Thermal Analysis of Candidate Armor Materials for Use in the Magnetic Cusp Field HAPL Reactor Design

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IFE Chamber Dynamics and Clearing

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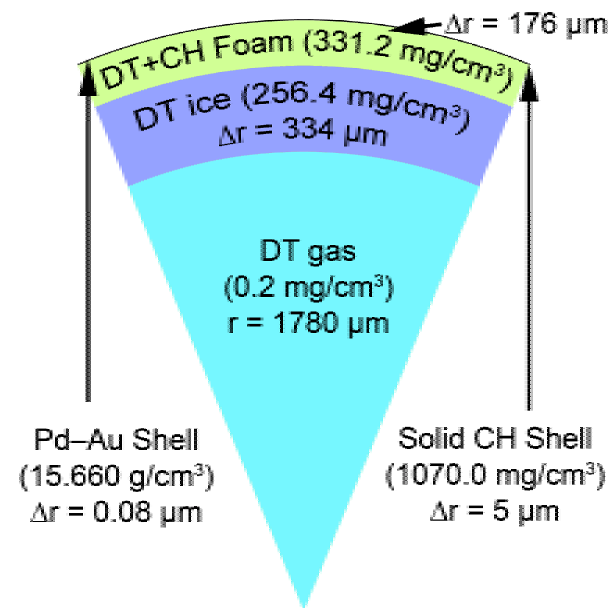
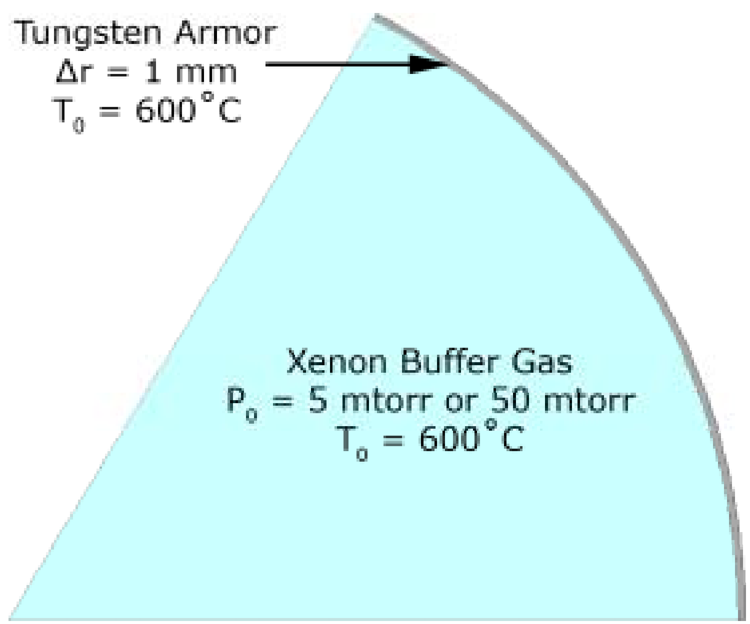
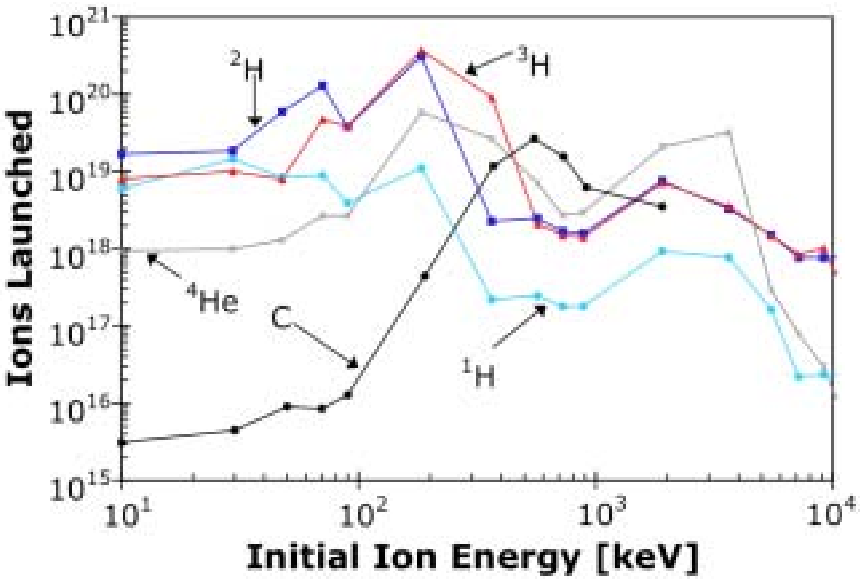
"Big dumb chamber" reactor design

