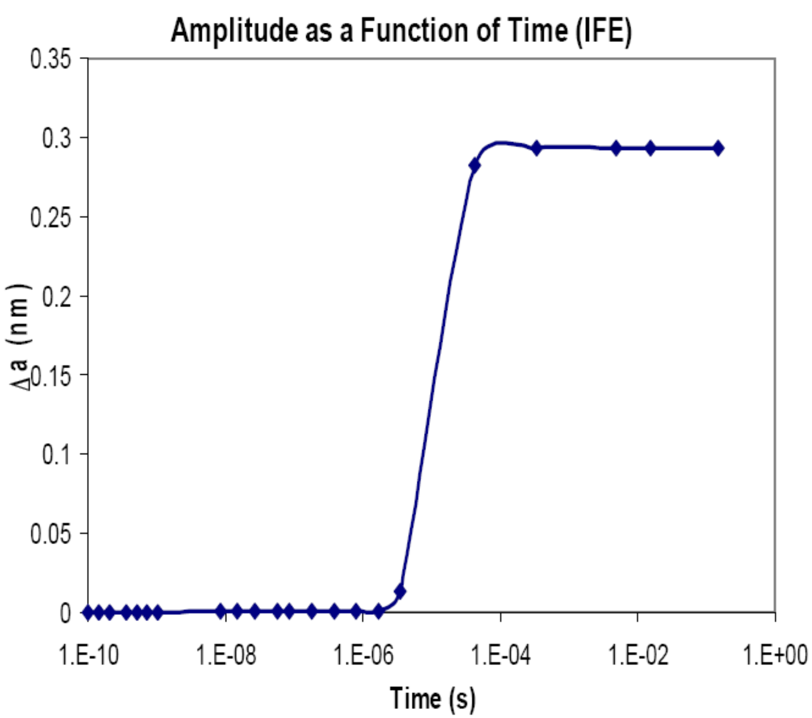
- Waves induced by volumetric heating
- Inelastic waves
- Understanding of time at temperature issues
- Other

