Thermal Effect of Off-Normal Energy Deposition on Bare Ferritic Steel First Wall

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Power Plant FW Under Energy Deposition from Off-Normal Conditions

- **Thermal impact of off-normal events on power plant FW presented before for SiC and W**
- **Questions arise as to the possibility of utilizing a bare FS FW in a power plant**
- **Thermal effect on FS FW investigated**

Off-Normal Thermal Loads for Analysis with RACLETTE Code

From ITER

(from PID and C. Lowry's presentation at 2007 ITER WG8 Design review Meeting)

- **Disruptions:**
  - Parallel energy density for thermal quench = 28-45 MJ/m^2 near X-point
  - Deposition time ~ 1-3 ms
  - Perpendicular energy deposition will be lower, depending on incidence angle (at least 1 order of magnitude lower)
  - Parallel energy deposition for current quench = 2.5 MJ/m^2
  - For power plant, fusion energy is ~ 4x higher than ITER and the energy deposition will also be higher
  - Parametric analysis over 1-10 MJ/m^2 and 1-3 ms

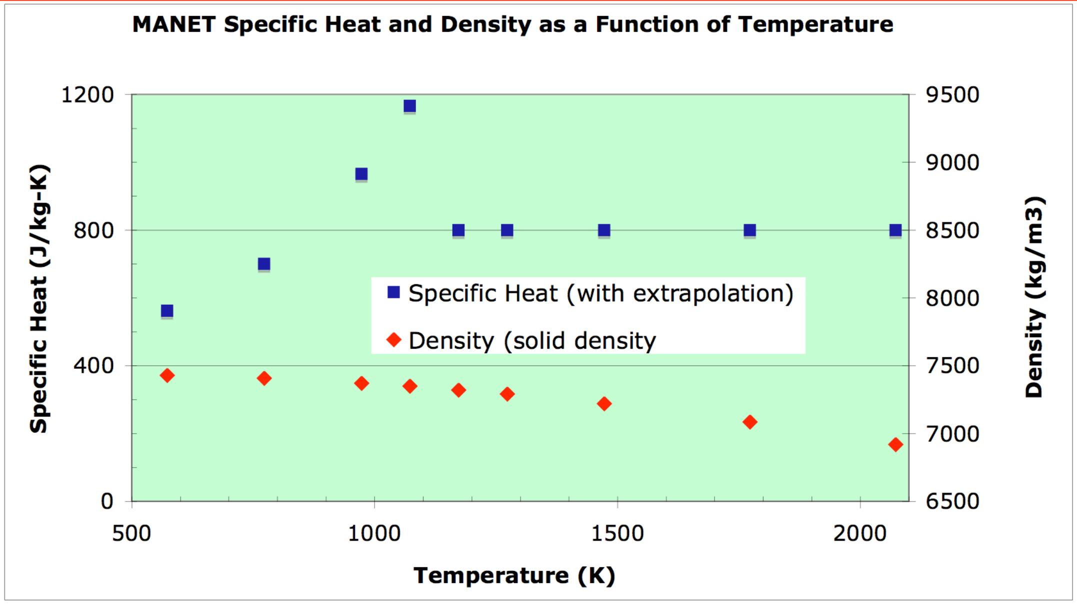
- **VDE's:**
  - Energy deposition = 60 MJ/m^2
  - Deposition time ~ 0.2 s

