Target threat spectra

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with

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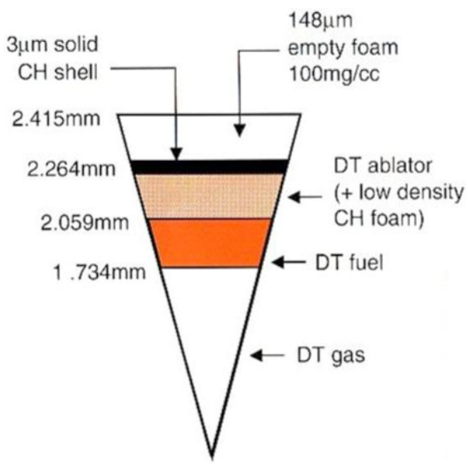
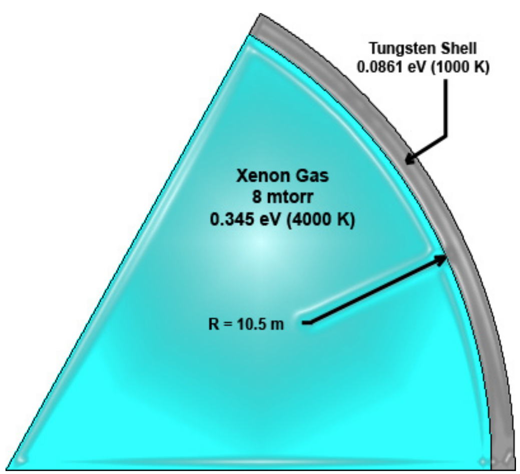
Outline of presentation

- Collisional hydrodynamic expansion or kinetic ions as the threat spectrum model.
- Kinetic target source term – chamber gas – first wall simulation with BUCKY.
  - Empty foam target source term.
  - Tungsten first wall physical data.
  - Tungsten first wall response to x-rays and ionic debris for Xe and Ar chamber gases.
- Ion instability analysis using Clark, et. al.
- Conclusions

Empty foam target and 10.5 m W chamber filled with 8 mTorr Xe

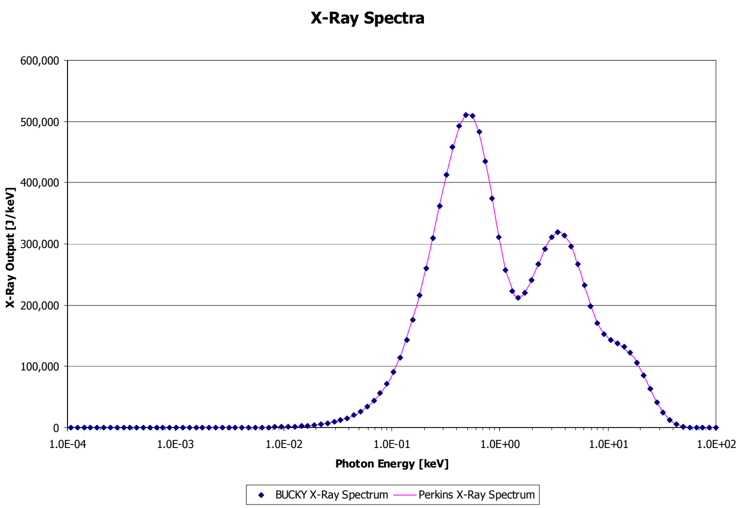


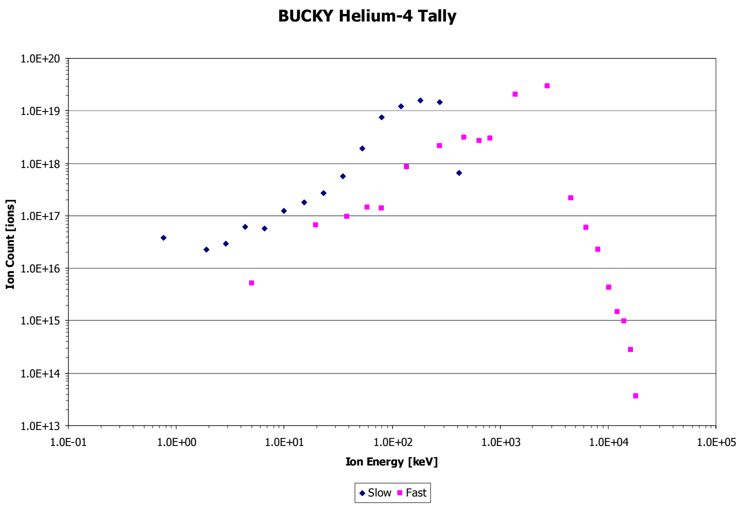


- 343 MJ Yield
  - 4.57 MJ x-rays
  - 81.8 MJ ions
  - 252 MJ neutrons
- 8 mTorr Xe gas
  - Sesame eq. of state
  - IONMIX non-LTE opacities
- W first wall
  - Sesame eq. of state
  - YAC LTE opacities

X-ray and ion spectra

(taken from Perkins' fax)

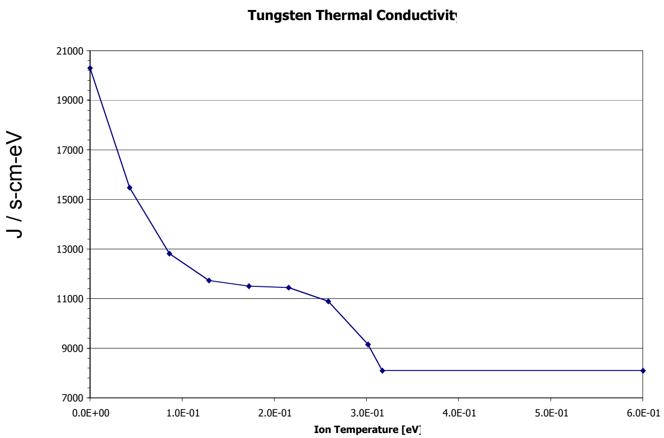


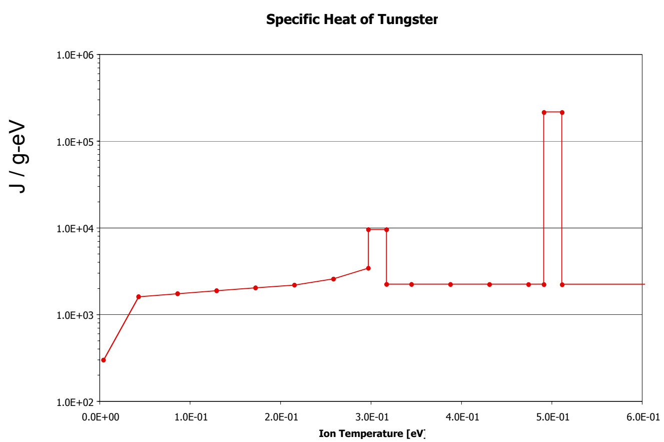


- X-ray spectrum computed directly from 3 T blackbody fit.
- Group-wise ion spectra (#/keV) converted to ion bunches of N_g ions at average group energies E_g (keV) for each specie.
- ***Total ion energy adds to 72.75 MJ rather than 81.8 MJ***

	Total Number of Ions		Bucky Ion Energy [MJ]	
	Perkins	BUCKY	Slow	Fast
P	8.384E+19	8.376E+19	8.119E-01	7.307E-01
D	6.930E+20	6.932E+20	1.222E+01	6.799E+00
T	6.977E+20	6.972E+20	1.716E+01	6.167E+00
3He	1.033E+18	1.034E+18	2.256E-02	2.879E-02
4He	1.172E+20	1.172E+20	1.517E+00	1.909E+01
C	8.047E+19	8.041E+19	8.200E+00	6.390E-04
		Totals:	3.994E+01	3.282E+01
			=	7.275E+01

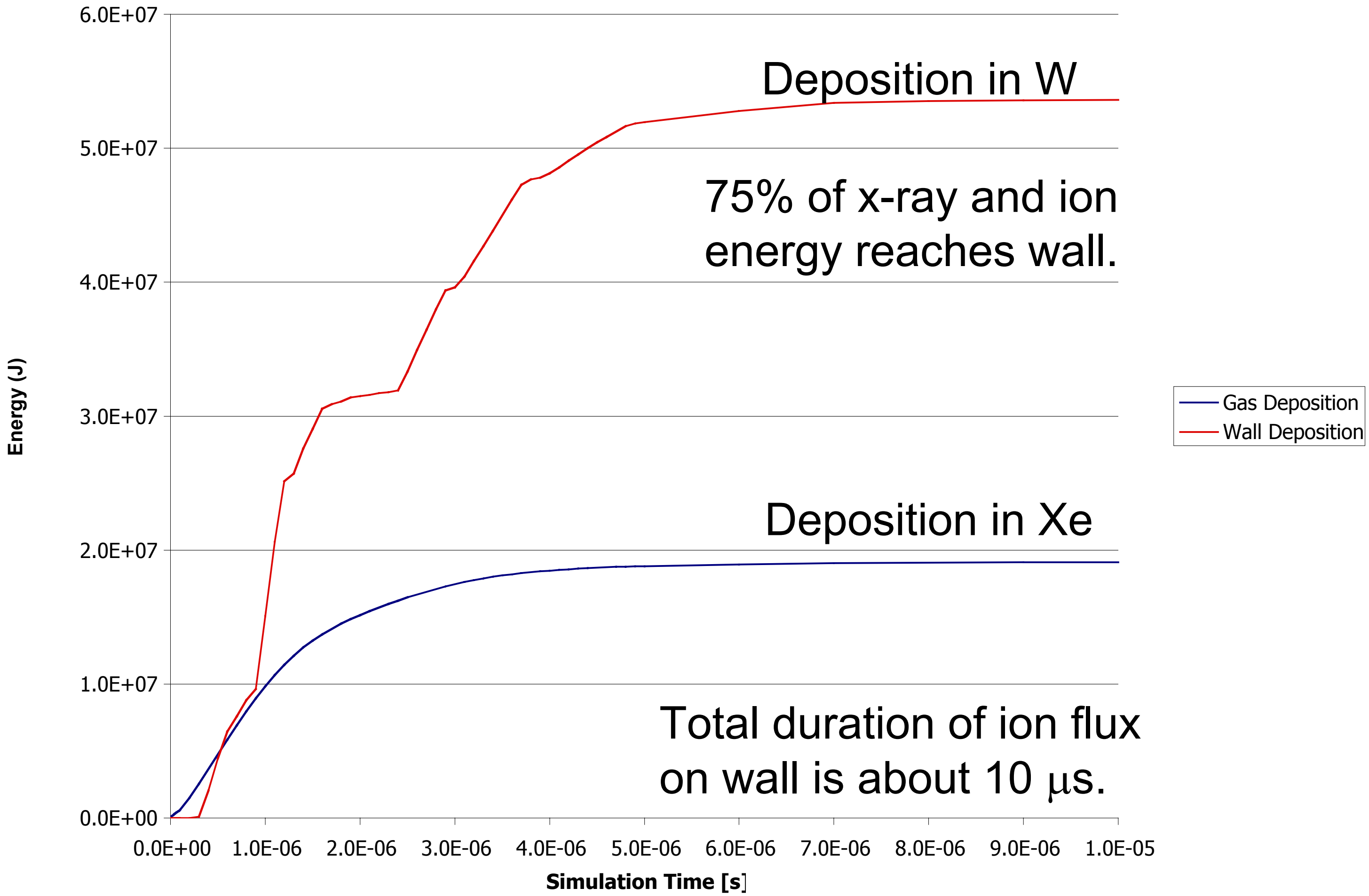
Tungsten properties and BUCKY first wall modeling



