Power Core Engineering: Design Updates and Trade-Off Studies

A. René Raffray

University of California, San Diego

ARIES Meeting
Georgia Tech., Atlanta, GA
December 12-13, 2007

Engineering and Trade-Off Studies

- Power cycle choice: Rankine vs Brayton (done, UCSD)
- Impact of tritium breeding requirement on fuel management and control (done, UW/UCSD)
- Evaluation of different He-cooled divertor concepts based on thermo-mechanical performance and initial reliability assessment (in progress, UCSD/INL/Georgia Tech.)
- Assessment of off-normal conditions for a power plant
  - how to avoid disruptions and other off-normal events (in progress, GA)
  - impact of off-normal events on power plant (thermal impact presented here, UCSD)
- Impact of design choice on reliability, availability and maintenance (L. Waganer)
- Lead lithium based blanket as example development pathway (DCLL design updates and discussion at this meeting)

Vapor Pressure and Heat of Dissociation of SiC

Heat of sublimation of Si = 454 kJ/mol (108.4 kcal-mol^{-1})

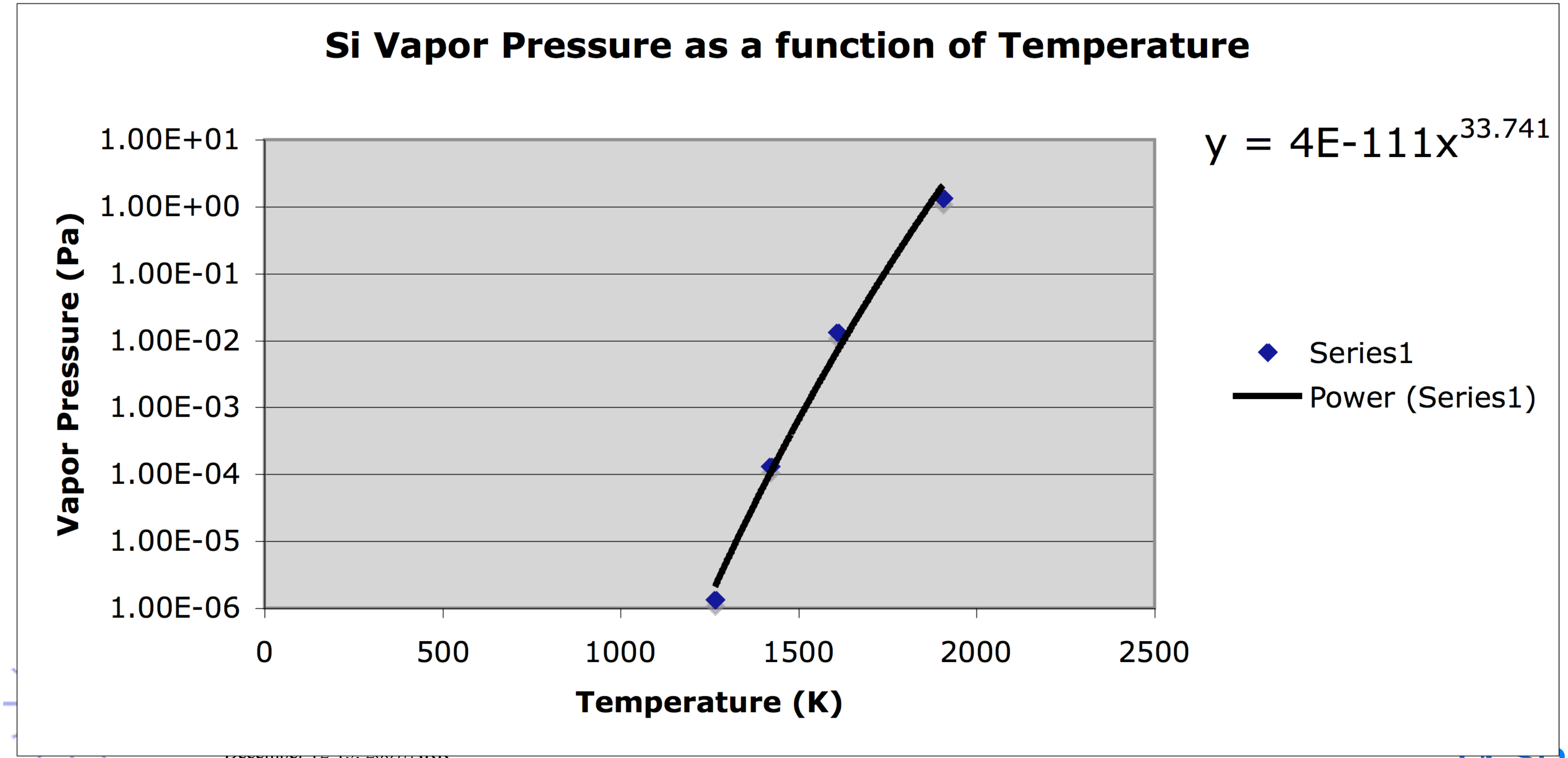
(from S. G. Davis, et al., Journal of Chemical Physics, Vol. 34, No. 2, p659-663, Feb 1961)

Heat of formation of SiC = 62.85 kJ/mol (15 kcal-mol^{-1})