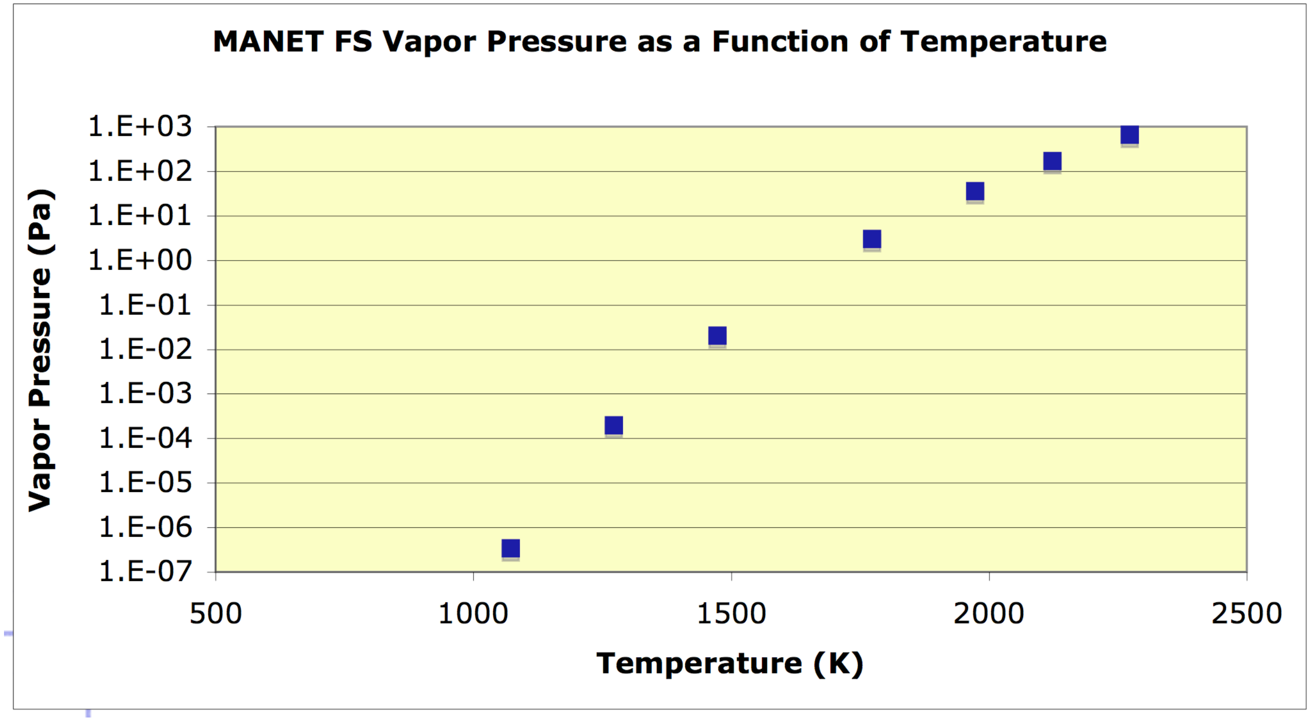
- **ELMS:**
  - Parallel energy density for thermal quench (controlled/uncontrolled) ~ 0.77/3.8 MJ/m^2
  - Deposition time ~ 0.4 ms
  - Frequency (controlled/uncontrolled) = 4/1 Hz
  - Assumed power plant case ~0.3/1.5 MJ/m^2 incident energy deposition over 0.4 ms

Vapor Pressure and Thermal Properties of FS

MANET properties assumed for ferritic steel (from Panayiotis J. Karditsas and Marc-Jean Baptiste)

Heat of evaporation = 7450.4 kJ/kg
Heat of fusion = 269.87 kJ/kg
Melting point = 1450-1530°C
k = 31-33 W/m-K
P_{vap}(Pa) = $10^{(11.118417-18868/T(K))}$