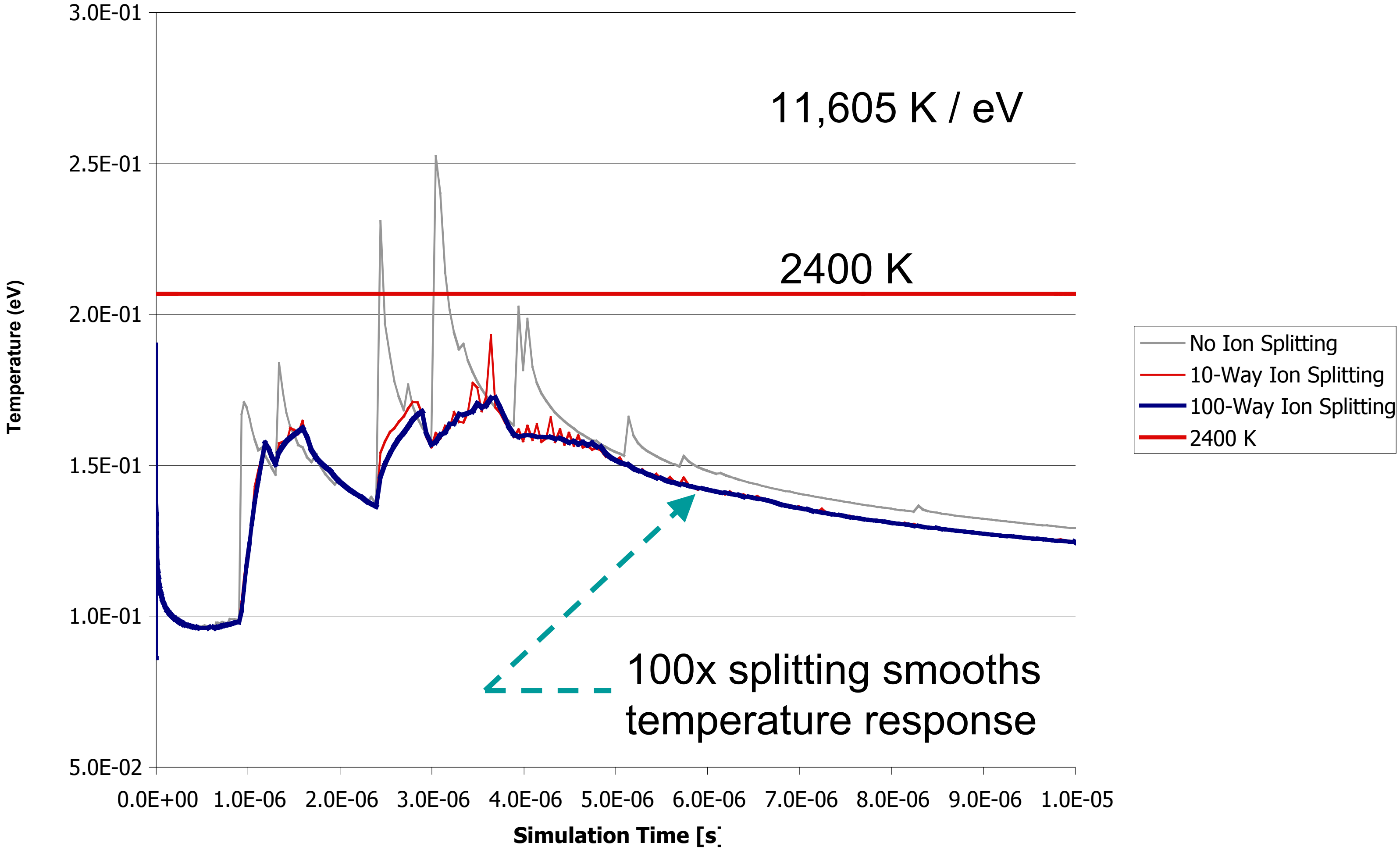


- Thermal conductivity data from *ITER Materials Handbook.*
- Specific heat data from NIST.gov thermochemistry database.
- BUCKY transitions between solid state data and plasma data.
- Heats of fusion and vaporization are treated using specific heat function in BUCKY model.
- Solid finite difference zones are “released” when vaporization temperature is reached in BUCKY model.

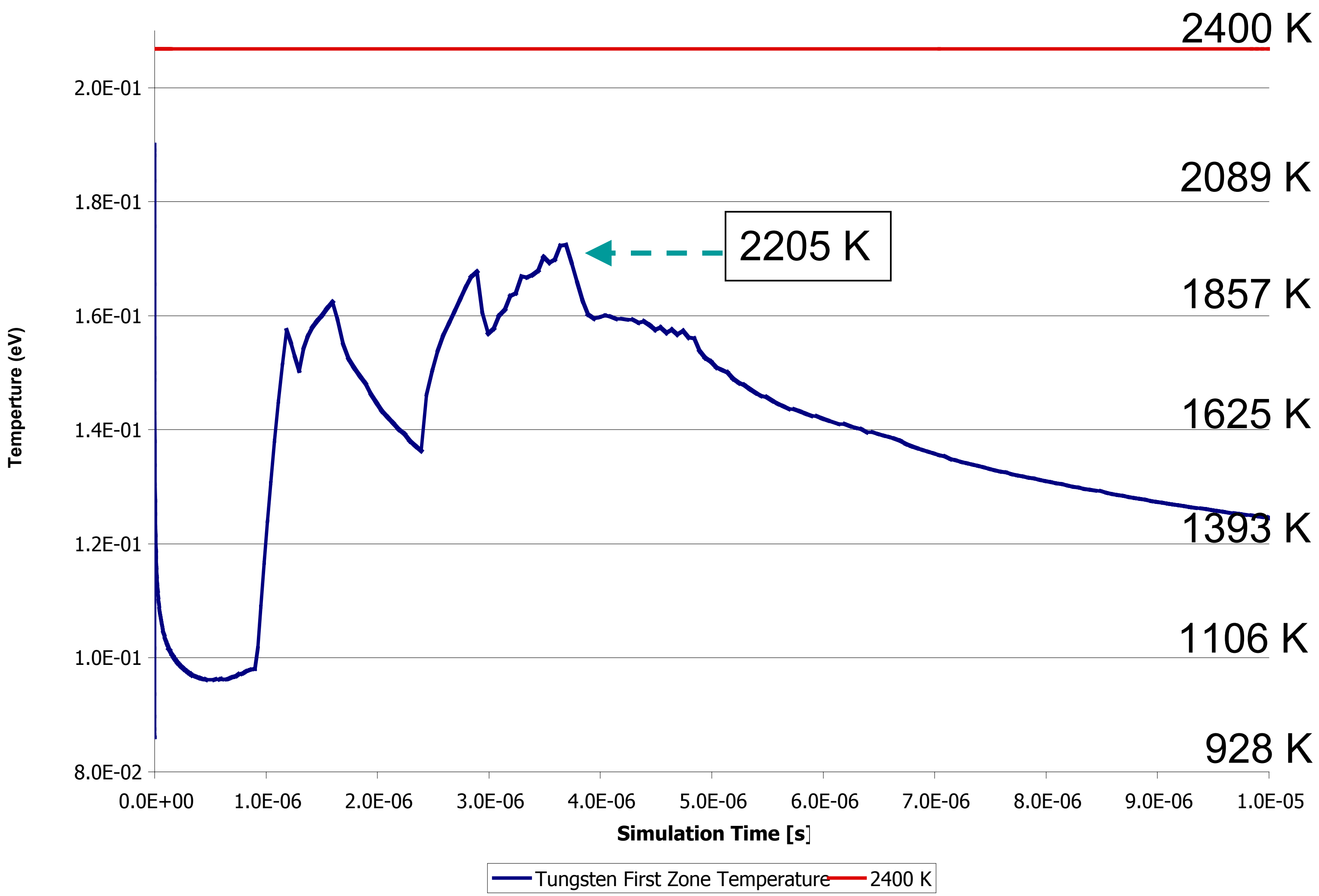
Cumulative target energy deposition in Xe gas and W wall