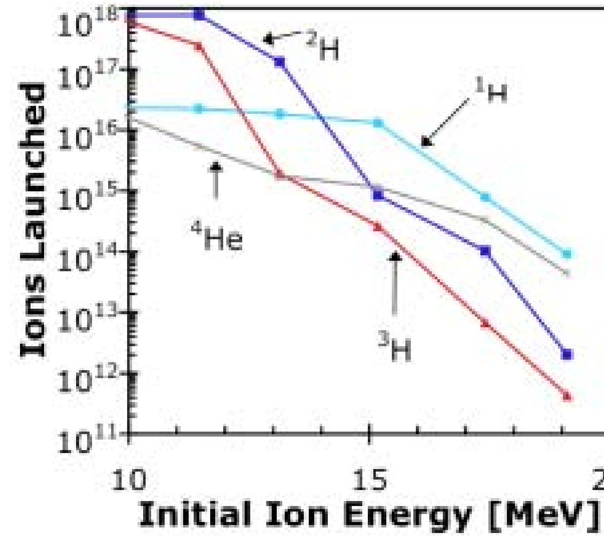
- 365 MJ Pd/Au coated target is ignited in the reactor chamber at a rate of 10 Hz
  - 274.3 MJ of neutrons
  - 4.9 MJ of X-rays
  - 85.8 MJ of ions
- Chamber contains a low-pressure buffer gas (0.5 mtorr)
  - Chamber radius of 10.5 m
  - Xenon was used for these calculations
  - For an "empty chamber" the constituent gas would be a mix of helium and hydrogen
- The ferritic steel first wall is protected by an armor layer consisting of
  - 1 mm tungsten, or
  - 1 cm silicon carbide

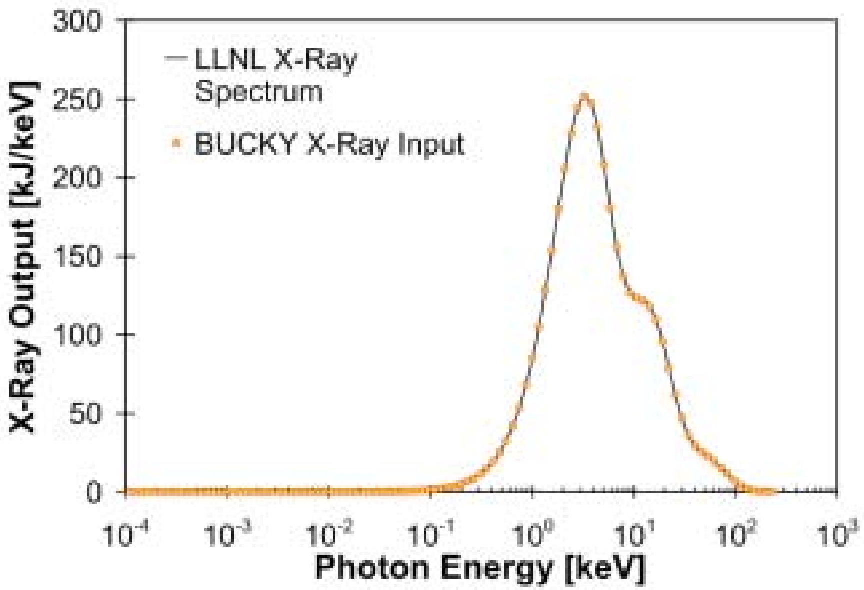


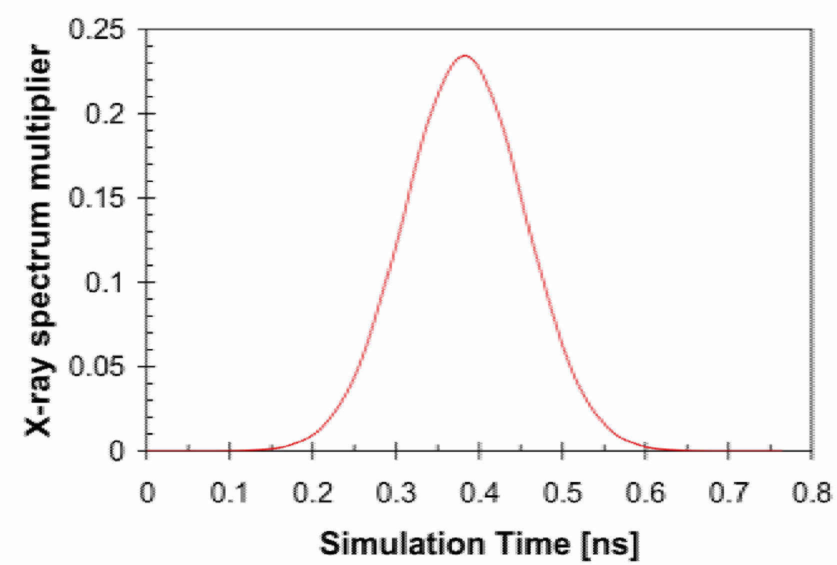


LASNEX was used to simulate the ion and X-ray spectra emanating from the target at 100 ns