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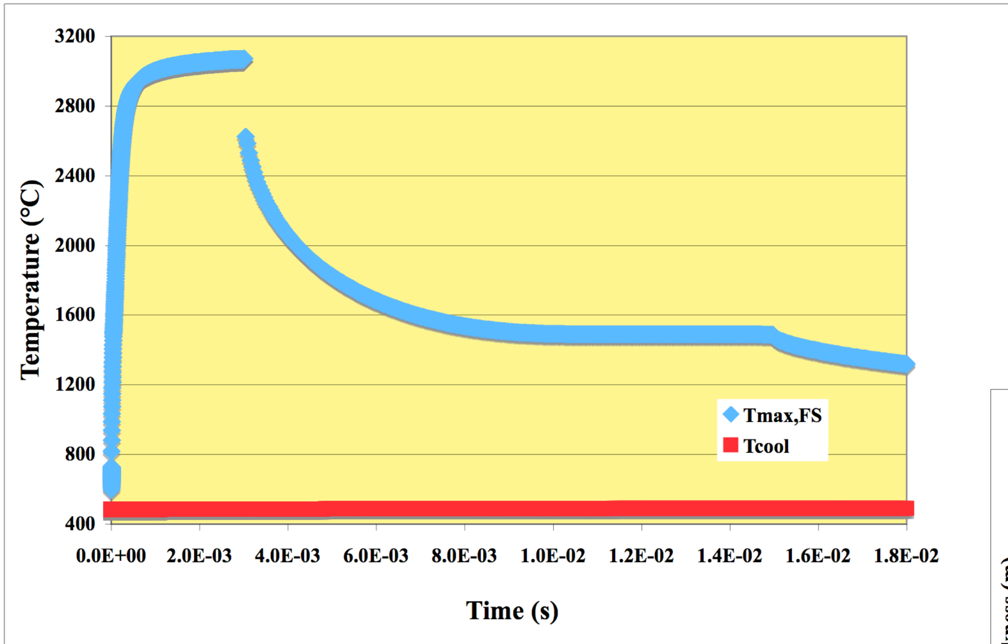
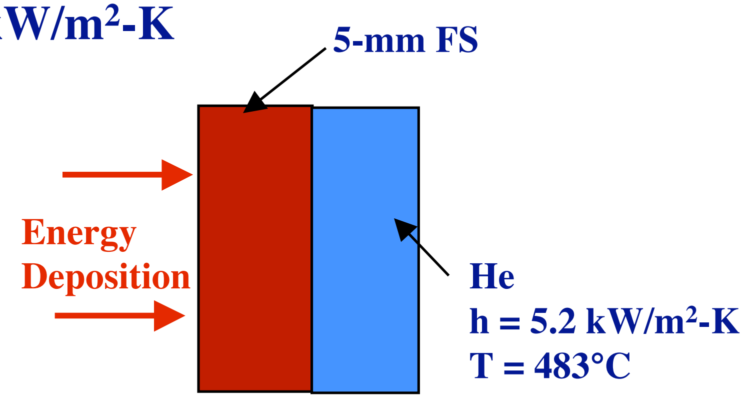
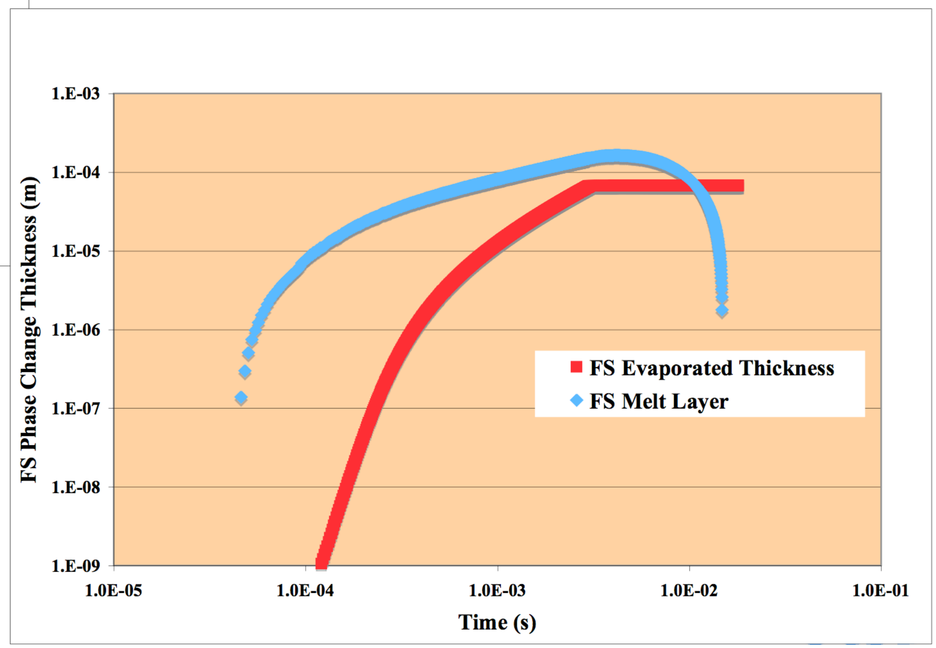
Example Disruption Case for Power Plant with Bare FS FW

- Disruption simulation: $q''=1.667 \times 10^9$ W/m^2 over 3 ms (~5 MJ/m^2)
- 4+1 mm FS FW Cooled by He at 483°C with h = 5.2 kW/m^2-K