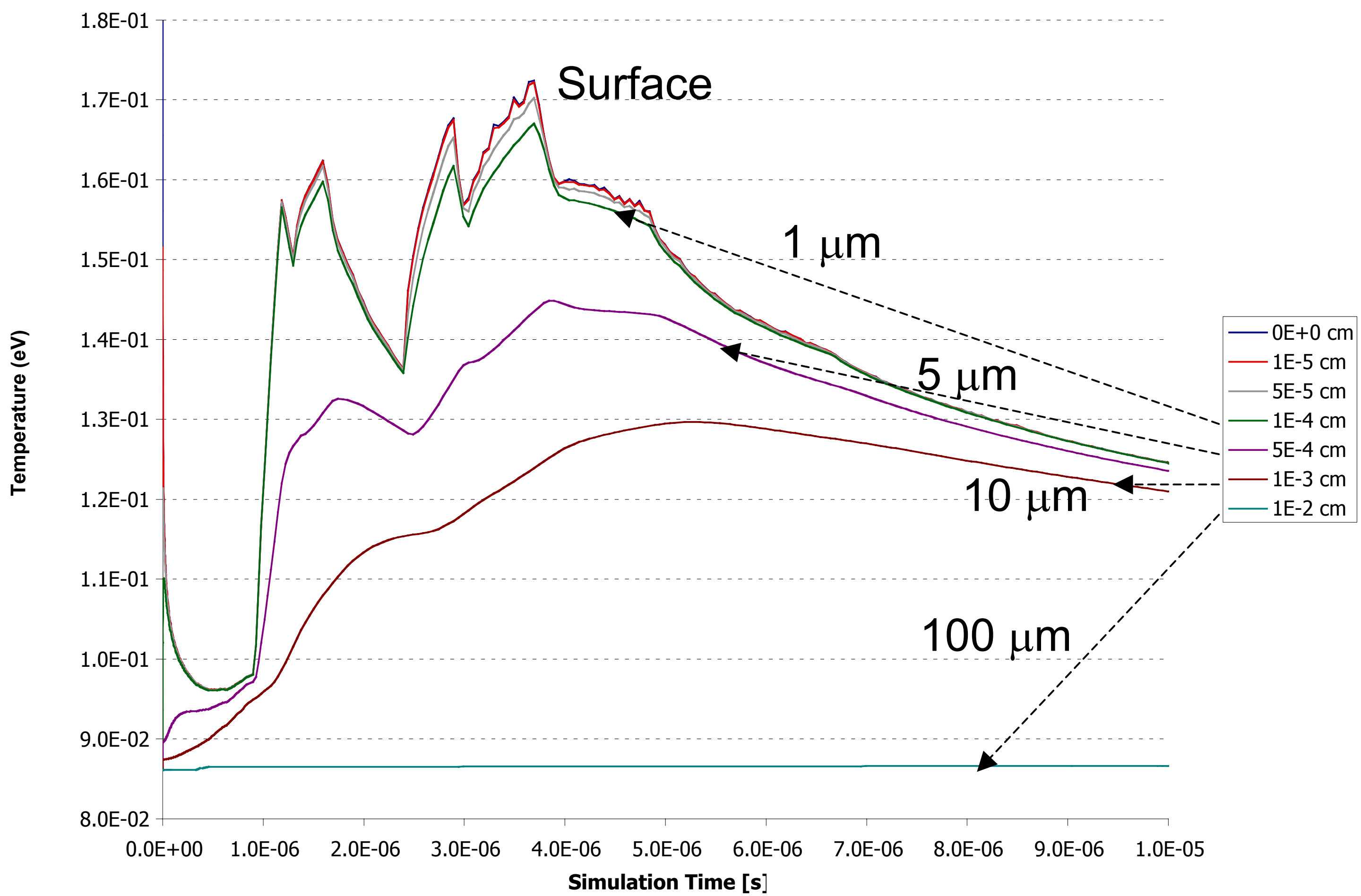
Tungsten surface temperature
(varies with splitting parameter)



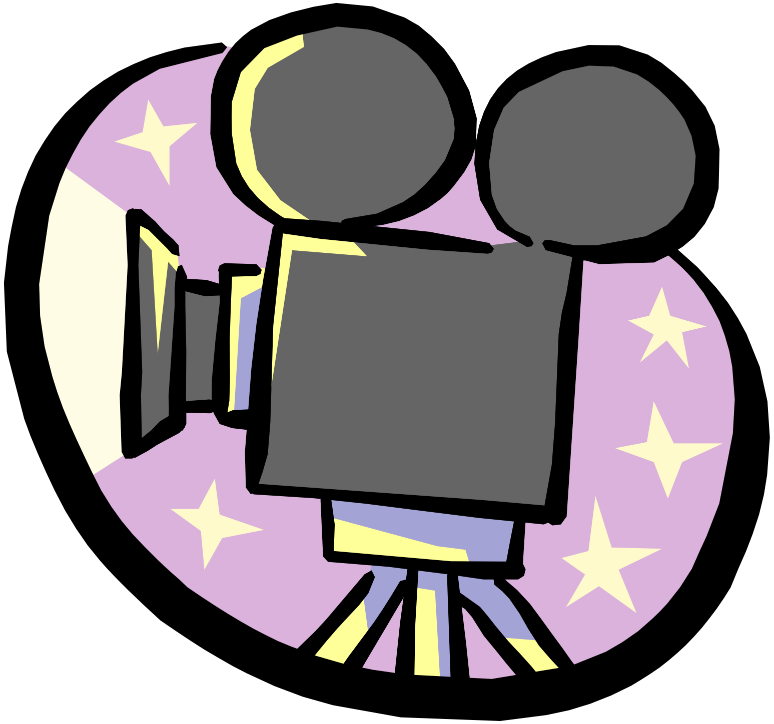
Tungsten surface temperature vs. time



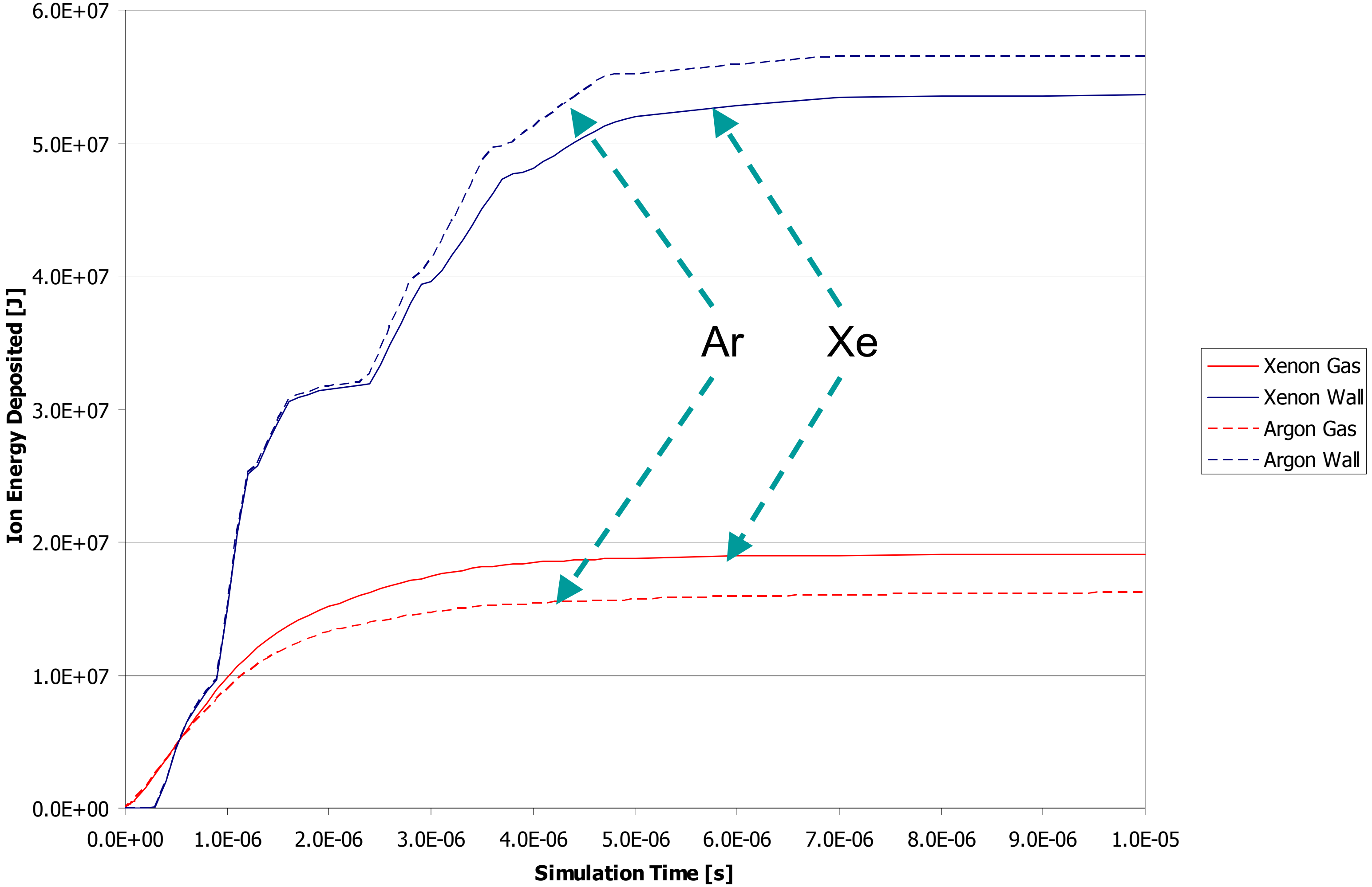
Tungsten temperature vs. time at various depths from surface



Tungsten wall temperature movie



Comparison of ion energy deposition for Xe & Ar chamber gas



First wall surface temperature vs. time for Xe and Ar gas

Zone-by-zone instability analysis performed on the HAPL target

- Based on the NRL HANE and SN 1987A Papers.
- Slight modifications of theory were done to account for streaming of ions and electrons in both directions with streams of different temperatures.
  - Post-processed using Mathematica®.
  - Details shown at right.

Buneman 1", $U_{1e} \geq v_{e2}$

$$\&\&\ \mathrm{Abs}\left[1 - \frac{Ti1}{Te2}\right] < 0.5\},$$

Buneman 2", $U_{2e} \geq v_{e1}$

$$\&\&\ \mathrm{Abs}\left[1 - \frac{Ti2}{Te1}\right] < 0.5\},$$

Ion-Acoustic 1", $\frac{Te2}{Ti1} > \frac{3}{zi1^2}\ \frac{ne2}{ni1}$

$$\&\&\ \frac{U_{1e}}{v_{e2}} > \frac{\omega_{pi1}}{\omega_{pe2}} + \left(\frac{\omega_{pi1}\, v_{e2}}{\omega_{pe2}\, v_{i1}}\right)^3 \mathrm{Exp}\left[-0.5\left(\frac{\omega_{pi1}\, v_{e2}}{\omega_{pe2}\, v_{i1}}\right)^2 - 1.5\right]$$

$$\&\&\ U_{12} > 2\,\mathrm{Max}[v_{e1}, v_{e2}]\ \frac{\omega_{pi1} + \omega_{pi2}}{\omega_{pe}}\},$$

Ion-Acoustic 2", $\frac{Te1}{Ti2} > \frac{3}{zi2^2}\ \frac{ne1}{ni2}$

$$\&\&\ \frac{U_{2e}}{v_{e1}} > \frac{\omega_{pi2}}{\omega_{pe1}} + \left(\frac{\omega_{pi2}\, v_{e1}}{\omega_{pe1}\, v_{i2}}\right)^3 \mathrm{Exp}\left[-0.5\left(\frac{\omega_{pi2}\, v_{e1}}{\omega_{pe1}\, v_{i2}}\right)^2 - 1.5\right]$$

$$\&\&\ U_{12} > 2\,\mathrm{Max}[v_{e1}, v_{e2}]\ \frac{\omega_{pi1} + \omega_{pi2}}{\omega_{pe}}\},$$