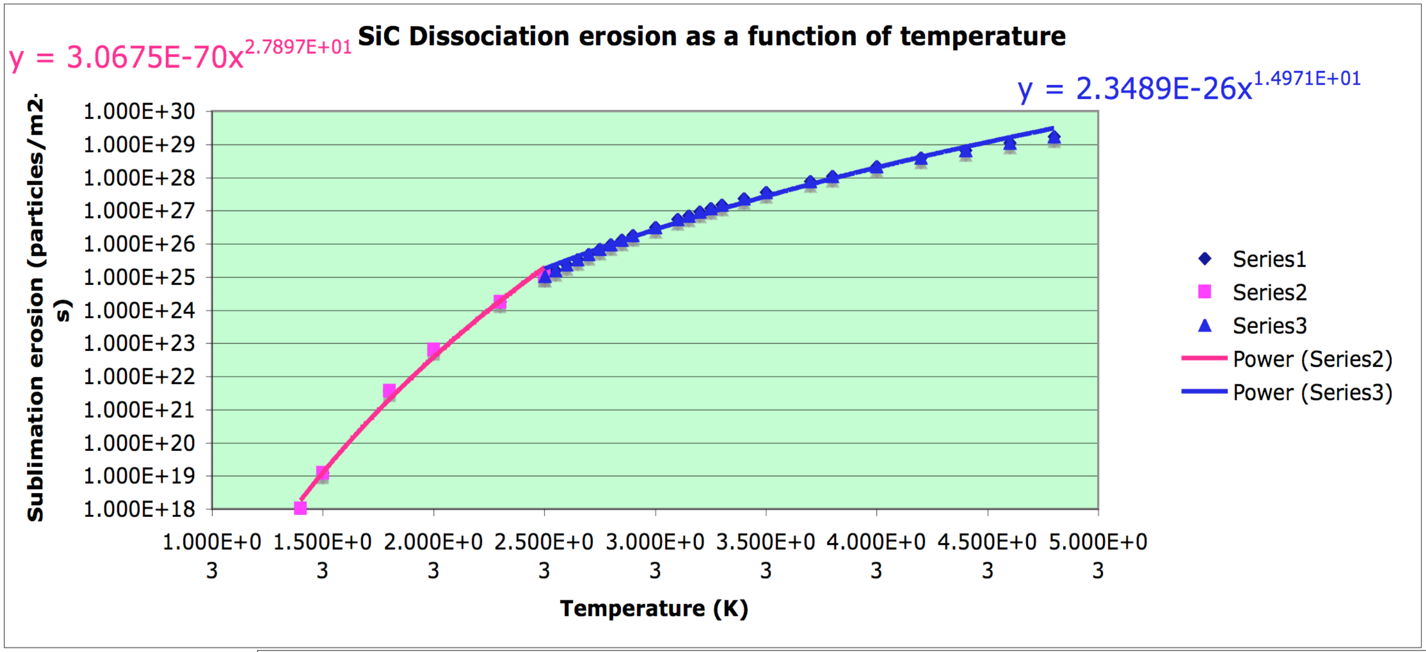
Heat of dissociation of SiC = 516.9 kJ/mol

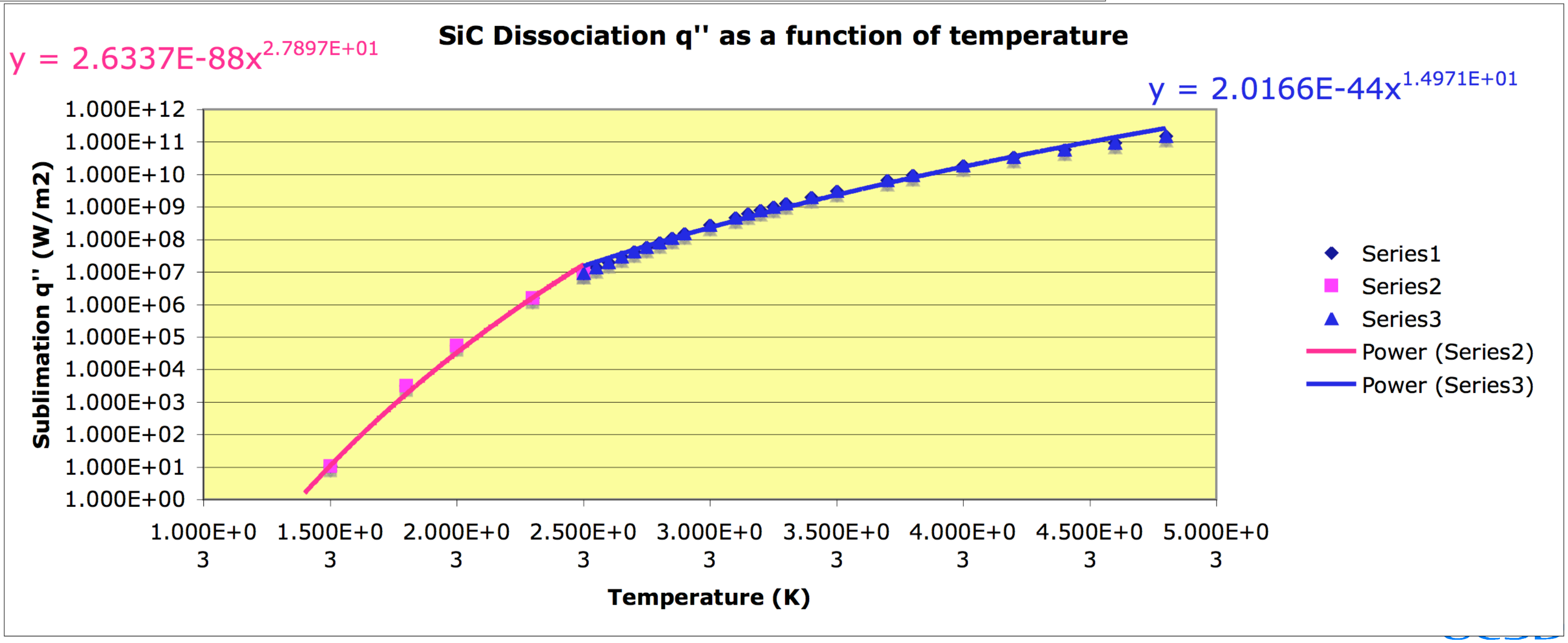
Si melting point/boiling point= 1412°C/2355°C

C sublimation point >3500°C



SiC Dissociation





Off-Normal Thermal Loads for Analysis with RACLETTE Code

From ITER

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

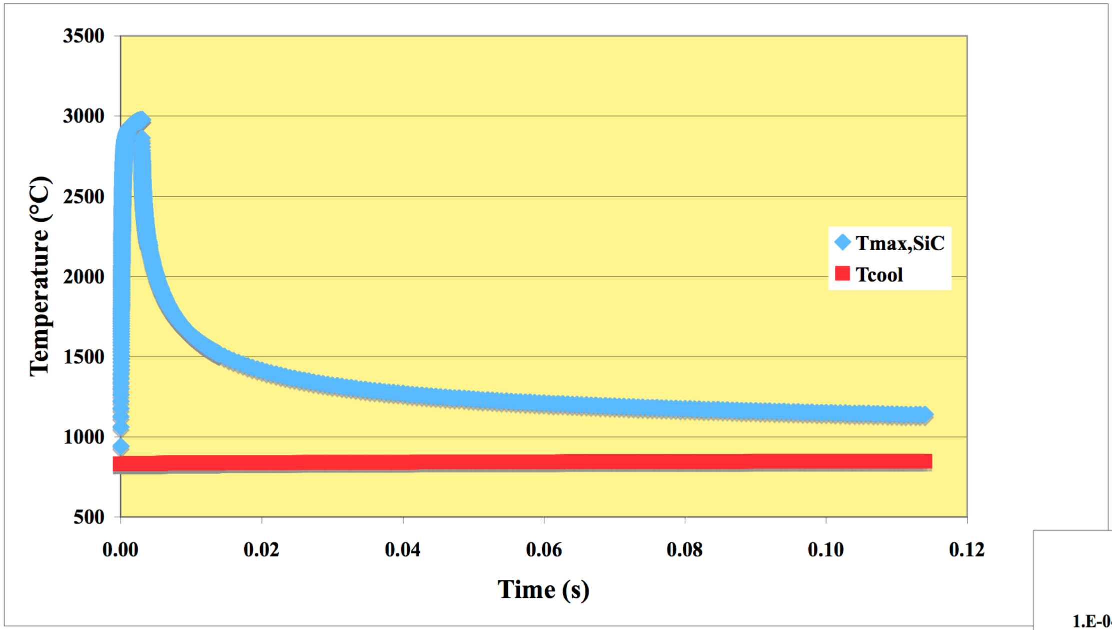
- **Disruptions:**
  - Parallel energy density for thermal quench = 28-45 MJ/m^2 near X-point
  - Deposition time ~ 1-3 ms
  - Perpendicular energy deposition will be lower, depending on incidence angle (at least 1 order of magnitude lower)
  - Parallel energy deposition for current quench = 2.5 MJ/m^2
  - 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