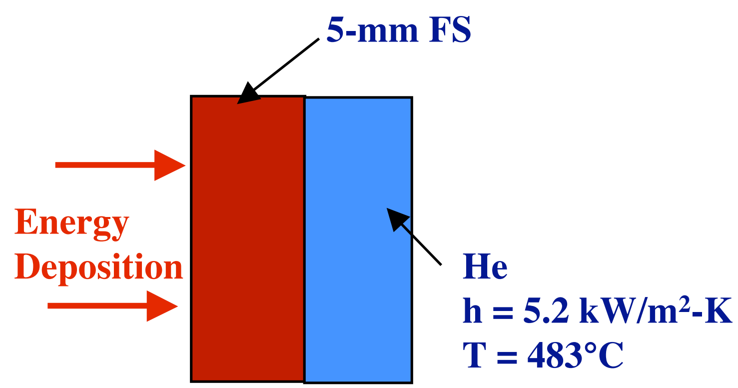


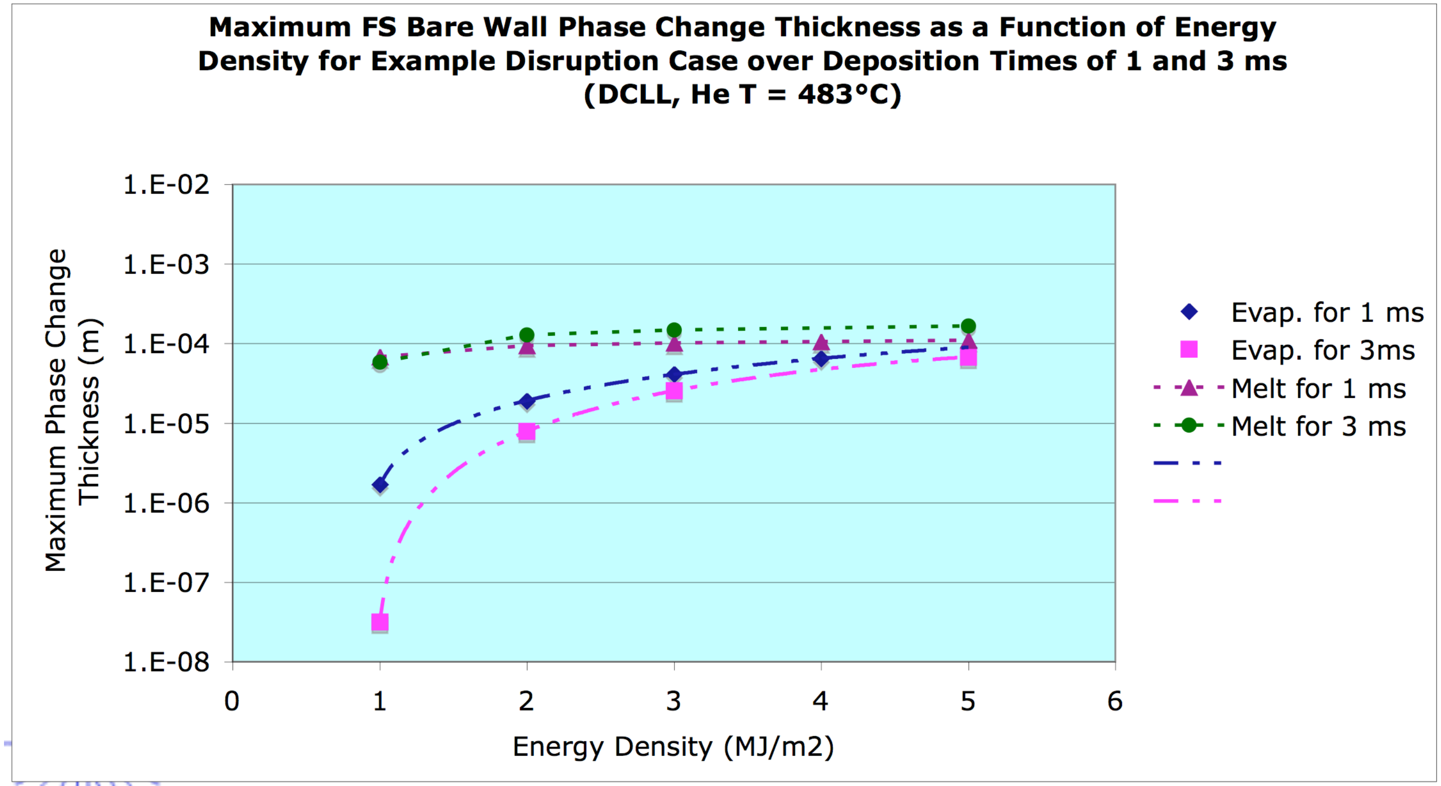




Parametric Study of Maximum Phase Change Thickness of a FS FW Temperature for Different Disruption Scenarios (DCLL Case)

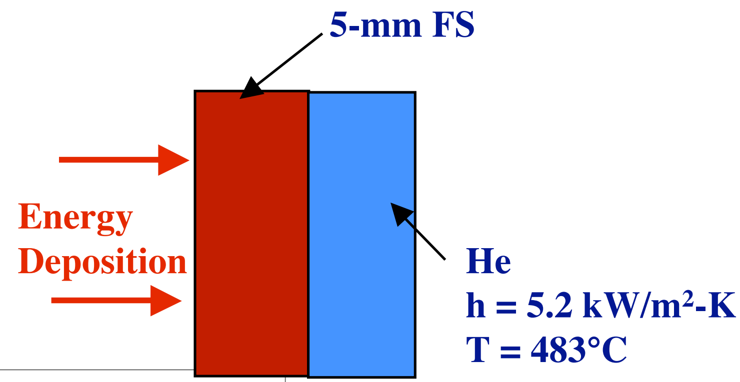
- 4+1 mm FS FW cooled by He at 483°C with h = 5.2 kW/m^2-K
- Up to ~0.1 mm melt layer and ~0.1 mm evaporation loss per event
- Only a few events allowable based on erosion lifetime depending on energy density