Ion-ion", $U_{12} \geq v_{i1} + v_{i2}$

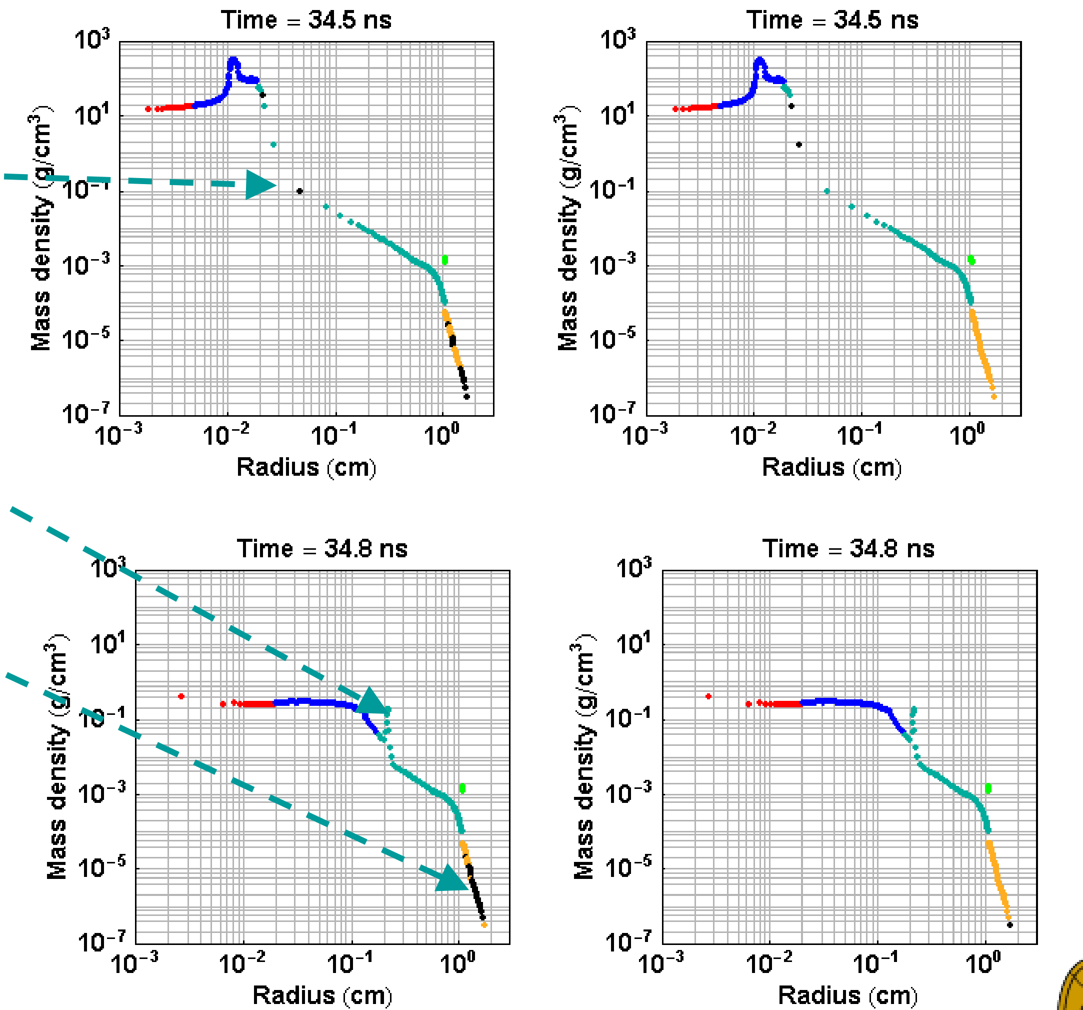
$$\&\&\ U_{12} \geq \frac{2\, v_j}{\alpha_{ji}^{1/3}}$$

$$\&\&\ U_{12} \leq 1.5\,\mathrm{Max}[v_{e1}, v_{e2}]\ \frac{\mathrm{Max}[\omega_{pi1}, \omega_{pi2}]}{\omega_{pe}}\left(1 + \alpha_{ji}^{1/3}\right)^{3/2}\}$$

Two-stream instabilities appear to play only a small role during target plasma expansion

- Near ignition, potentially unstable zones (in black) appear at the shock front.
- Main shock wave then propagates stably.
- Instabilities may affect the pressure-driven Au expansion.
- Calculations needed to evaluate whether wavelengths and growth times allow these instabilities to be important (seems unlikely).

Ion-ion instability | Ion-acoustic instability



Future plans for kinetic-ion modeling

1. Implement zone-by-zone diffusion in BUCKY.
   - Summer, 2005.
2. Generate detailed ion energy spectra at first wall.
   - Summer/early Fall, 2005.
3. Perform more detailed assessment of potential two-stream instabilities.
   - Fall, 2005, if evaluated as worth pursuing by NRL/UW consensus
4. Simulate empty foam target with BUCKY to allow complete analysis.

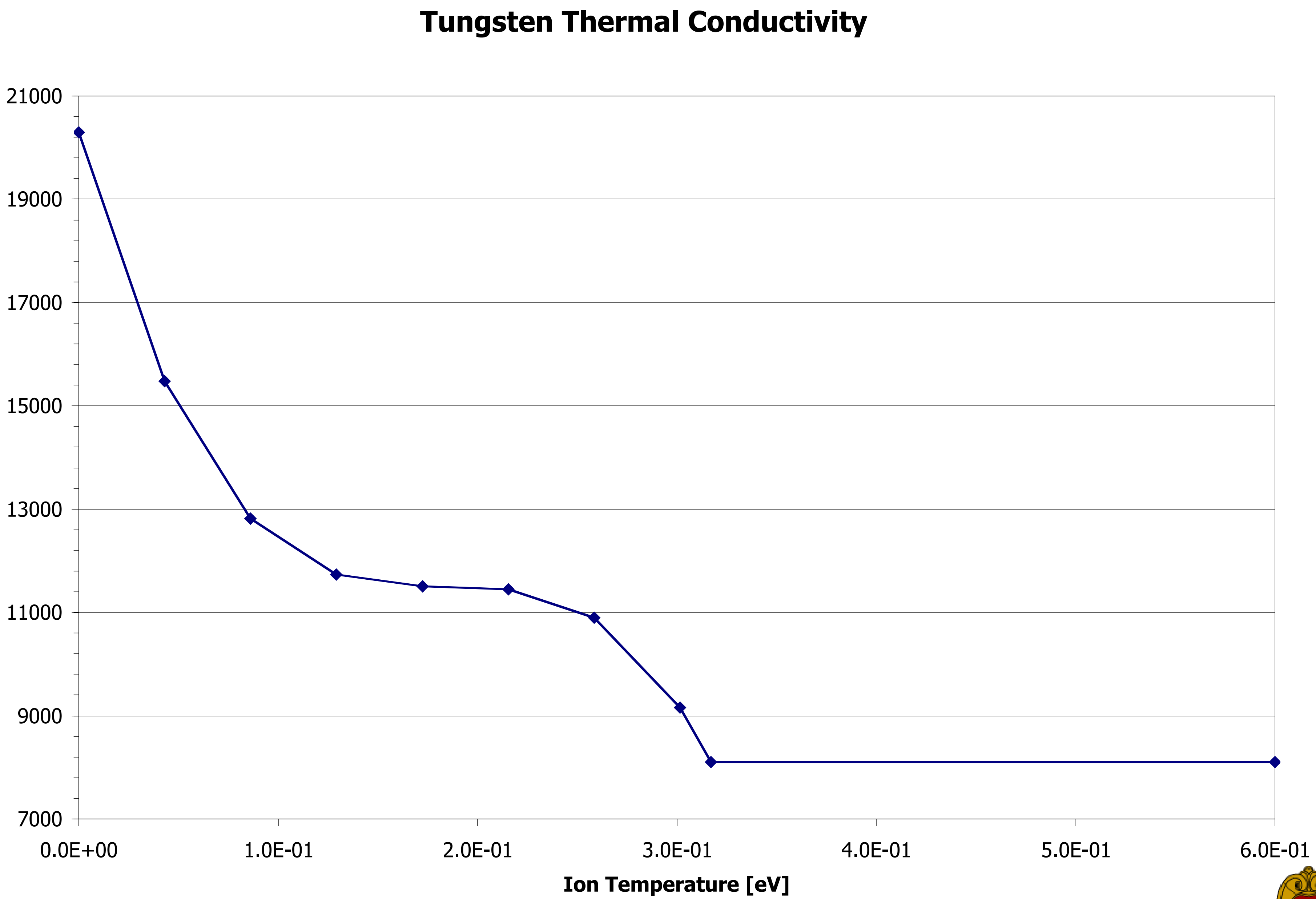
Conclusions

- Collisional hydrodynamic expansion of HAPL target into 50 mTorr Xe gas yields no disturbance at 6.5 m. Shock is dissipated about 2 m from chamber center. Ion instability analysis suggests that collisional expansion model is unlikely to be valid.
- Integrated BUCKY simulation of kinetic target source term – chamber gas – first wall response is being used in “production mode”.