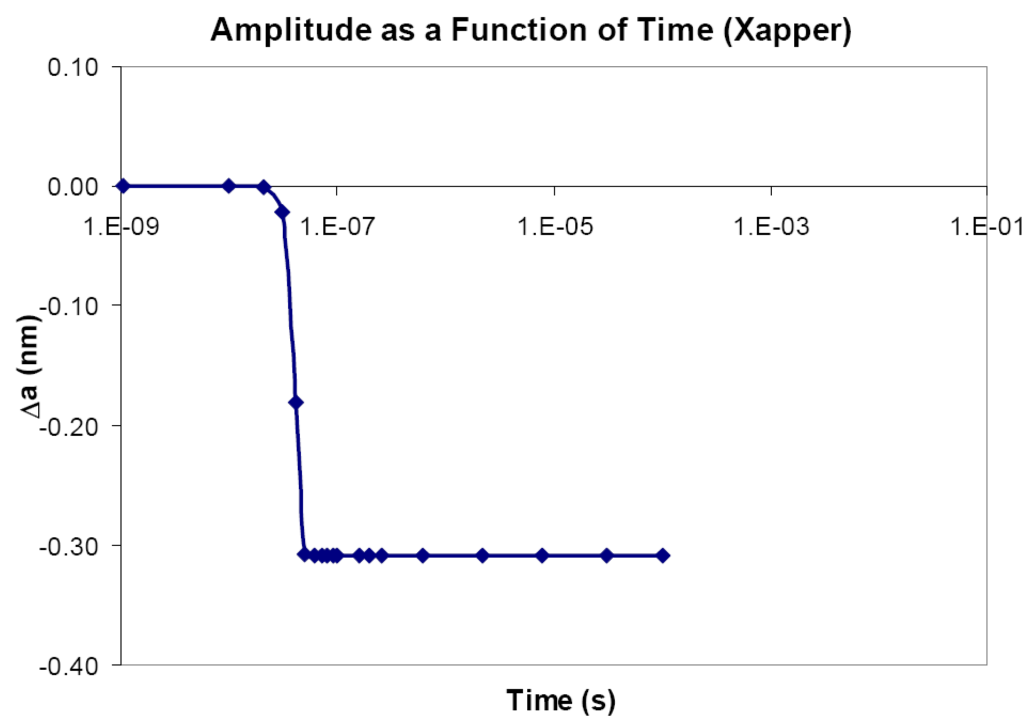
Waves

- Rapid heating launches waves in walls
- Ablation is needed for shock waves
- For surface heating without ablation, stress from wave is always smaller than surface stress from quasi-static model
- For ion heating in HAPL, stress at wavefront is just a few MPa
- For x-rays, wavefront stress is comparable to yield stress

Time at Temperature

- UCLA: “roughening is competition between stress and surface diffusion”
- Both processes are enhanced by time at temperature





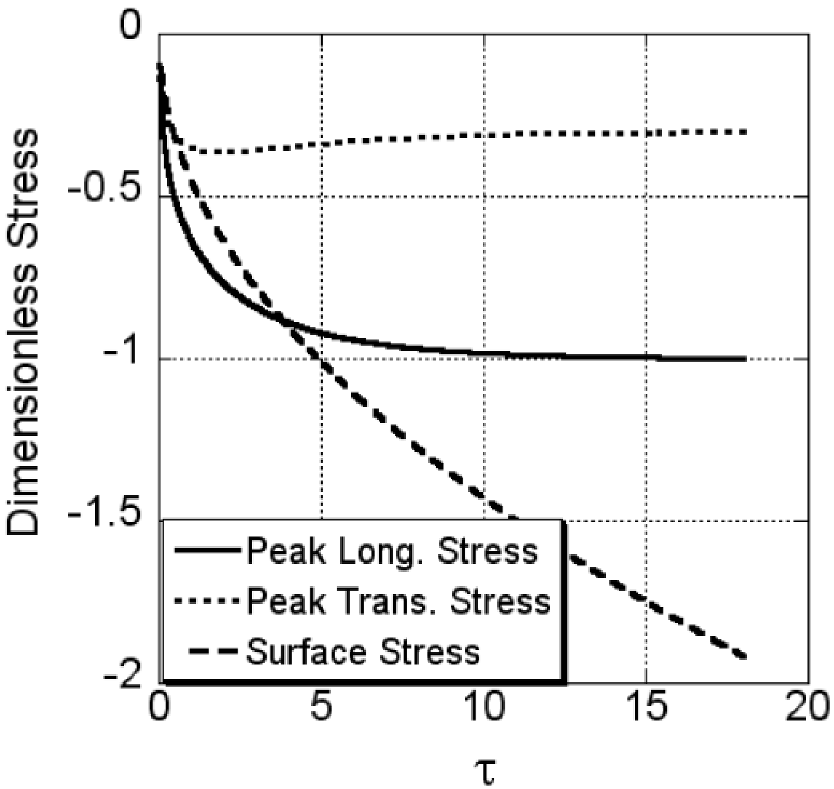
Longer Term Issues

- Neutron damage – property changes
- Ion issues – IEC results, property changes, blistering, embrittlement, compound formation

Conclusions

- Thermomechanical hypothesis is still in question
- 2400 C peak temperature limit (with 600 C initial temperature) may be OK

Elastic Waves Due to Surface Heating



$$\xi = \frac{x}{a} \qquad \phi = \frac{kT}{qa}$$

$$\tau_w = \frac{\kappa t}{a^2} \qquad \hat{\sigma}_x = \frac{(1-2\nu)}{2(1+\nu)} \frac{k\sigma_x}{\alpha\, q a \mu}$$

$$a = \frac{\kappa}{c} \qquad c^2 = \frac{2(1-\nu)\mu}{(1-2\nu)\rho}$$