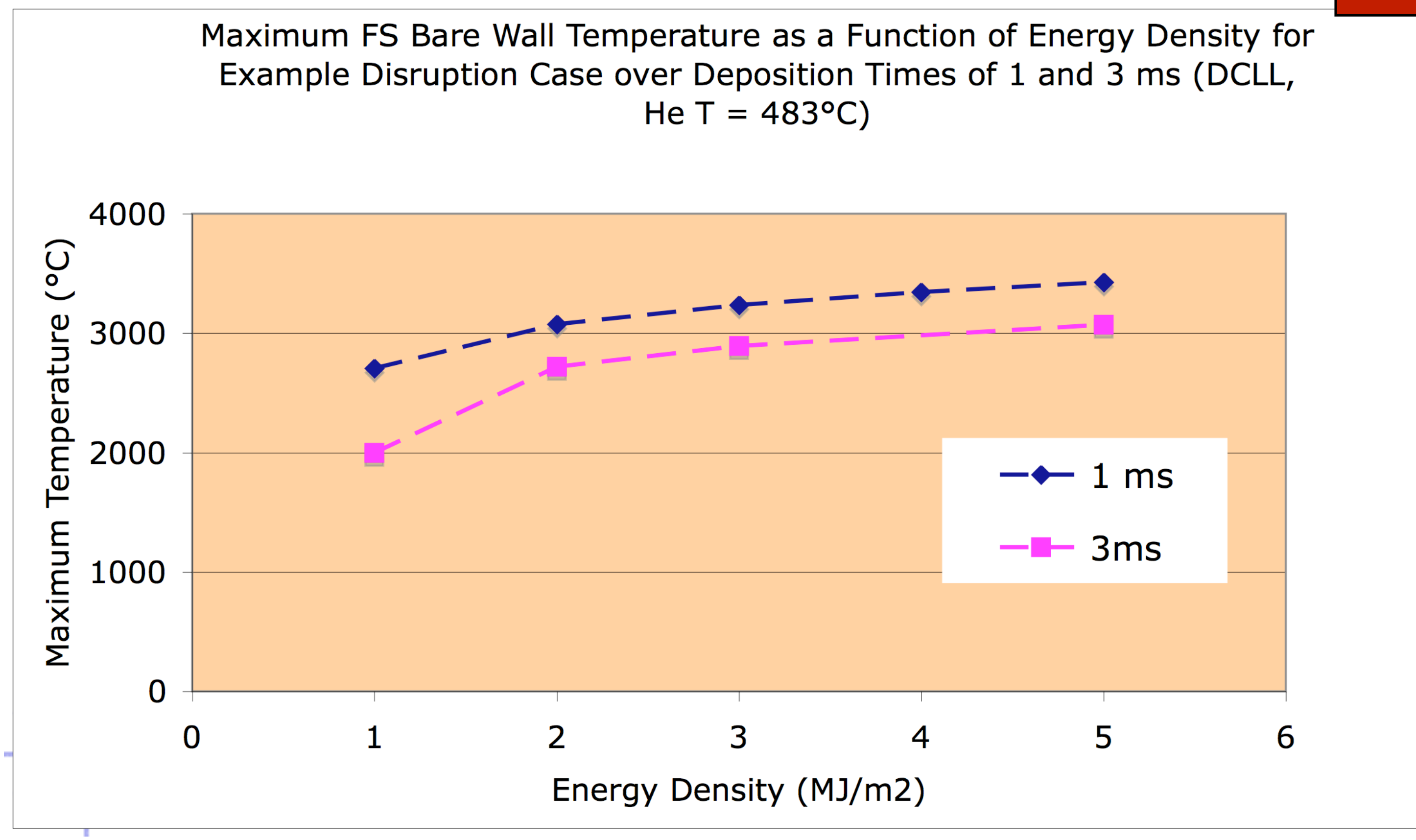




Parametric Study of Maximum Temperature of FS FW for Different Disruption Scenarios (DCLL Case)