Conclusions

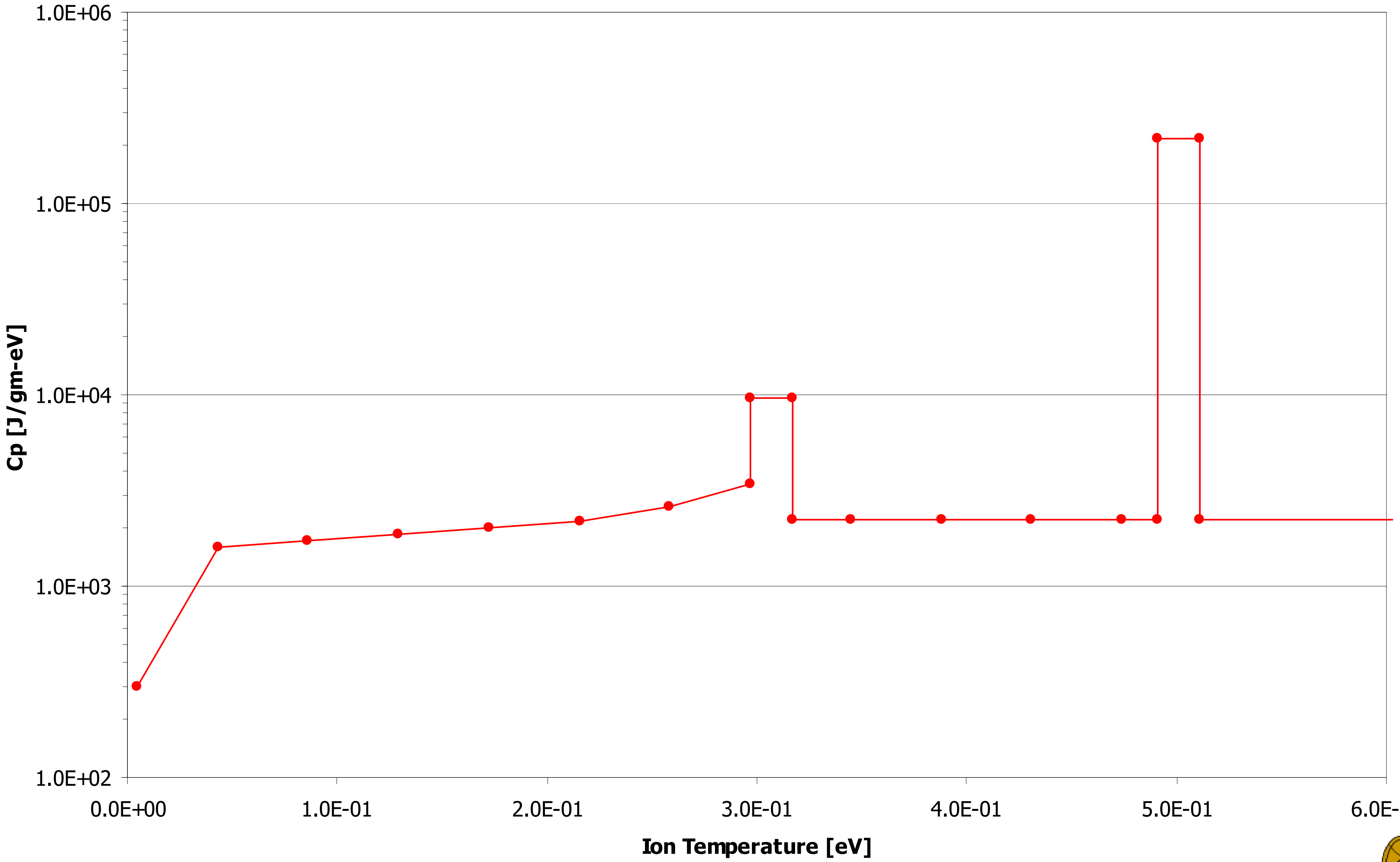
- For chamber radius of 10.5 m, 8 mTorr Xe chamber gas and 343 MJ empty foam target spectra, maximum temperature in tungsten first wall is predicted to be 2205 K at 3.6 μs.
- For 8 mTorr Ar gas, maximum surface temperature is 2287 K.
- Anomalous ion kinetic transport due to ion instabilities appears to be low probability for target expansion conditions.

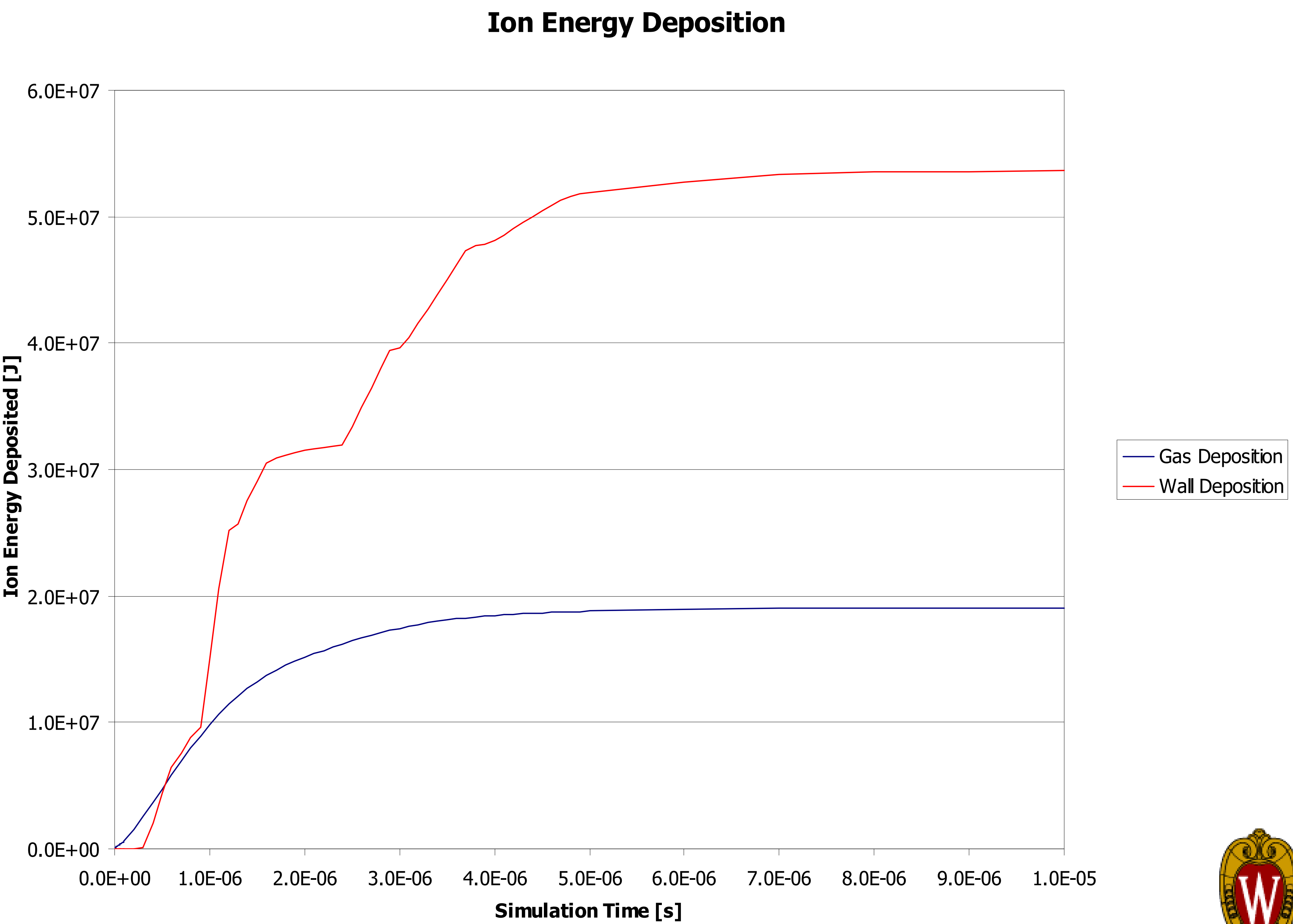
Extra slides



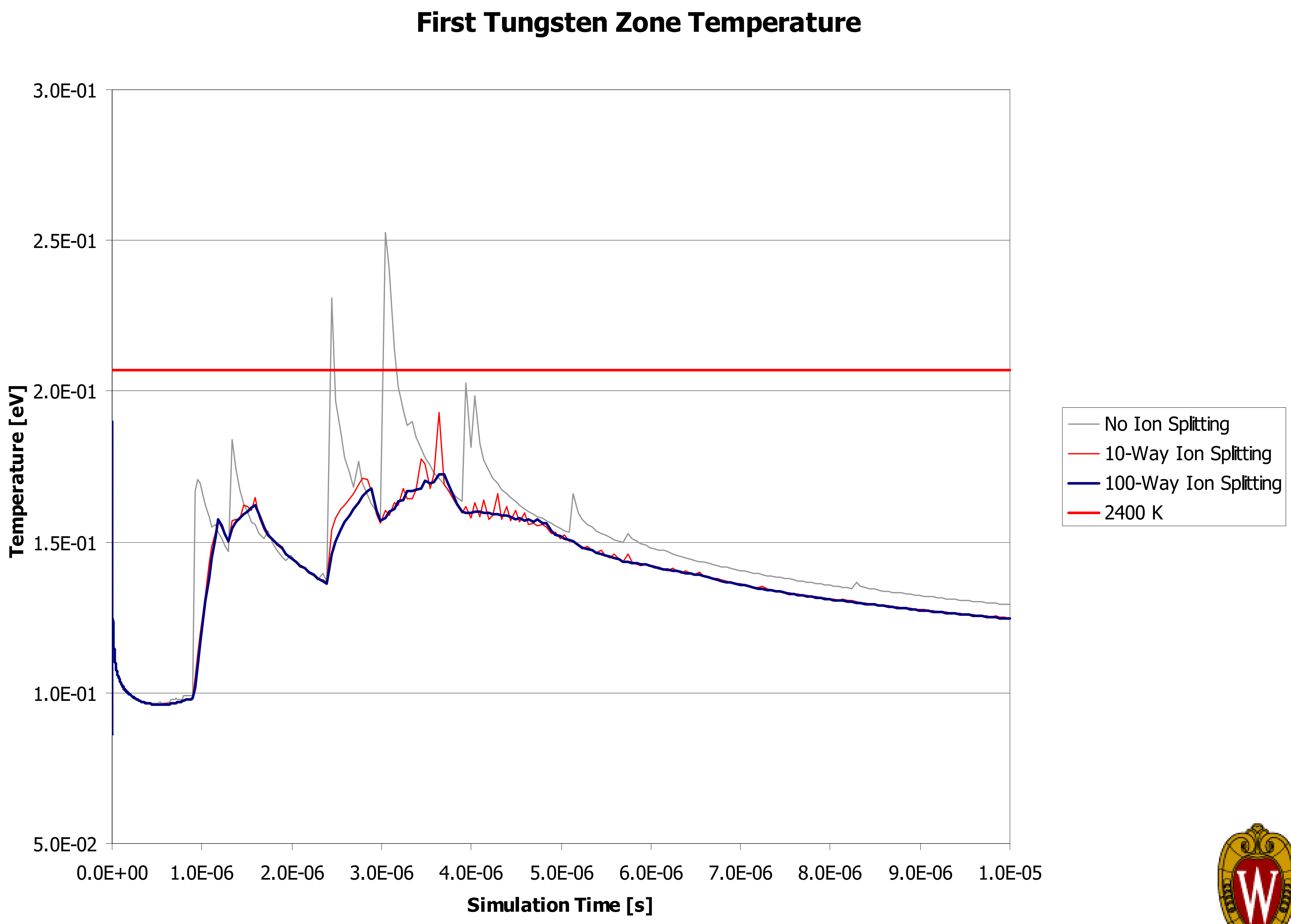
Tungsten Thermal Conductivity
21000
19000
17000
15000
13000
11000
9000
7000
0.0E+00
1.0E-01
2.0E-01
3.0E-01
4.0E-01
5.0E-01
6.0E-01
Ion Temperature [eV]