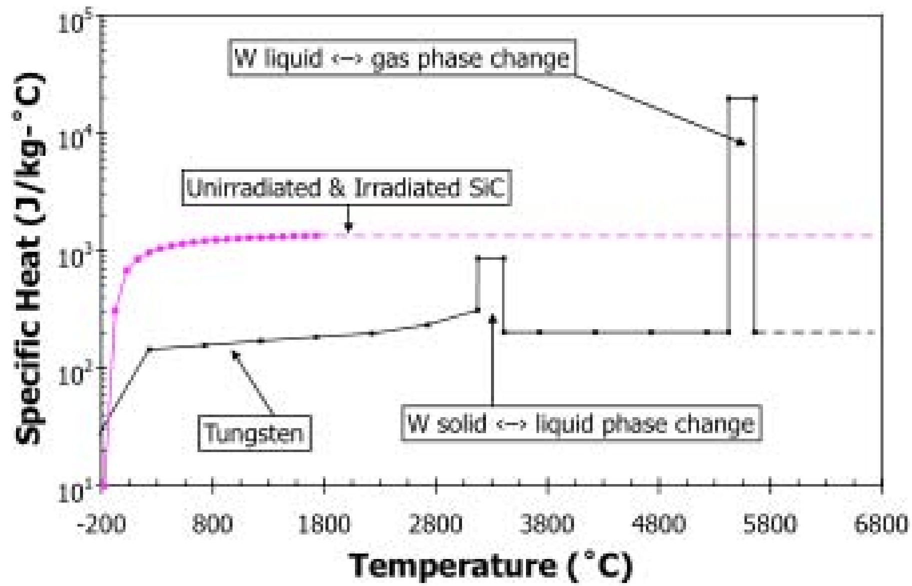


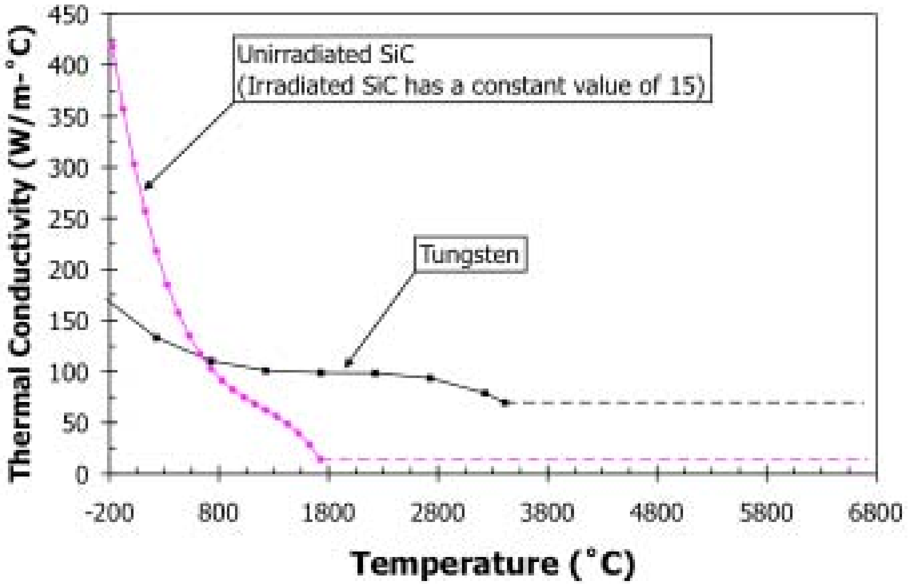




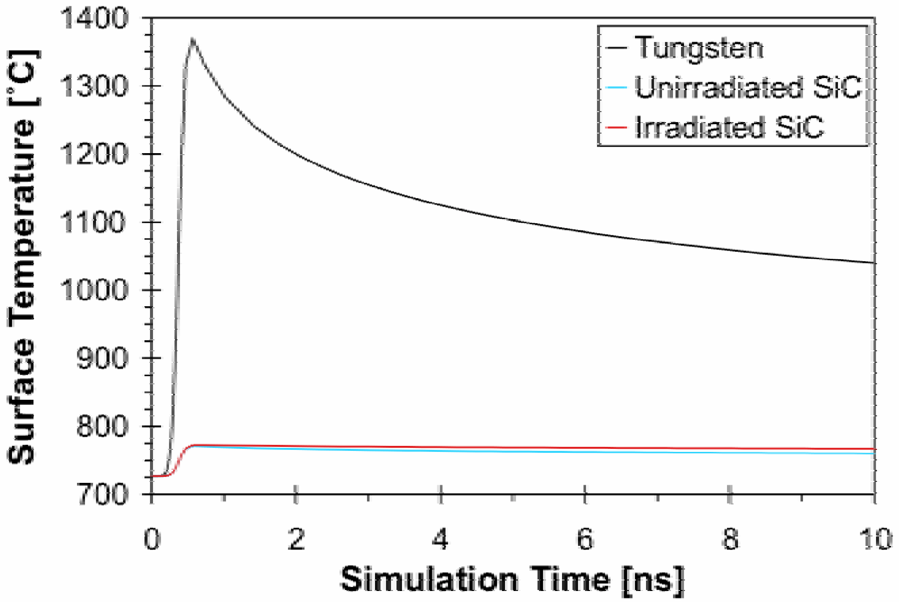
NIST data for tungsten and silicon carbide were used to generate EOS tables