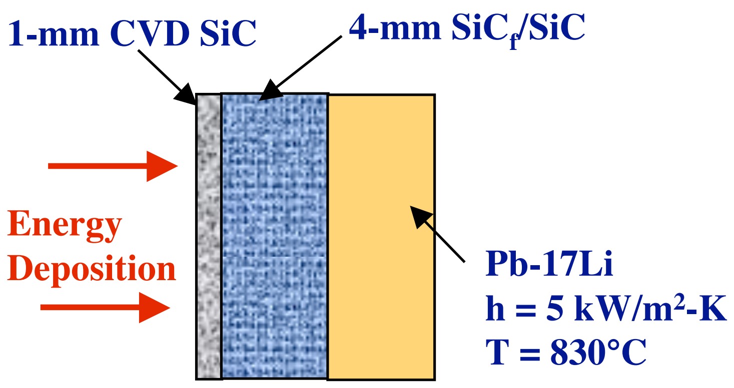
- **VDE's:**
  - Energy deposition = 60 MJ/m^2
  - Deposition time ~ 0.2 s

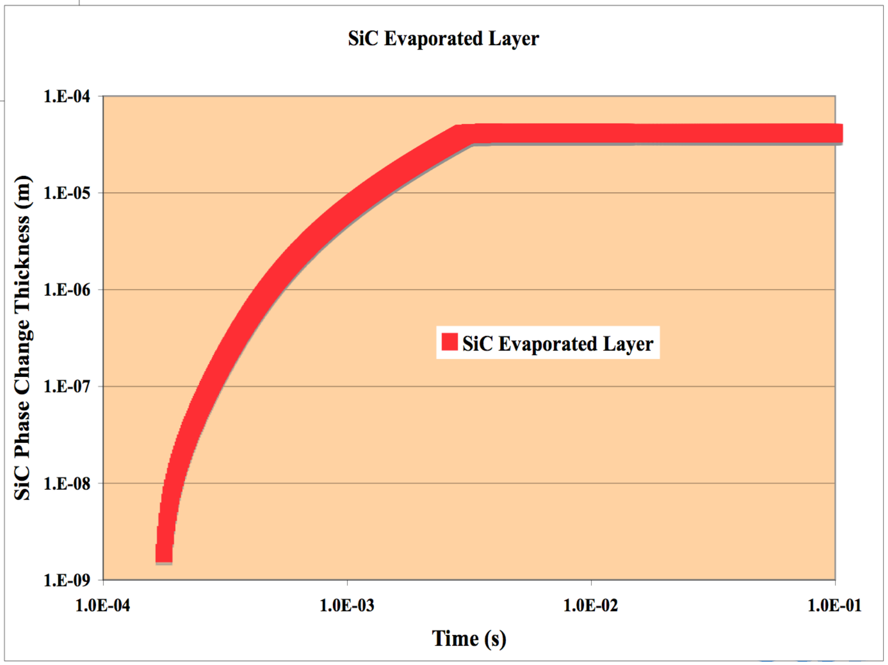
- **ELMS:**
  - Parallel energy density for thermal quench (controlled/uncontrolled) ~ 0.77/3.8 MJ/m^2
  - Deposition time ~ 0.4 ms
  - Frequency (controlled/uncontrolled) = 4/1 Hz
  - Assumed power plant case ~0.3/1.5 MJ/m^2 incident energy deposition over 0.4 ms

Example Disruption Case for Power Plant with SiC FW

- Disruption simulation: q''=10^9 W/m^2 over 3 ms (~3 MJ/m^2)
- 1 mm CVD SiC armor on 4-mm SiC_f/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K