- **4+1 mm FS FW cooled by He at 483°C with $h = 5.2\ kW/m^2\text{-}K$**





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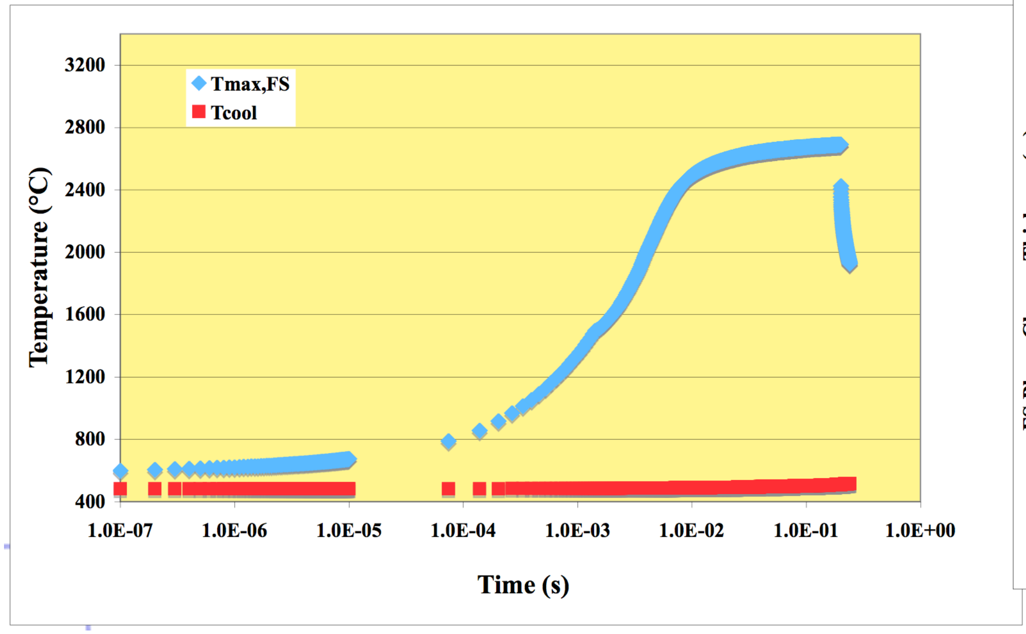
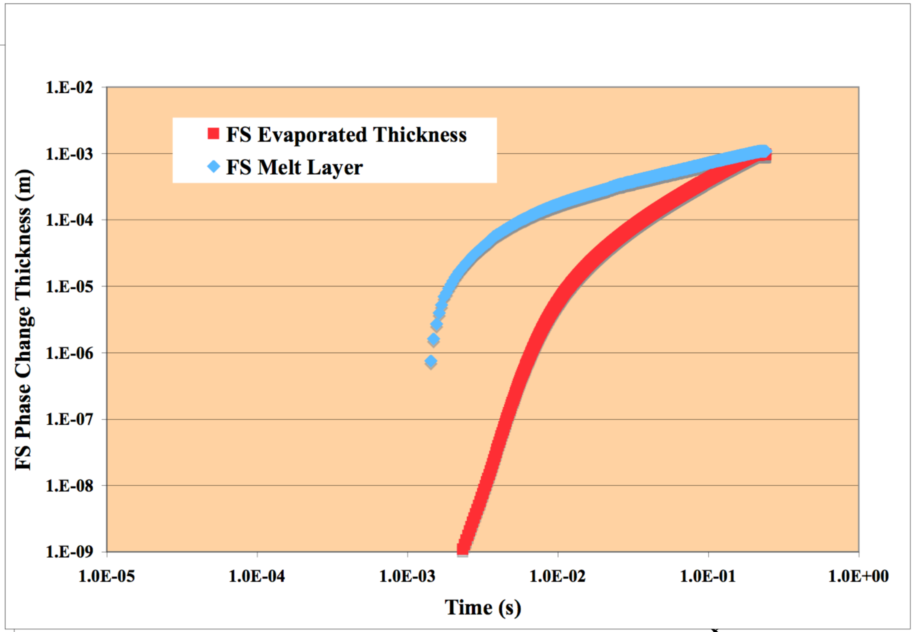
Example VDE Case for Power Plant with FS FW

- VDE simulation: $q'' = 3 \times 10^8$ W/m^2 over 0.2 s (60 MJ/m^2)
- 4+1 mm FS FW cooled by He at 483°C with h = 5.2 kW/m^2-K
- Even 1 event is not acceptable (complete loss of armor)
- Same conclusions previously for W and SiC armor