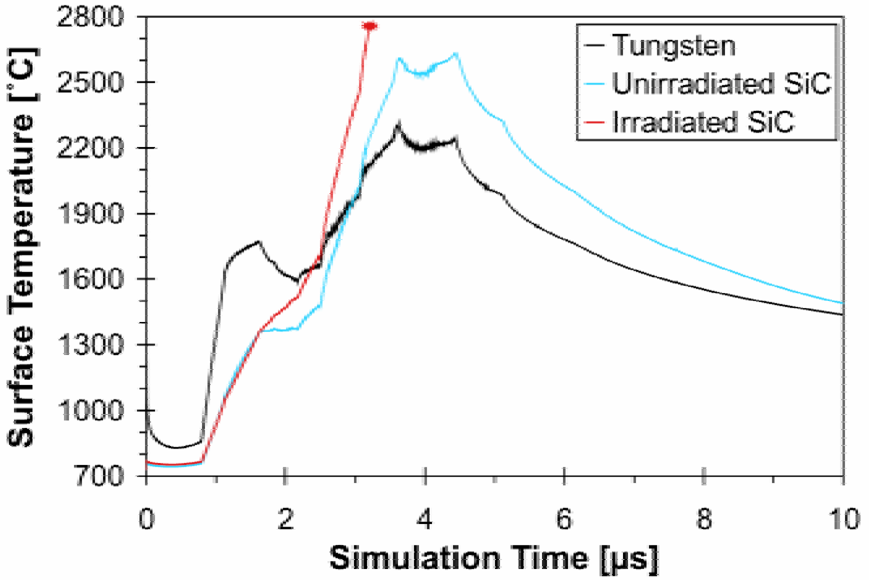
- NIST data were used to generate specific heat and thermal conductivity values.
- Tungsten phase change regions have a ΔT of 252 °C (0.02eV)
- Dashed lines indicate extrapolated data
- SESAME data used for plasma and high-temperature gas EOS for all materials
- YAC LTE opacities were used for xenon, tungsten and silicon carbide

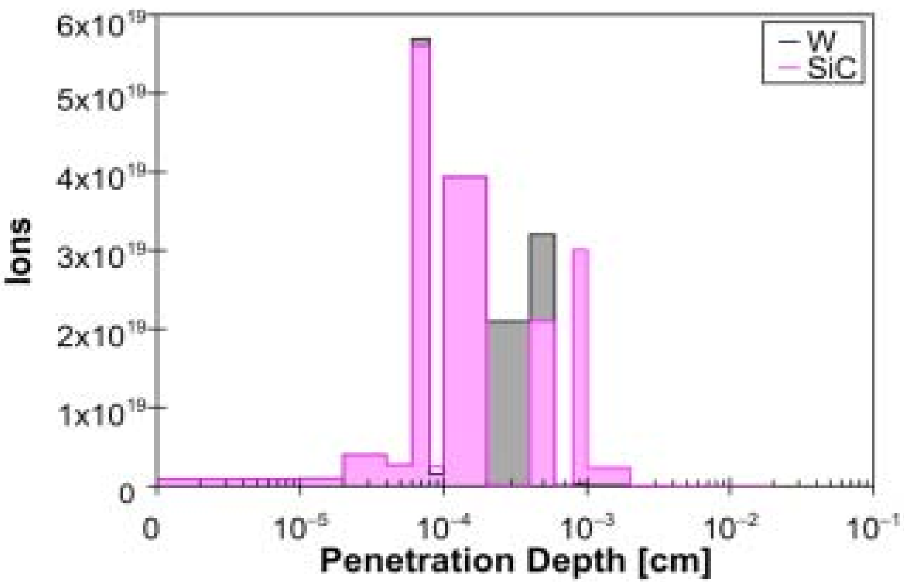




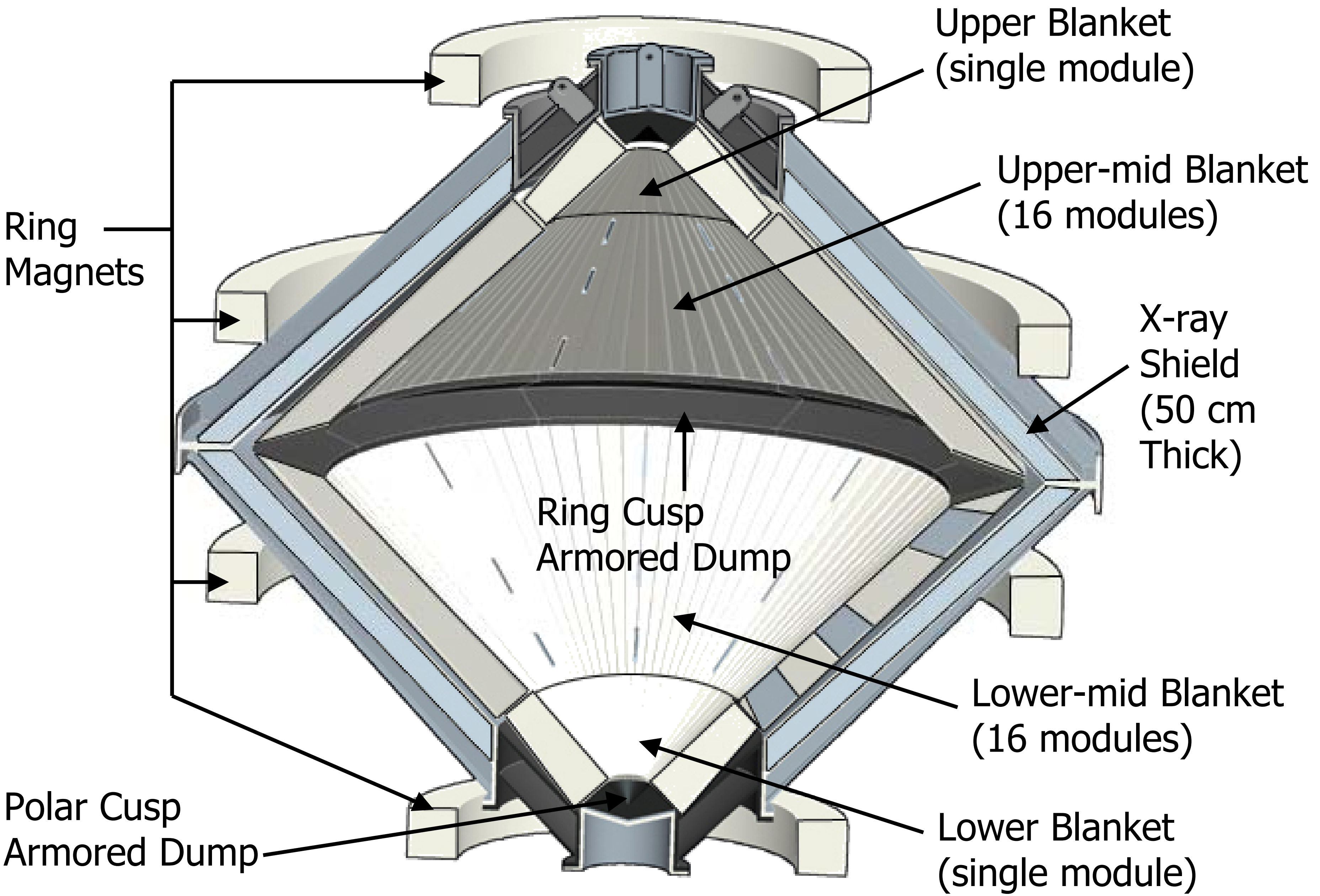
The 10.5 m radius "big dumb chamber" yields unsatisfactory results for thermal loading