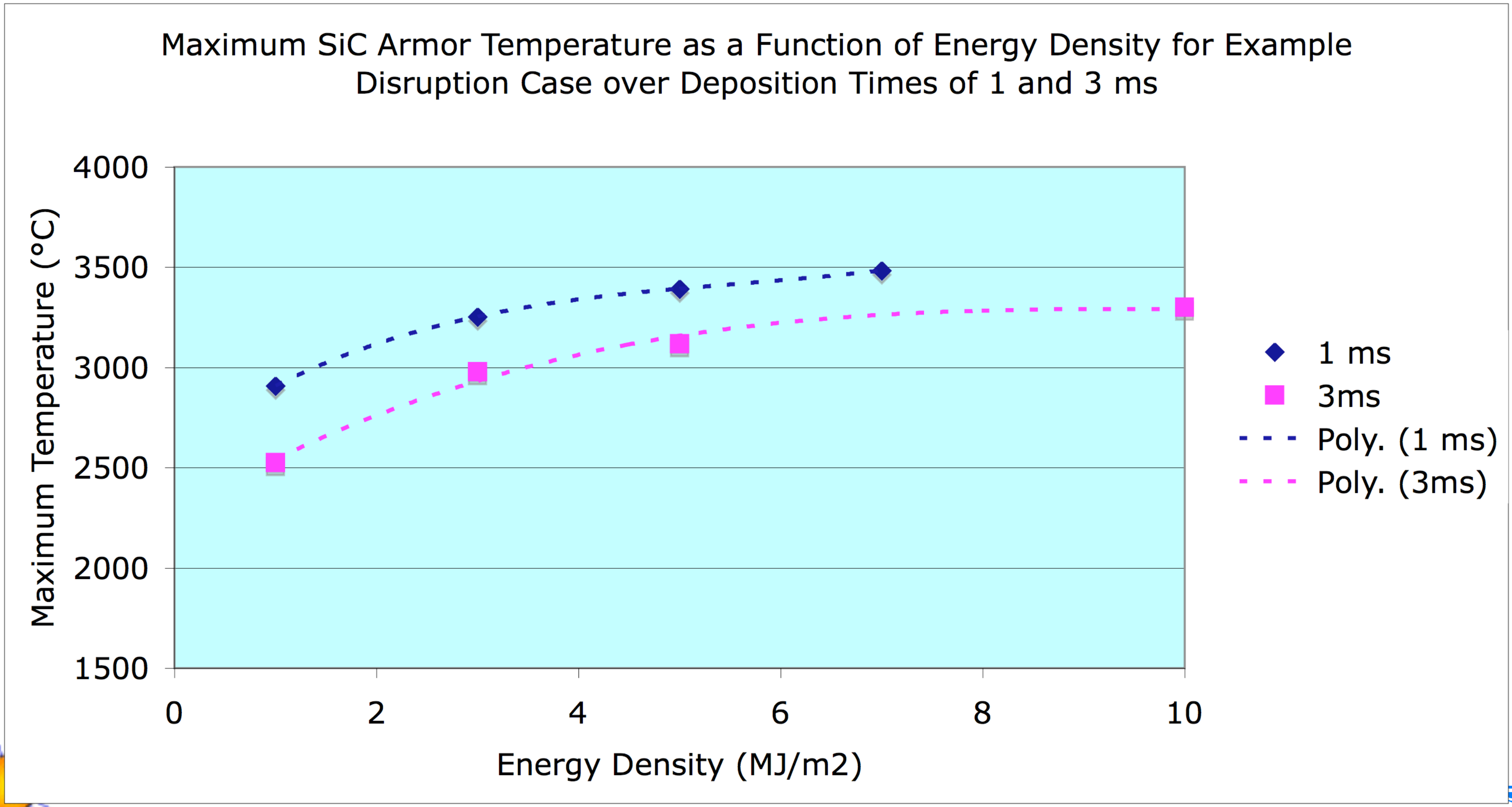






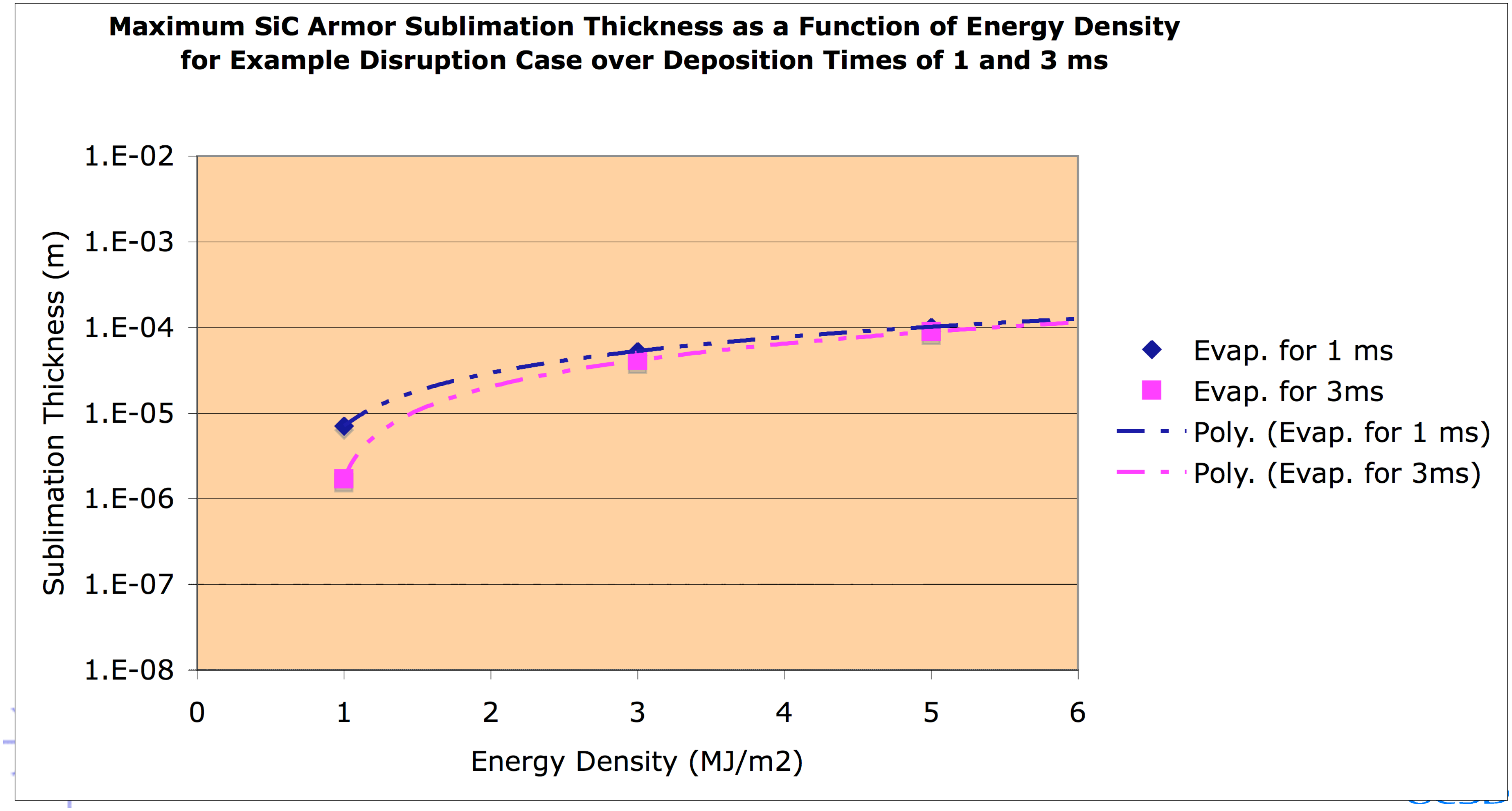
Parametric Study of Maximum SiC FW Temperature for Different Disruption Scenarios

- **1 mm armor (CVD SiC) on 4-mm SiC_f/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K**