Specific Heat of Tungsten

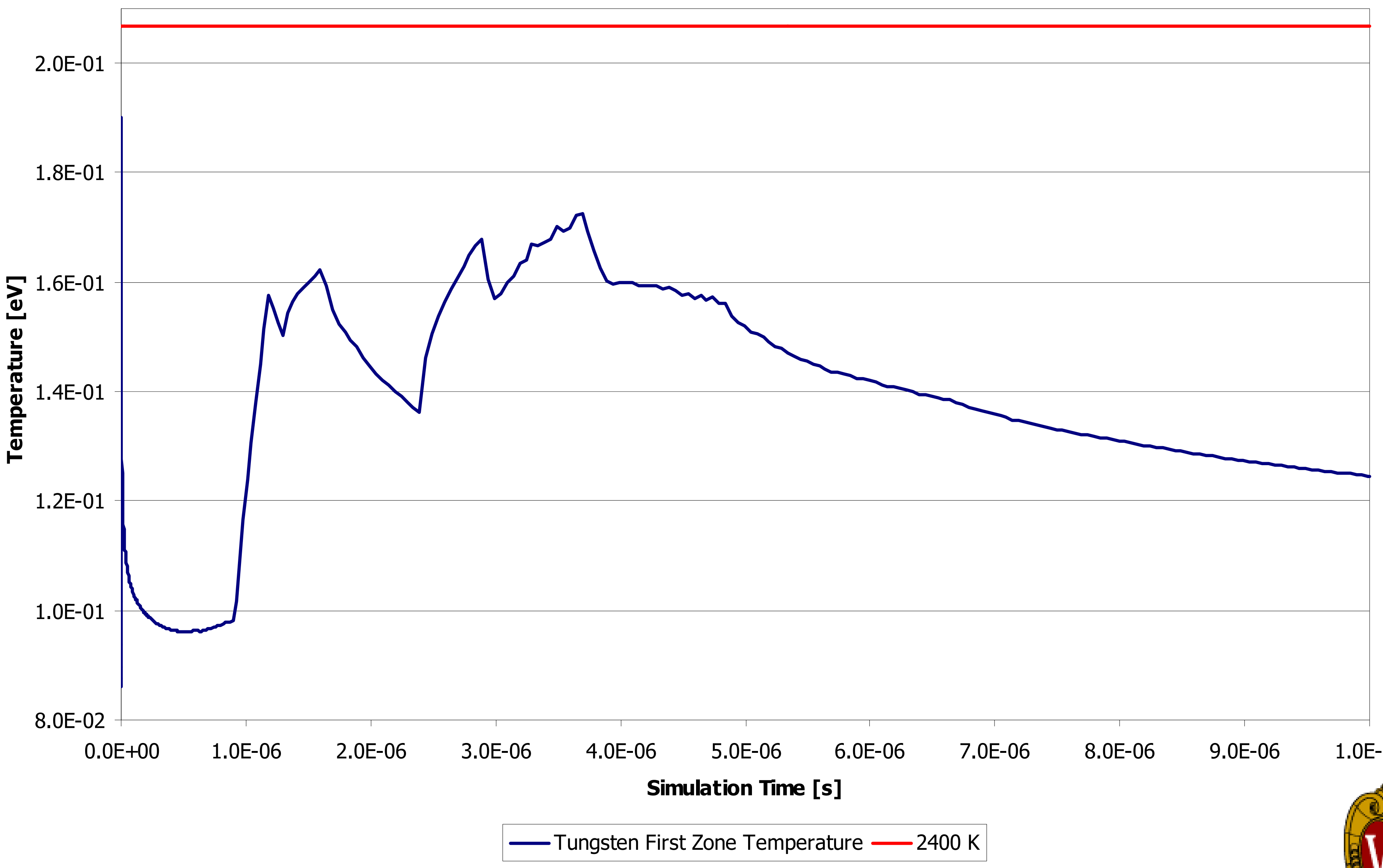




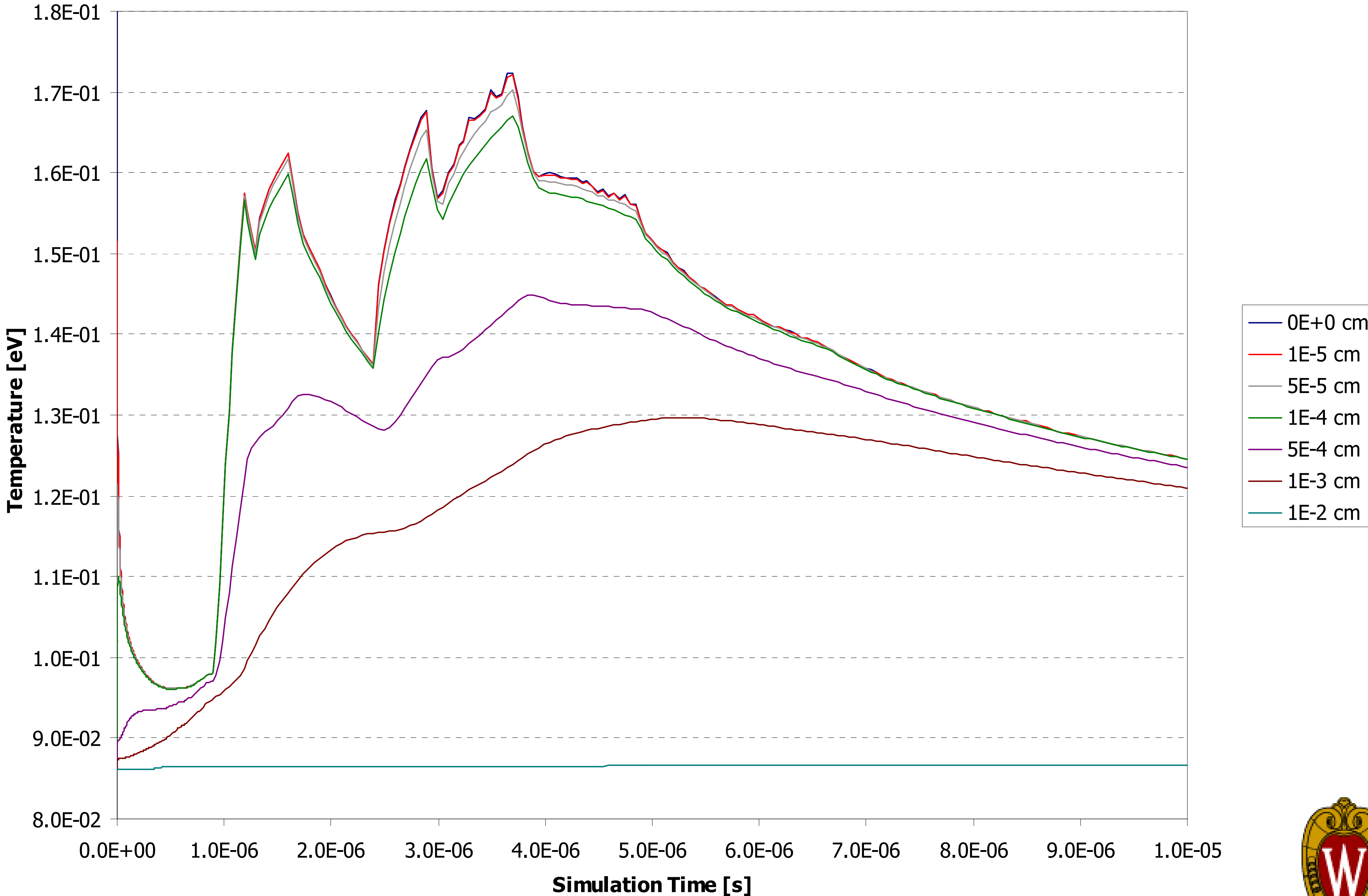
Ion Energy Deposition
6.0E+07
5.0E+07
4.0E+07
3.0E+07
2.0E+07
1.0E+07
0.0E+00
Ion Energy Deposited [J]
0.0E+00
1.0E-06
2.0E-06
3.0E-06
4.0E-06
5.0E-06
6.0E-06
7.0E-06
8.0E-06
9.0E-06
1.0E-05
Simulation Time [s]
Gas Deposition
Wall Deposition

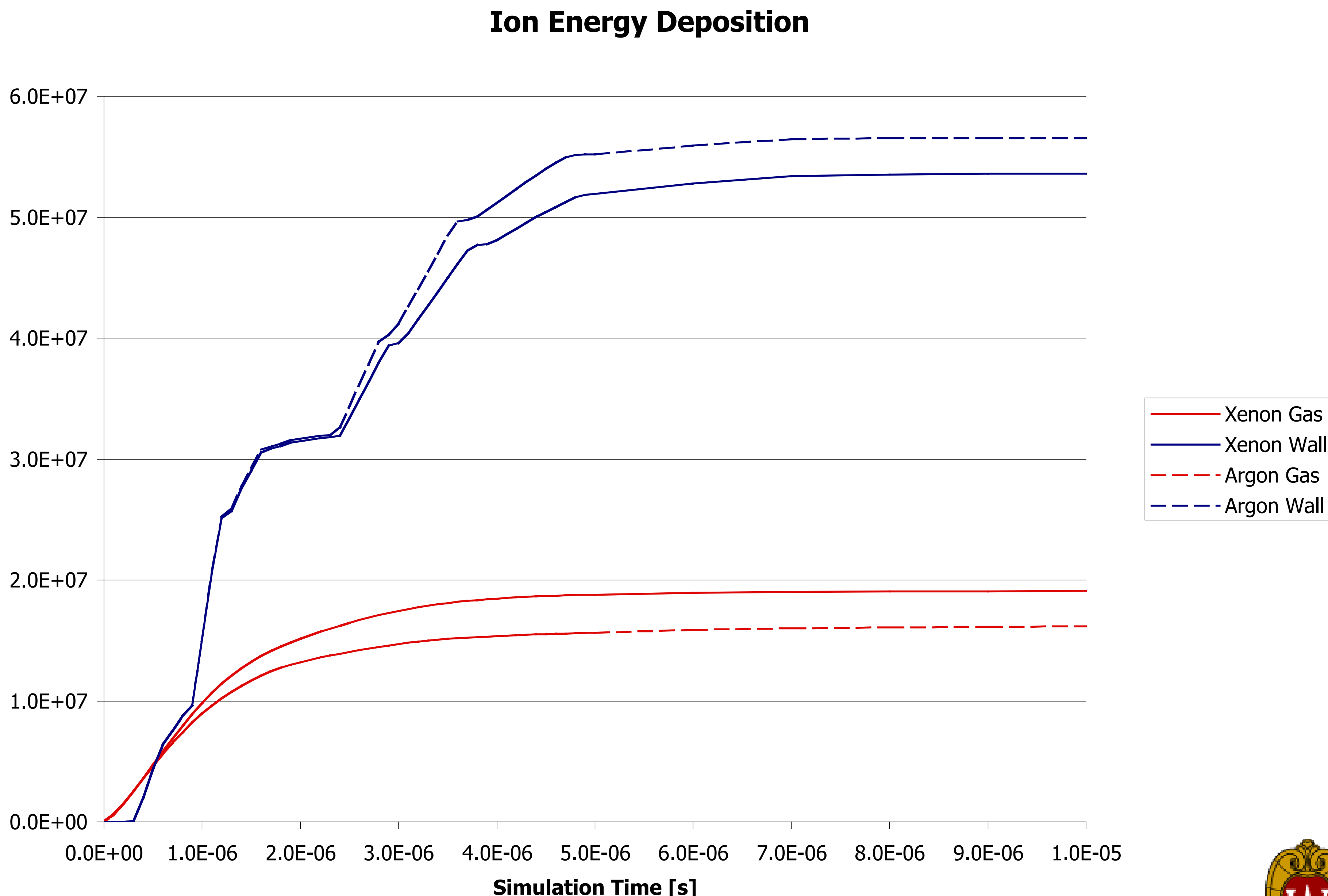

First Tungsten Zone Temperature
3.0E-01
2.5E-01
2.0E-01
1.5E-01
1.0E-01
5.0E-02
Temperature [eV]
0.0E+00
1.0E-06
2.0E-06
3.0E-06
4.0E-06
5.0E-06
6.0E-06
7.0E-06
8.0E-06
9.0E-06
1.0E-05
Simulation Time [s]
No Ion Splitting
10-Way Ion Splitting
100-Way Ion Splitting
2400 K