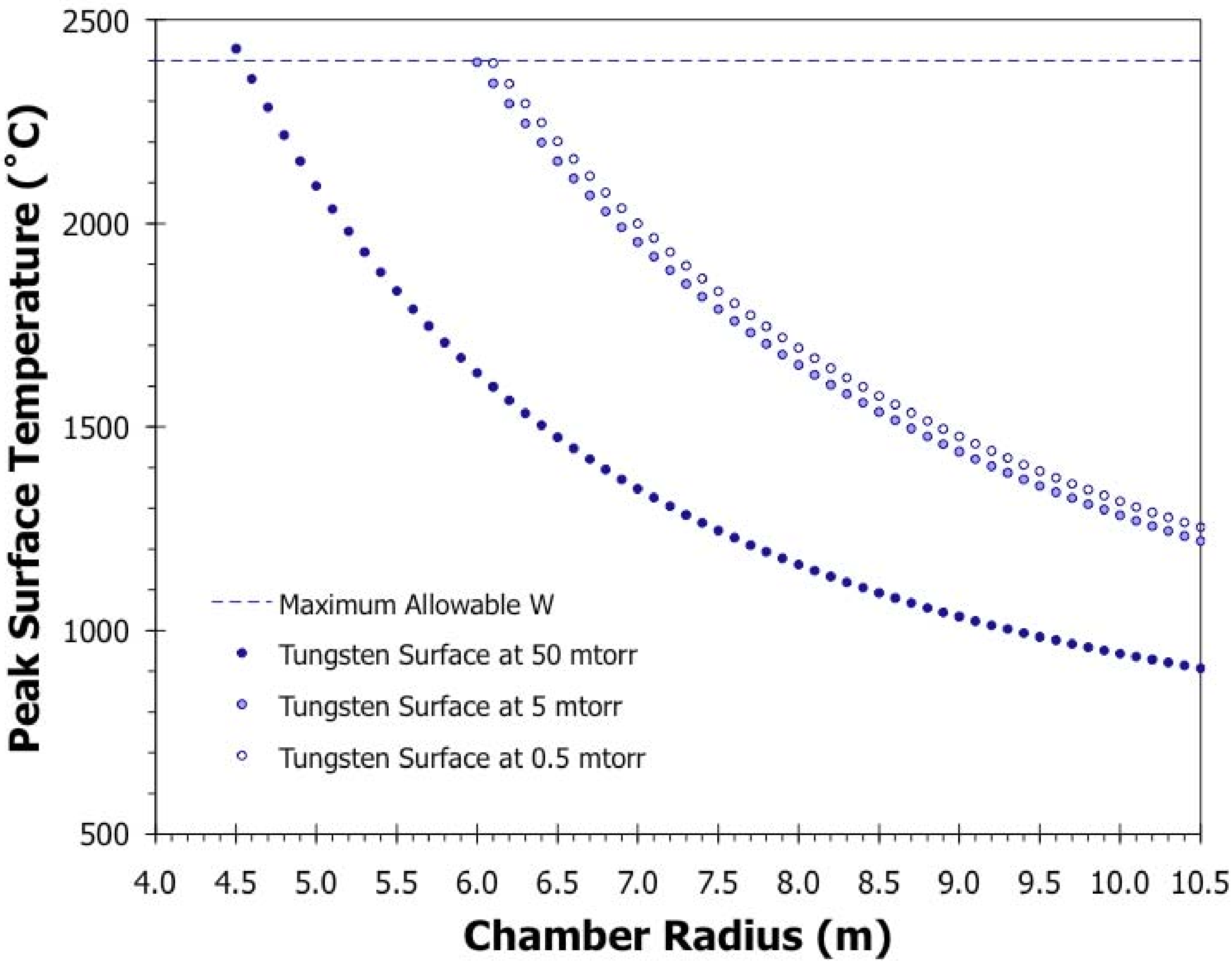
A proposed solution is the introduction of a magnetic cusp field to divert the ions away from the armor material