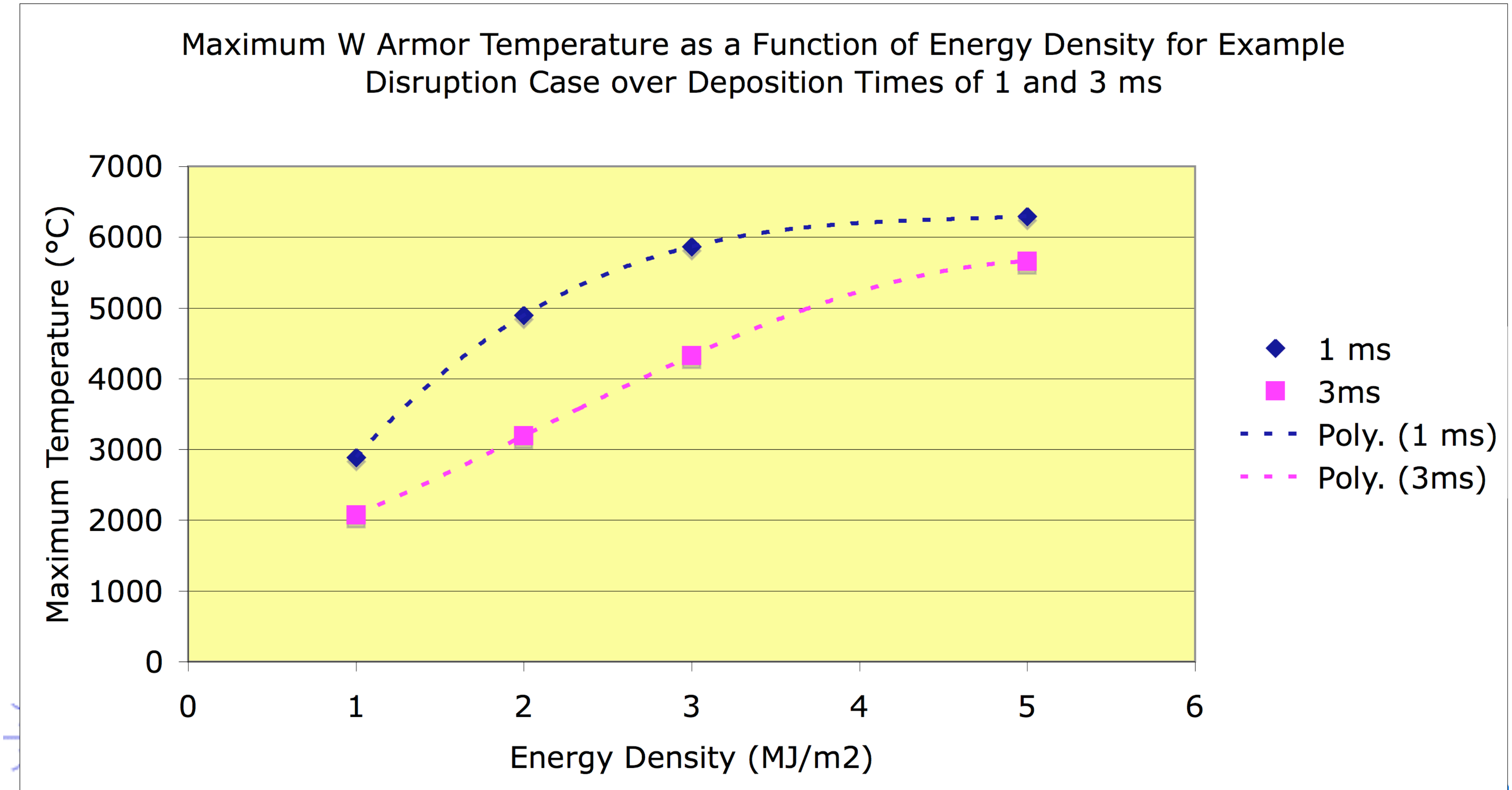
Parametric Study of Maximum Sublimation Thickness of a SiC FW Temperature for Different Disruption Scenarios

- **1 mm armor (CVD SiC) on 4-mm SiC_f/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K**
- **Up to ~0.1 mm lost per event**
- **Ony a few events allowable based on erosion lifetime**



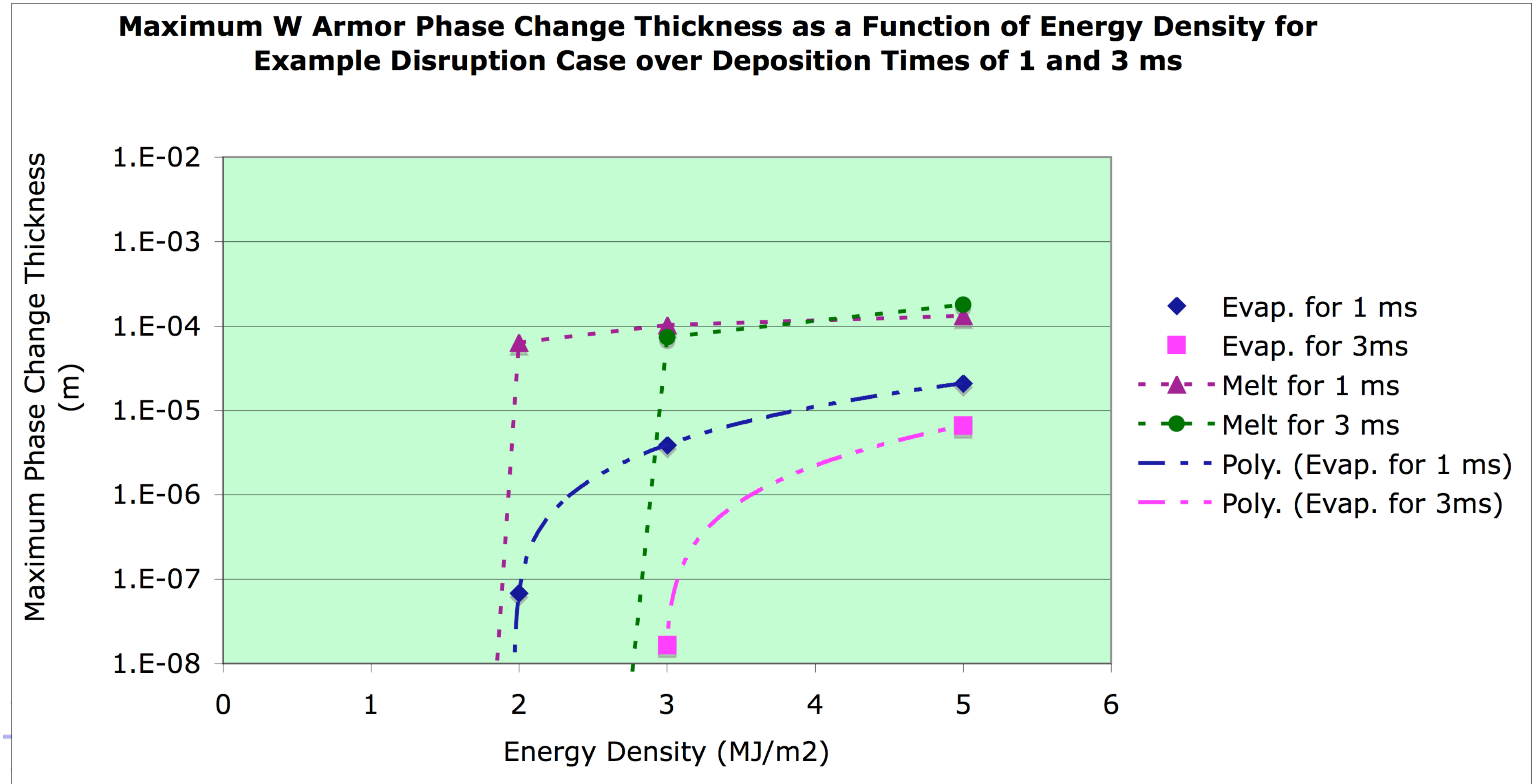
Parametric Study of Maximum W FW Temperature for Different Disruption Scenarios