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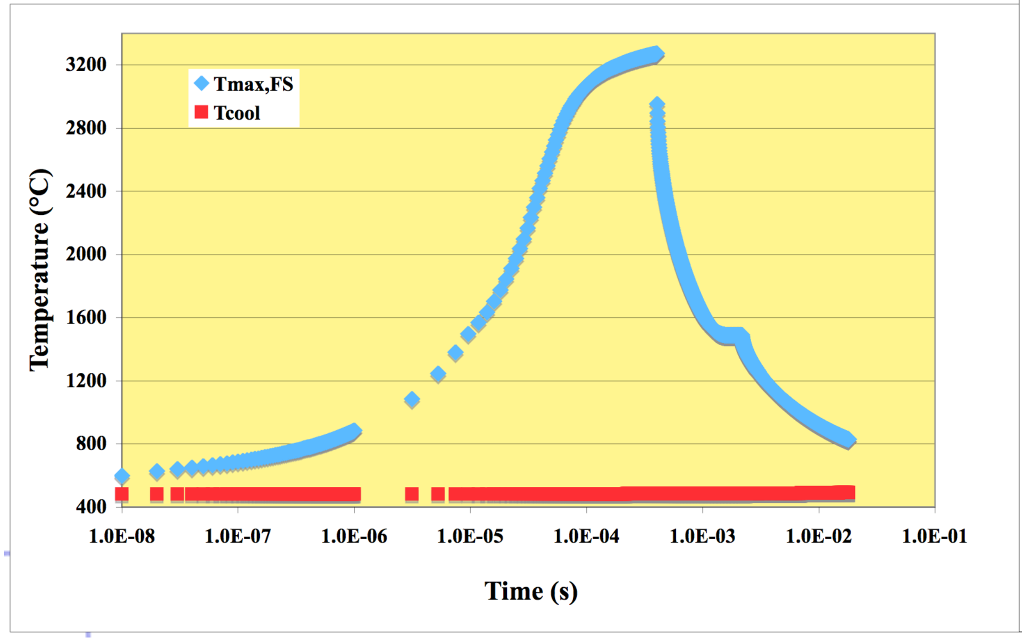
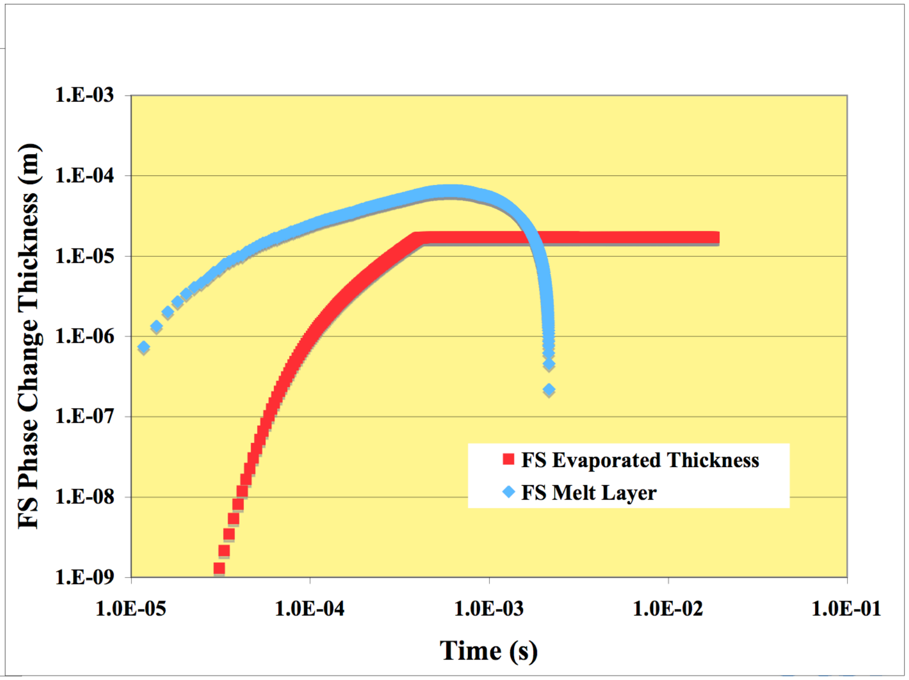
Example Uncontrolled ELM Case for Power Plant with FS FW