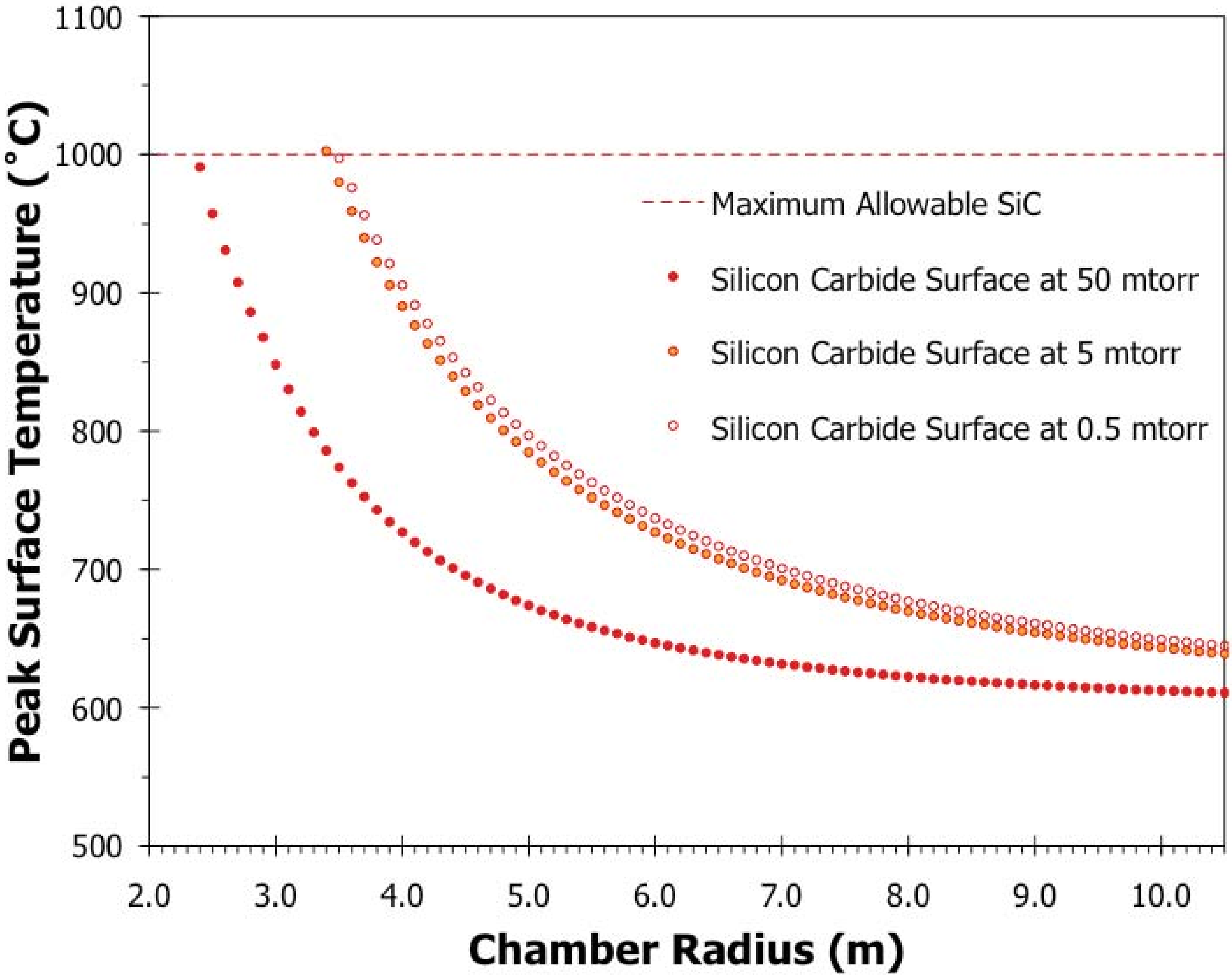
BUCKY magnetic cusp field simulation methodology

- The BUCKY 1-D radiation hydrodynamics code is not designed to model a system as complex as a magnetic intervention scheme
- For these simulations, the ions were allowed to stream through the buffer gas and were removed when they approached within 25 cm of the armor surface
- Removal of the ions in the code is handled by simply zeroing out their kinetic energy, allowing bucky to remove the ions from the simulation through accounting routines currently present in the code
- For gas-filled chambers, re-radiation from the buffer gas due to heating from streaming X-rays and ions can be a significant heating load over long time scales

Temperature rise on the surface of the tungsten armor due to the X-ray flash



Temperature rise on the surface of the silicon carbide armor due to the X-ray flash