- **1 mm armor (W) on 4-mm SiC_f/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K**
- **W MP = 3422°C; BP = 5555°C**



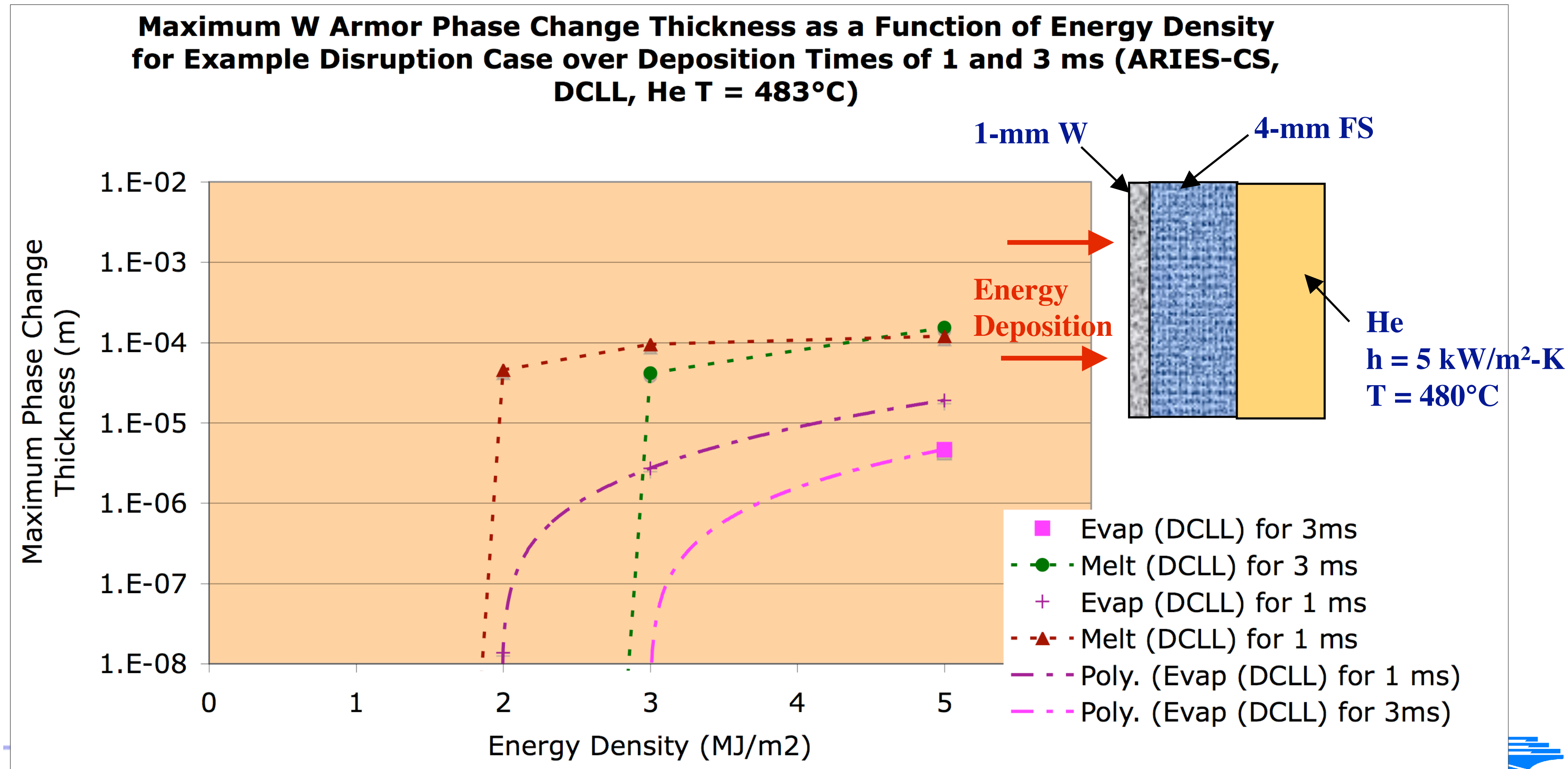
Parametric Study of Maximum Phase Change Thickness of a W FW Temperature for Different Disruption Scenarios

- 1 mm armor (W) on 4-mm SiC_f/SiC FW cooled by Pb-17Li at 830°C with h=5 kW/m^2-K
- Up to ~0.1 mm melt layer and ~0.01 mm evaporation loss per event
- Again, only a few events allowable based on erosion lifetime



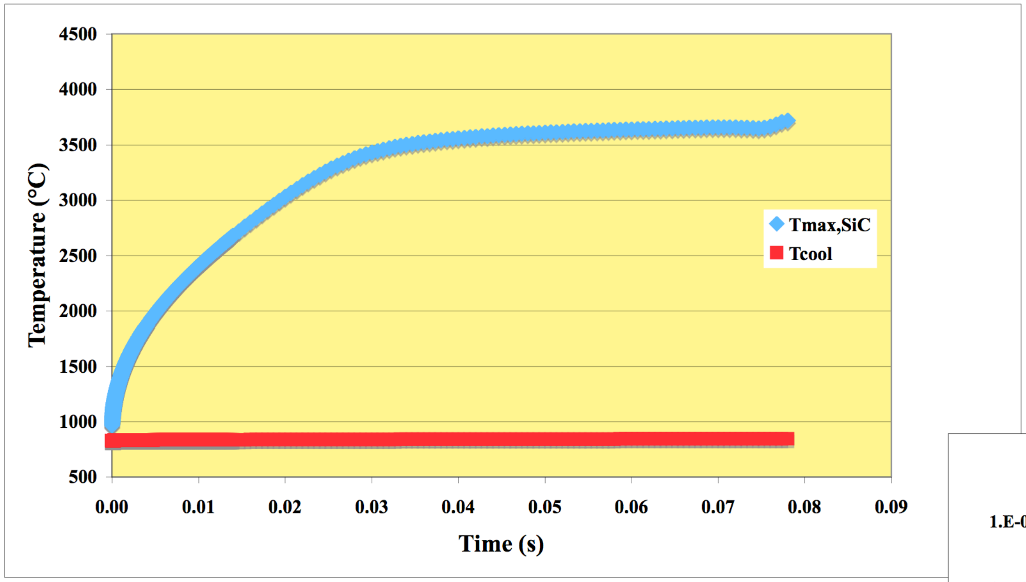
Parametric Study of Maximum Phase Change Thickness of a W FW Temperature for Different Disruption Scenarios (DCLL Case)