First Tungsten Zone Temperature



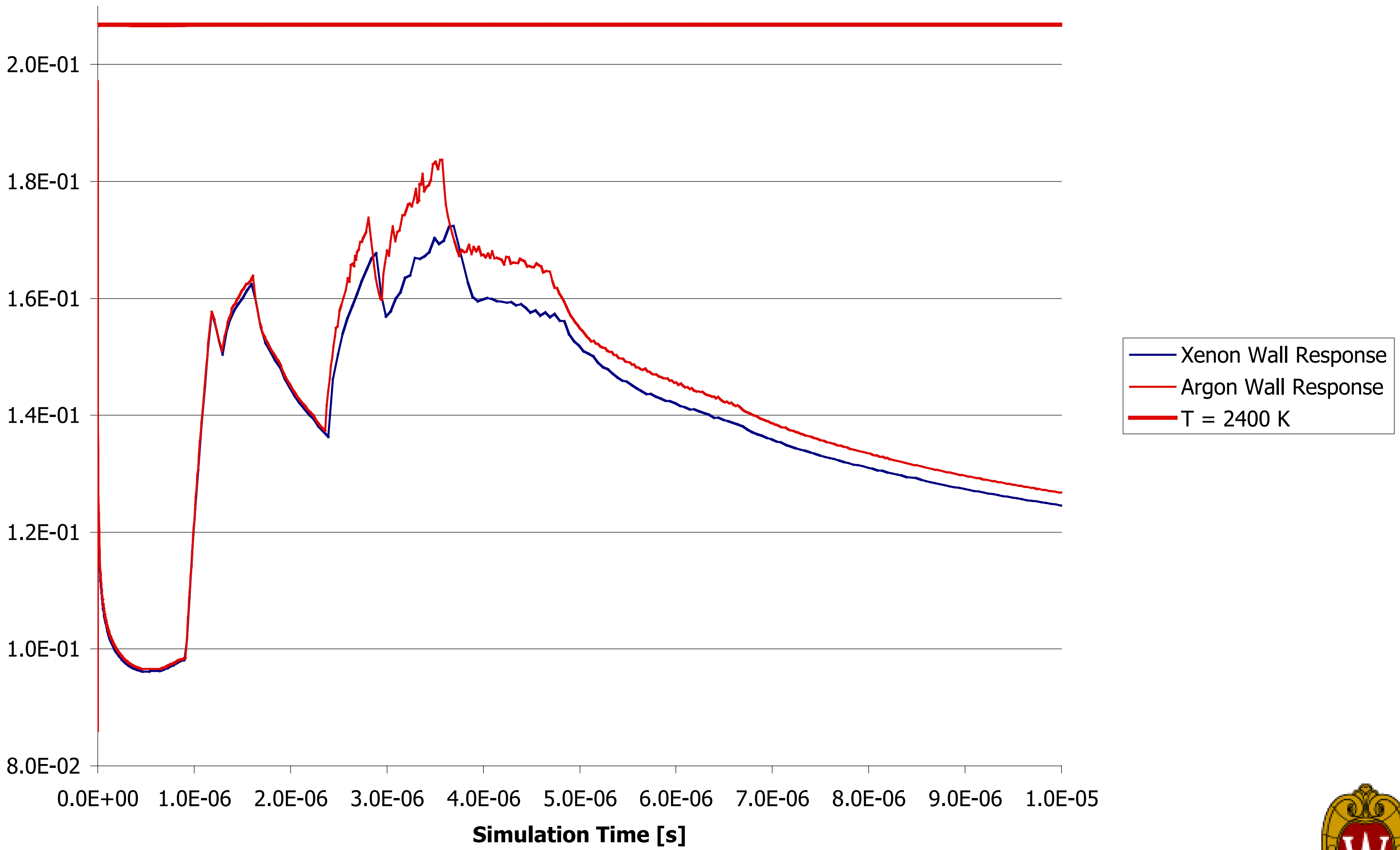
Tungsten Temperature by Depth

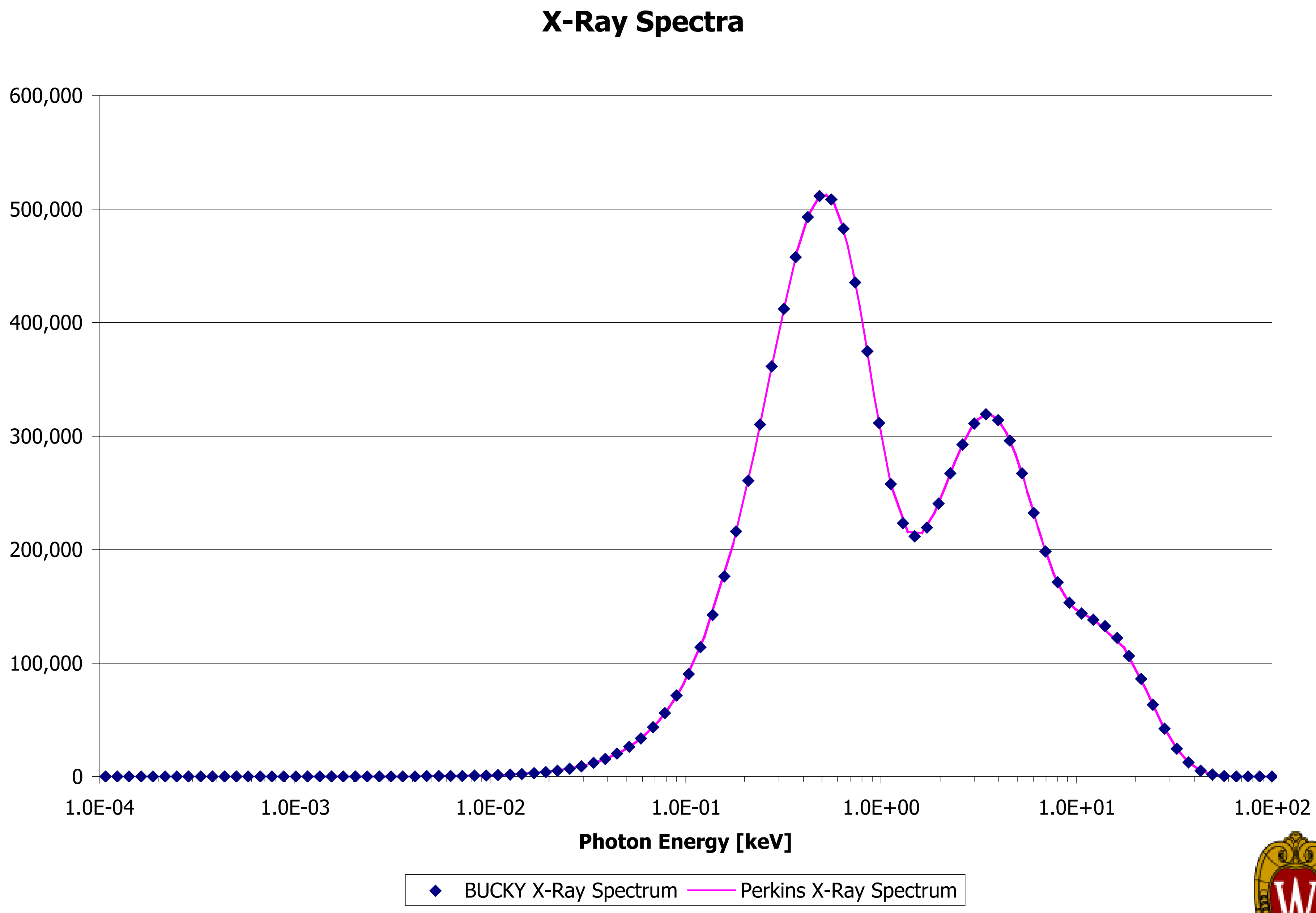




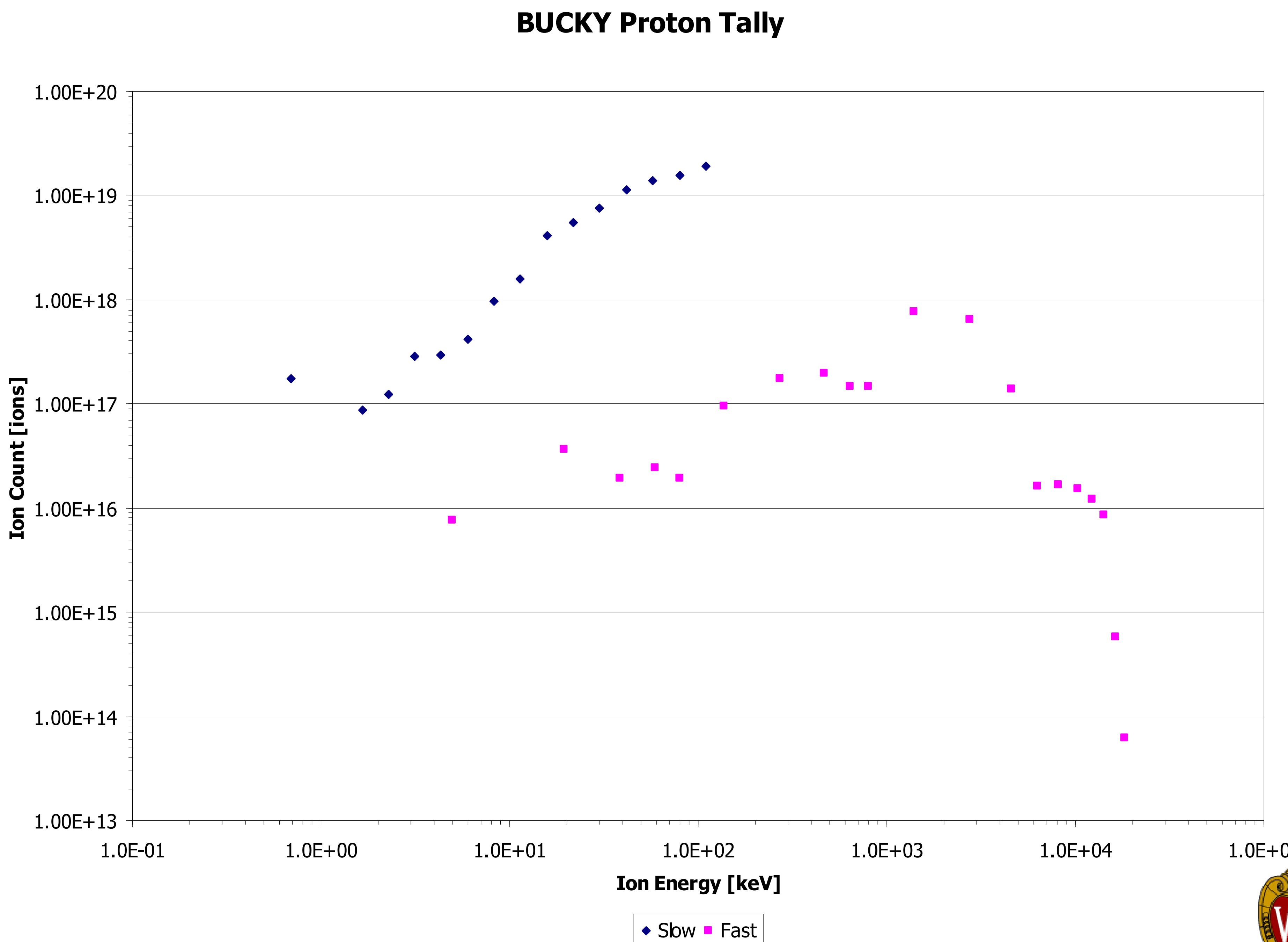
Ion Energy Deposition
6.0E+07
5.0E+07
4.0E+07
3.0E+07
2.0E+07
1.0E+07
0.0E+00
0.0E+00
1.0E-06
2.0E-06
3.0E-06
4.0E-06
5.0E-06
6.0E-06
7.0E-06
8.0E-06
9.0E-06
1.0E-05