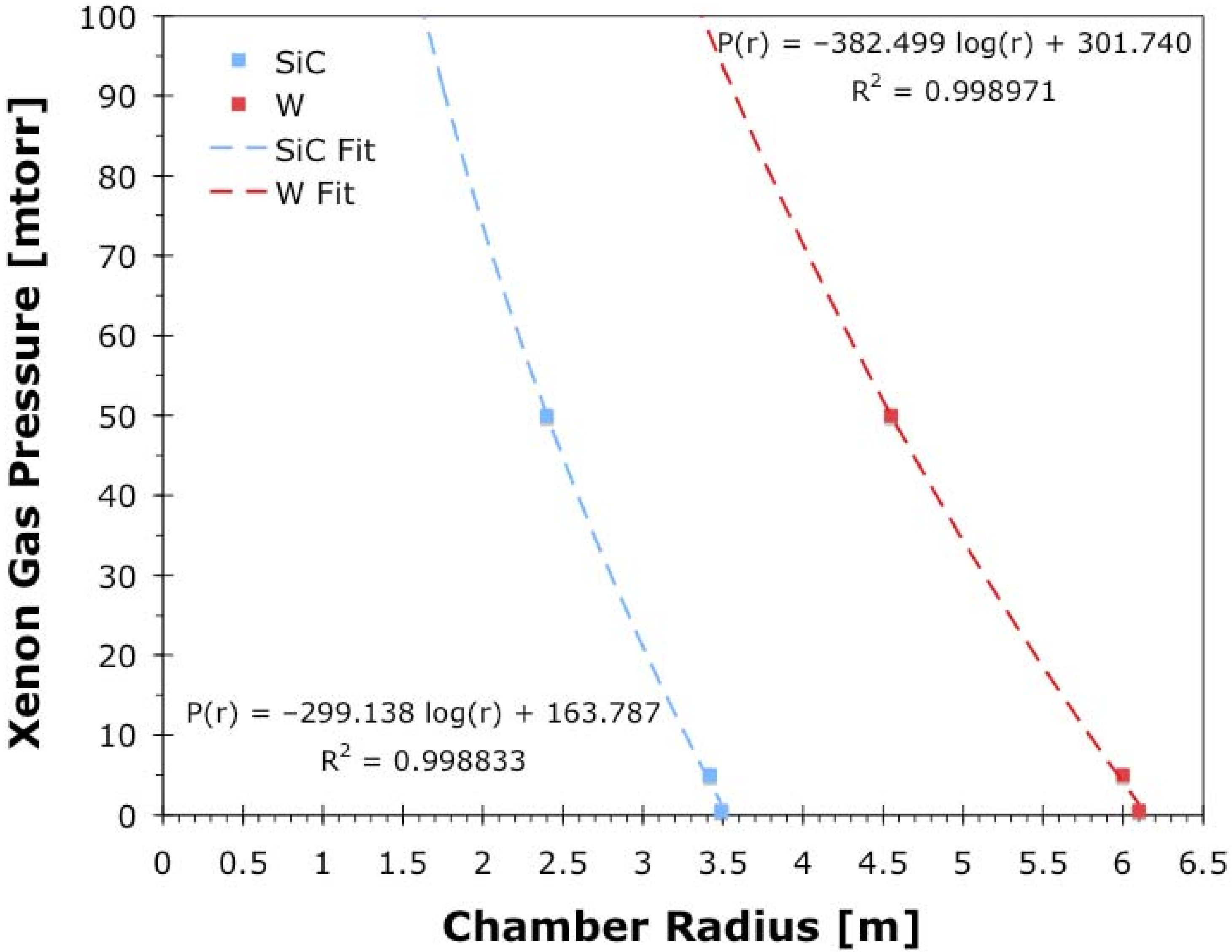


Results of the parametric study lead to analytic equations that express minimum chamber radius for each xenon gas pressure

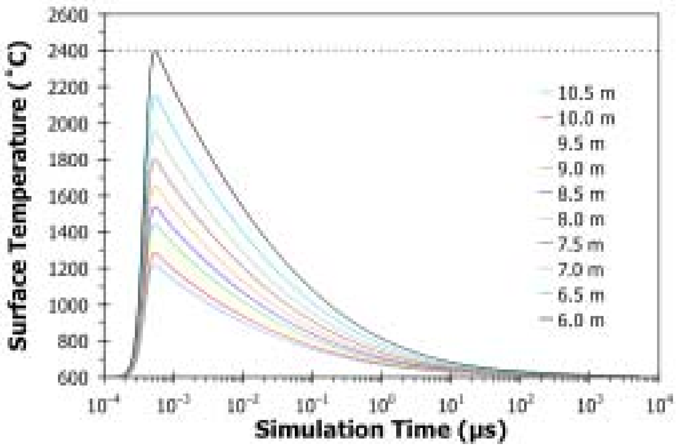
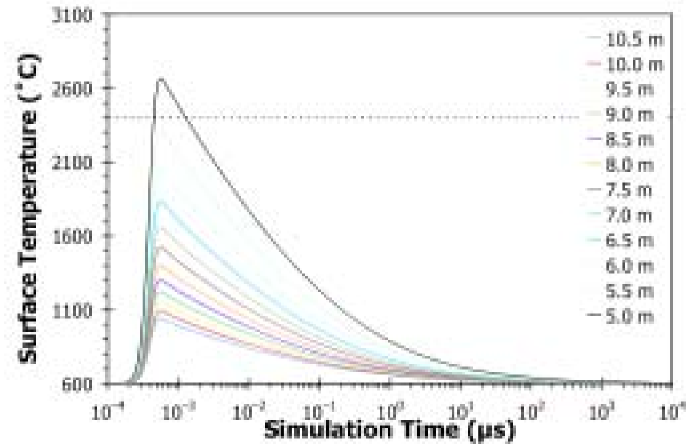
- Tungsten armor results
- 0.5 mtorr xenon gas
  - $T(r) = 4.5957x10^4\ r^{-2} + 4.7508x10^3\ r^{-1} + 3.8211x10^2$
  - $R^2 = 0.99999$
  - $r_{min} = 6.10$ m
- 5 mtorr xenon gas
  - $T(r) = 4.6495x10^4\ r^{-2} + 4.3488x10^3\ r^{-1} + 3.8271x10^2$
  - $R^2 = 0.99999$
  - $r_{min} = 6.00$ m
- 50 mtorr xenon gas
  - $T(r) = 3.4188x10^4\ r^{-2} + 1.2344x10^3\ r^{-1} + 4.7550x10^2$
  - $R^2 = 0.99996$
  - $r_{min} = 4.55$ m