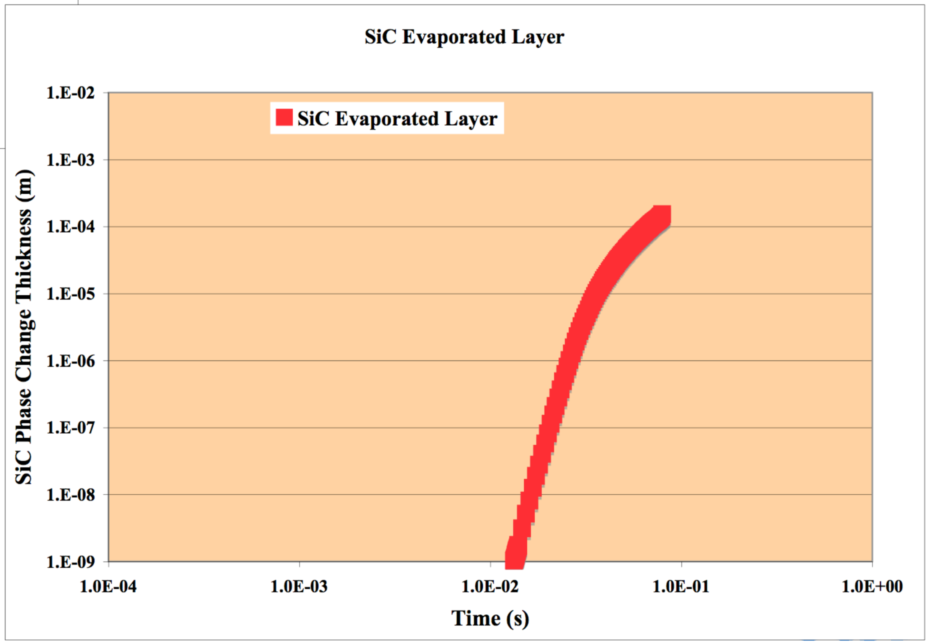
- 1 mm armor (W) on 4-mm FS FW cooled by He at 483°C with h=5.2 kW/m^2-K
- Up to ~0.1 mm melt layer and ~0.01 mm evaporation loss per event
- Again, only a few events allowable based on erosion lifetime depending on energy density



Example VDE Case for Power Plant with SiC FW

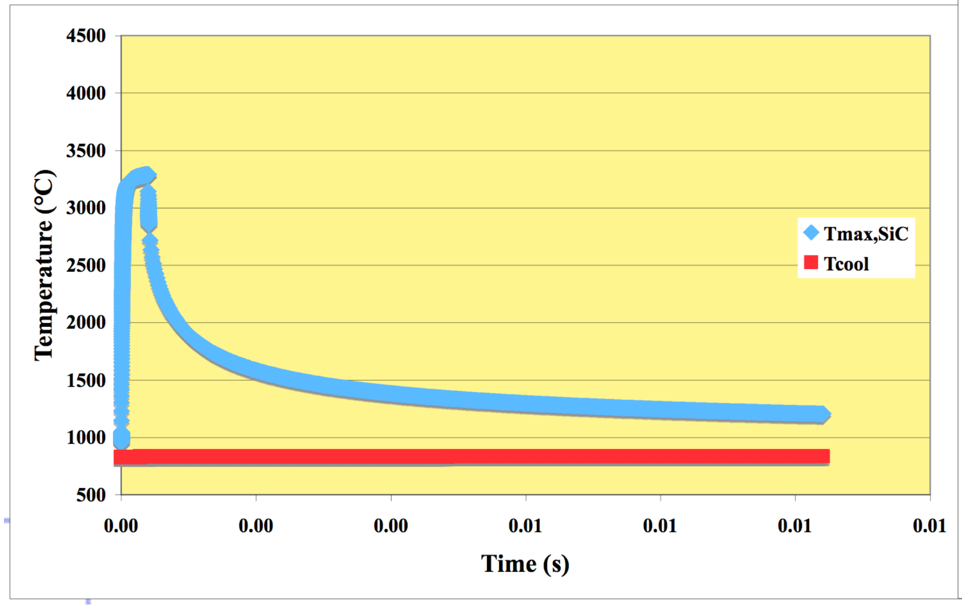
- VDE simulation: $q''= 3 \times 10^8$ W/m^2 over 0.2 s (60 MJ/m^2)
- 1 mm CVD SiC armor on 4-mm SiC_f/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K
- Even 1 event is not acceptable (complete loss of armor)
- Same conclusion for W armor