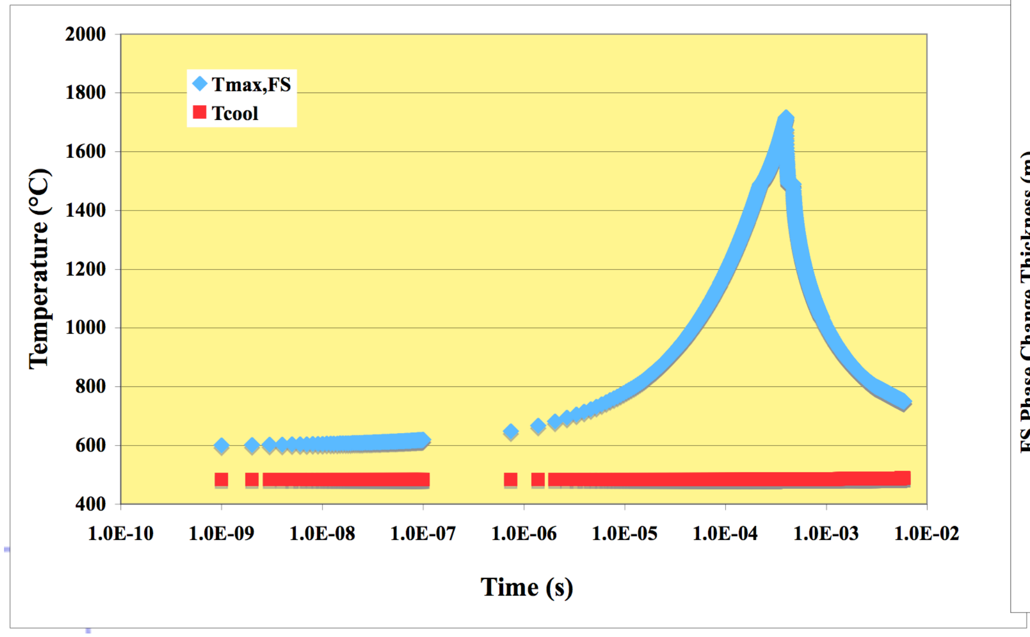
- ELM simulation: q''= 3.75×10^9 W/m^2 over 0.4 ms (1.5 MJ/m^2)
- 4+1 mm FS FW cooled by He at 483°C with h = 5.2 kW/m^2-K
- ~0.1 melt layer and ~0.01 mm evaporation loss per event (1 Hz frequency)
- Not acceptable (complete loss of armor after 10-100 such events)
- From previous study, also not acceptable for SiC (~0.02 mm armor loss per event) and W armor (5×10^{-5} melt layer and 3×10^{-7} evaporation loss per event)

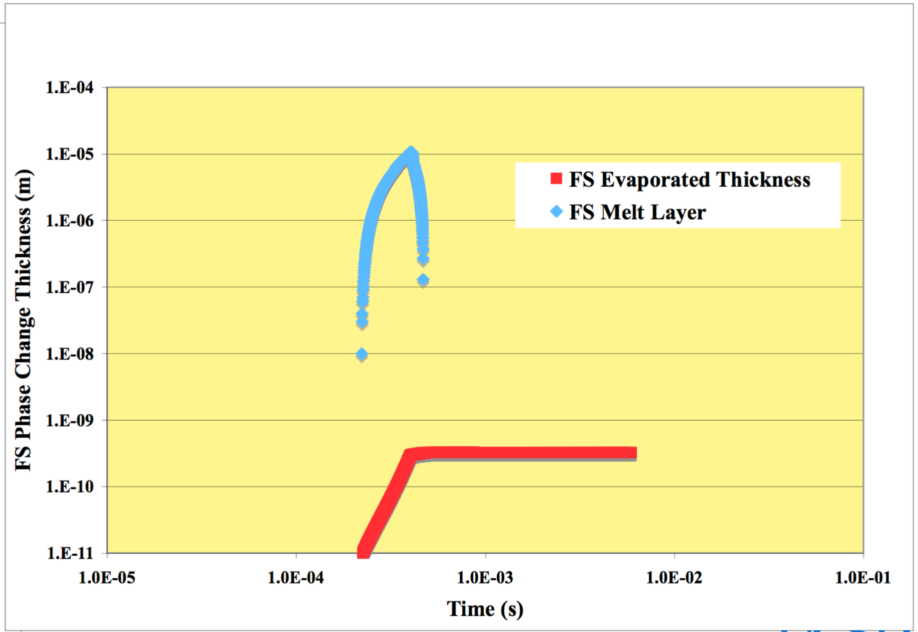




Example Controlled ELM Case for Power Plant with SiC FW

- ELM simulation: q''= 7.5 x 10^8 W/m^2 over 0.4 ms (0.3 MJ/m^2)
- 4+1 mm FS FW cooled by He at 483°C with h = 5.2 kW/m^2-K
- ~10^{-5} m melt layer and and <10^{-9} m evaporated thickness per event (5 Hz frequency)
- Complete loss of 1-mm FS armor after 100-10^6 such events, depending on stability of melt layer (at best ~55 hours if occurring at same location) - Not acceptable
- From previous study, also not acceptable for SiC (~0.08 µm of armor loss per event or ~ 1 month of operation) but probably ok for W armor (T_{max}=1872°C; no melt; 10^{-20} m evaporation loss per event)





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Summary of Assessment of Off-Normal Energy Deposition on FS FW (DCLL like) (based on assumed scenarios)

- Focus on thermal effects
- EM effects will be important for DCLL FS FW
- Only a few disruptions can be accommodated (depending on the energy density)
- VDE cannot be accommodated
- Only limited number of uncontrolled ELM cases can be accommodated
- Controlled ELM's would drastically limit the lifetime of FS armor (a few days) but might be acceptable for W armor based on previous study