- Silicon carbide armor results
- 0.5 mtorr xenon gas
  - $T(r) = 4.6816x10^3\ r^{-2} + 7.1560x10^1\ r^{-1} + 5.9511x10^2$
  - $R^2 = 1.0000$
  - $r_{min} = 3.49$ m
- 5 mtorr xenon gas
  - $T(r) = 4.6847x10^3\ r^{-2} + 7.7135\ r^{-1} + 5.9566x10^2$
  - $R^2 = 1.0000$
  - $r_{min} = 3.42$ m
- 50 mtorr xenon gas
  - $T(r) = 2.6773x10^3\ r^{-2} - 1.6708x10^2\ r^{-1} + 6.0144x10^2$
  - $R^2 = 0.99967$
  - $r_{min} = 2.40$ m

Results of the parametric study also allow us to estimate the required xenon gas pressure for any desired armor radius



The BUCKY simulations indicate that re-radiation from the low and moderate pressure xenon buffer gas is insignificant

<table>
<tr><th></th><th>5 mtorr xenon</th><th>50 mtorr xenon</th></tr>
<tr><td>Tungsten</td><td>
</td><td>
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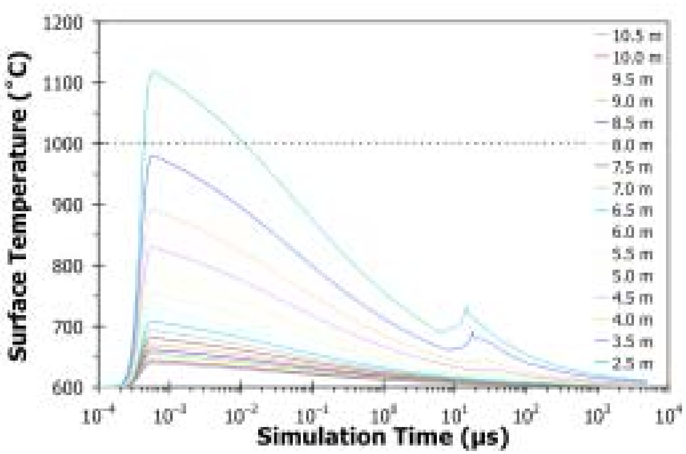
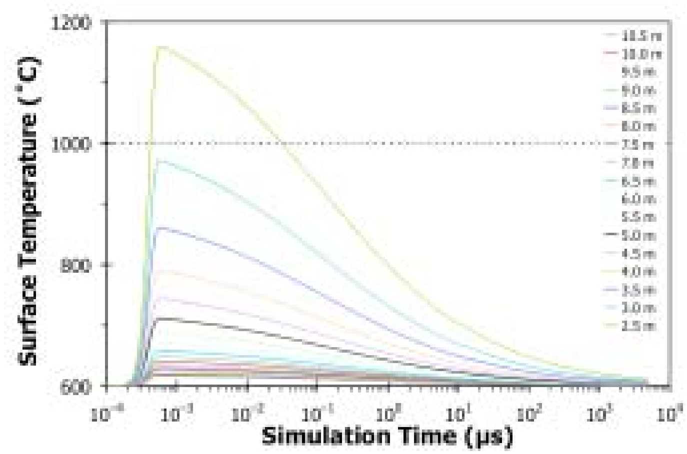
<tr><td>Silicon Carbide</td><td>
</td><td>
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Conclusions of the study and future work

- Magnetic diversion of ions in conjunction with 0.5 mtorr xenon buffer gas allows the inner radius of the armor material to be reduced from 10.5 m to
  - ♦ 6.1 m for tungsten
  - ♦ 3.5 m for silicon carbide
- Increasing the buffer gas pressure to 5 mtorr reduces the minimum chamber radius to
  - ♦ 6.0 m for tungsten
  - ♦ 3.4 m for silicon carbide
- Increasing the buffer gas pressure to 50 mtorr reduces the minimum chamber radius to
  - ♦ 4.6 m for tungsten
  - ♦ 2.4 m for silicon carbide
- Increasing the buffer gas pressure can significantly reduce the minimum radius of the armor
- The effect of re-radiation on surface temperature rise is negligible for gas pressures up to 50 mtorr

- Future work in this area includes
  - ♦ Study of exotic armor materials
    - Graphite
    - Carbon velvet
    - Metallic foams
  - ♦ Refinement of Equation of State models to incorporate elastic deformation to study shock dynamics in solid and liquid state materials
  - ♦ Simulate the divertor regions to estimate erosion rates of divertor materials