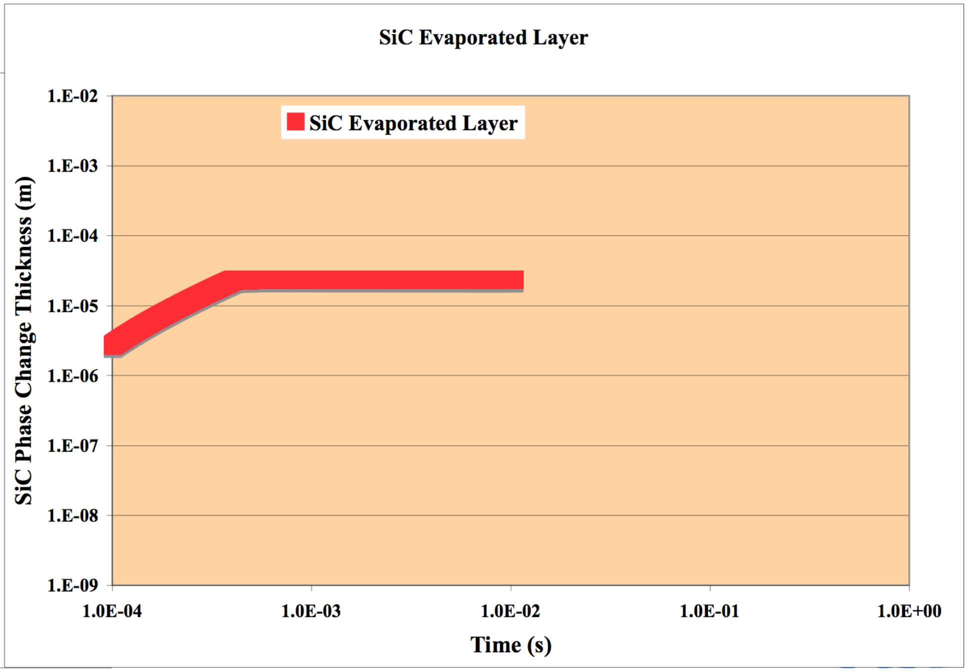




Example Uncontrolled ELM Case for Power Plant with SiC FW

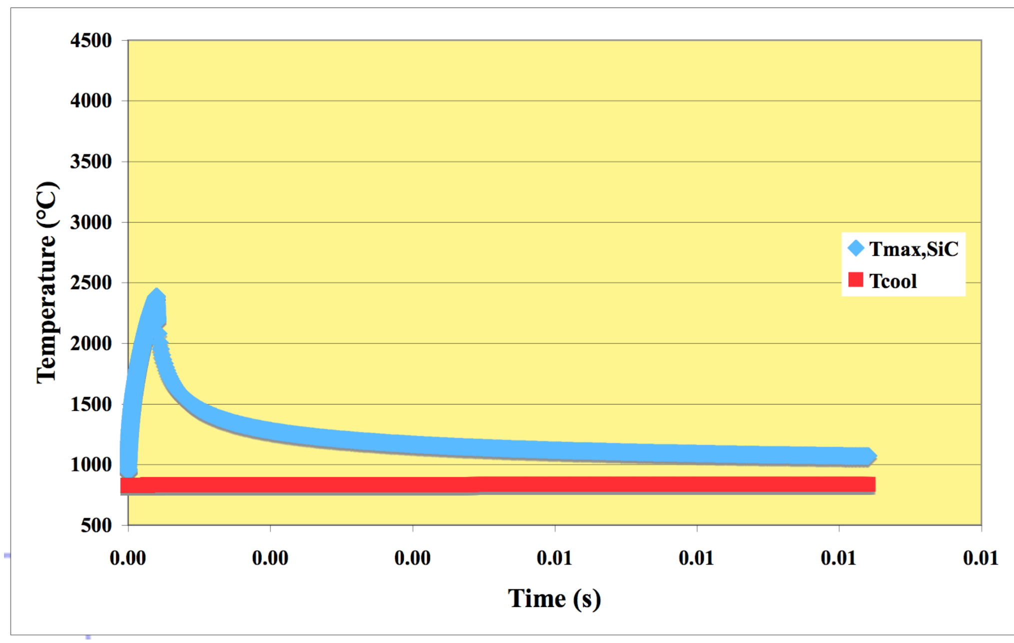
- ELM simulation: q''= 3.75 x 10^9 W/m^2 over 0.4 ms (1.5 MJ/m^2)
- 1 mm CVD SiC armor on 4-mm SiC_f/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K
- ~0.02 mm of armor loss per event (1 Hz frequency)
- Not acceptable (complete loss of armor after 50 such events)
- Similar conclusion for W armor
  - T_{max}= 5512°C; 5x10^{-5} m melt; 3x10^{-7} m evaporation loss per event
  - Complete loss of armor after 3333 such events even without melt loss

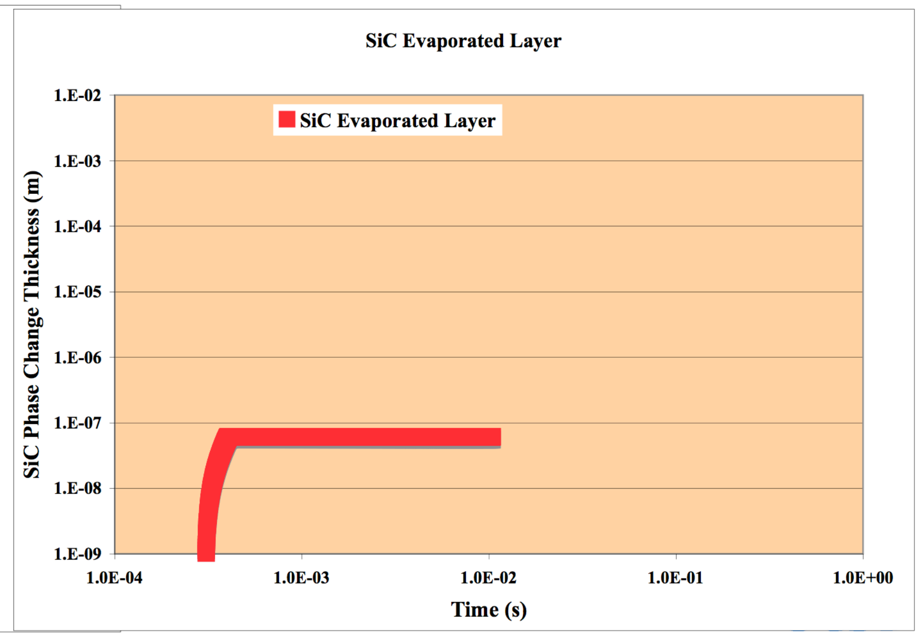




Example Controlled ELM Case for Power Plant with SiC FW

- ELM simulation: q''= 7.5 x 10^8 W/m^2 over 0.4 ms (0.3 MJ/m^2)
- 1 mm CVD SiC armor on 4-mm SiC$_f$/SiC FW by Pb-17Li at 830°C with h=5 kW/m^2-K
- ~0.08 µm of armor loss per event (5 Hz frequency)
- Complete loss of SiC armor after 1.25x10^7 such events (~1 month if occurring at same location) - Not acceptable
- OK for W armor (T_{max}=1872°C; no melt; 10^{-20} m evaporation loss per event)





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

- Focus on thermal effects
- EM effects will be important for DCLL but not as much for ARIES-AT with resistive FW (SiC_f/SiC)
- Only a few disruptions can be accommodated (depending on the energy density)
- DCLL slightly better than ARIES-AT (because of lower base temperature of FW)
- VDE cannot be accommodated
- Only limited number of uncontrolled ELM cases can be accommodated
- Controlled ELM's would limit the lifetime of SiC armor but might be acceptable for W armor