Simulation Time [s]
Xenon Gas
Xenon Wall
Argon Gas
Argon Wall

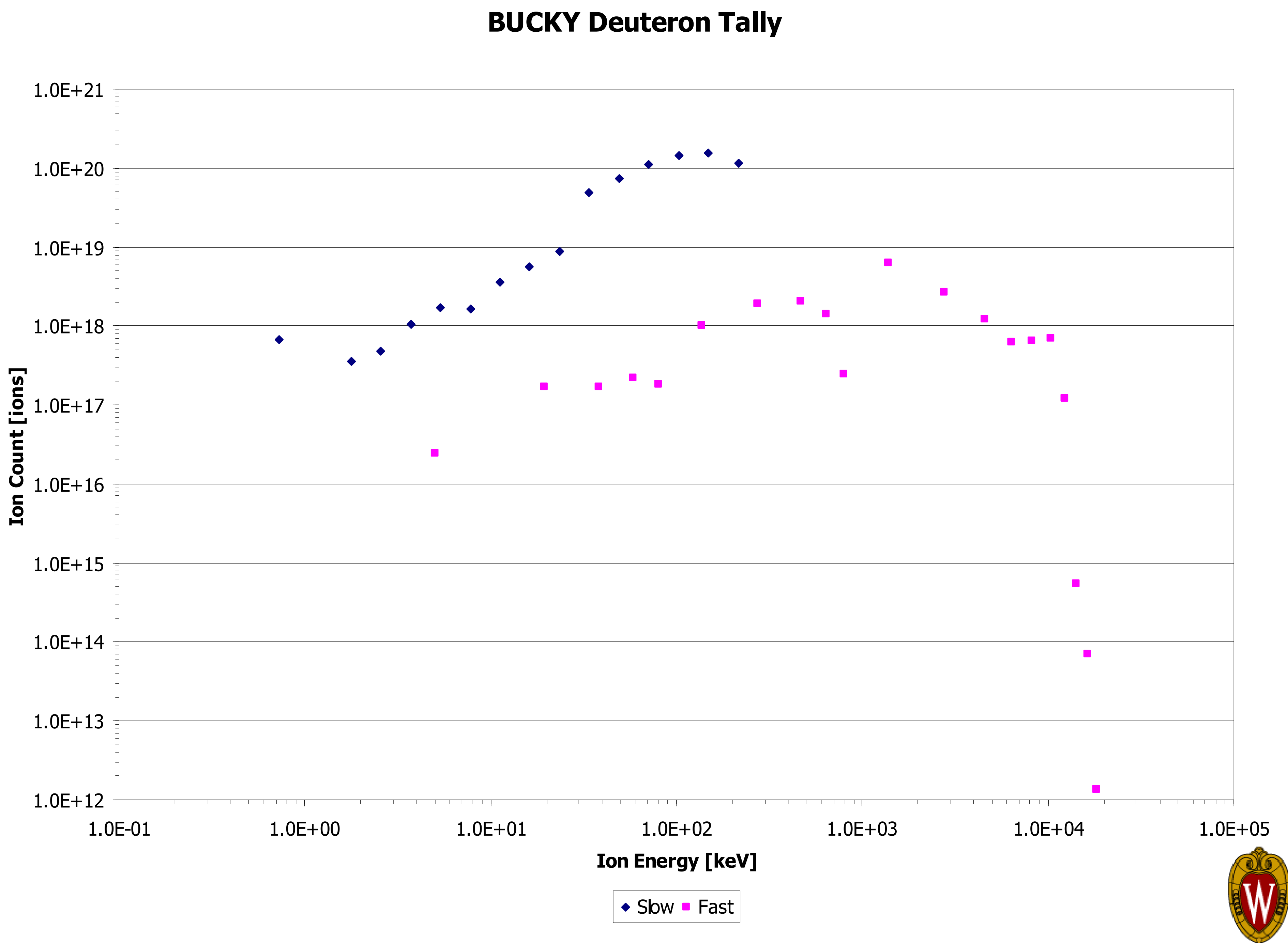
First Tungsten Zone Temperature



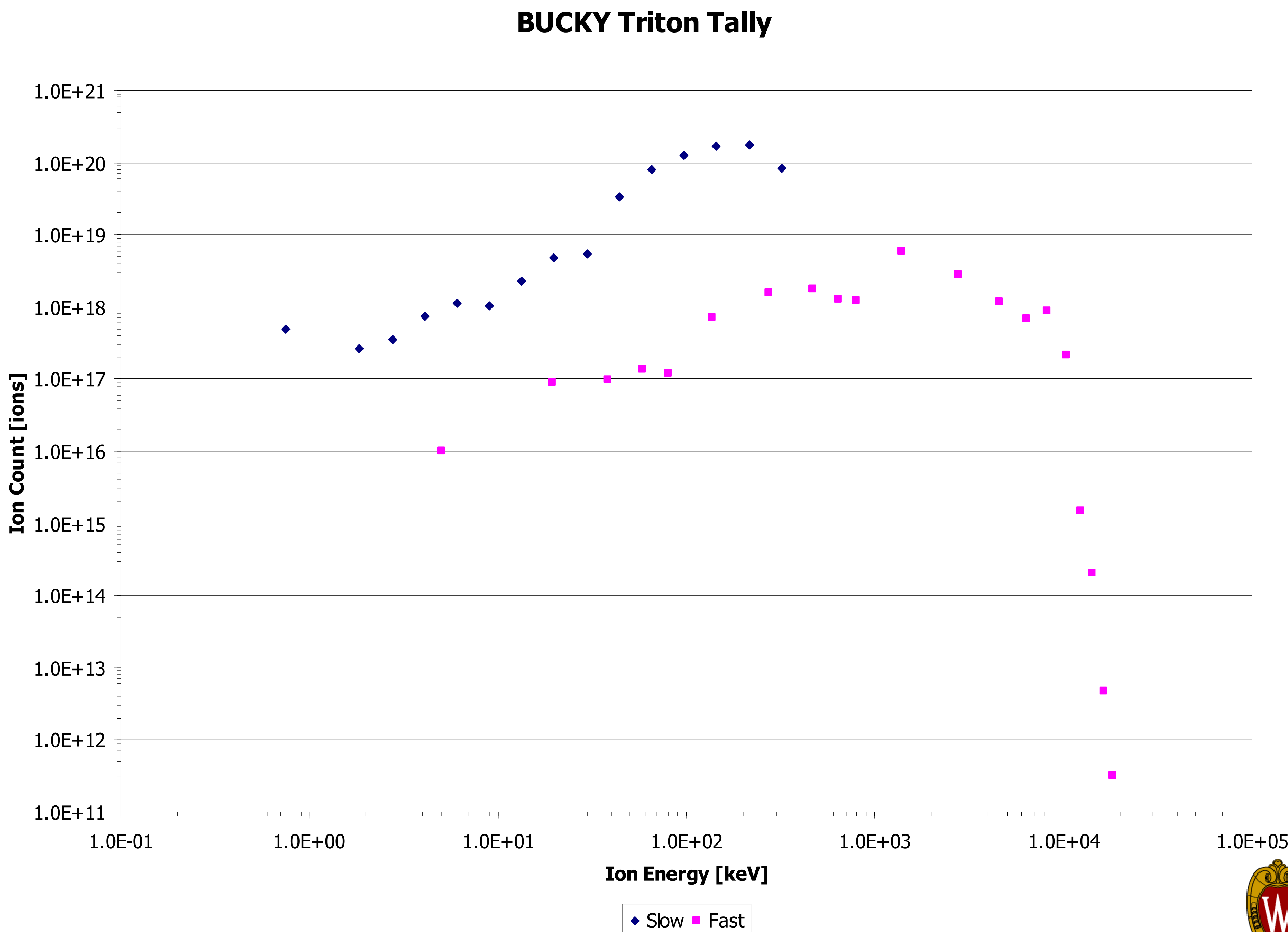


X-Ray Spectra
600,000
500,000
400,000
300,000
200,000
100,000
0
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
Photon Energy [keV]
BUCKY X-Ray Spectrum
Perkins X-Ray Spectrum

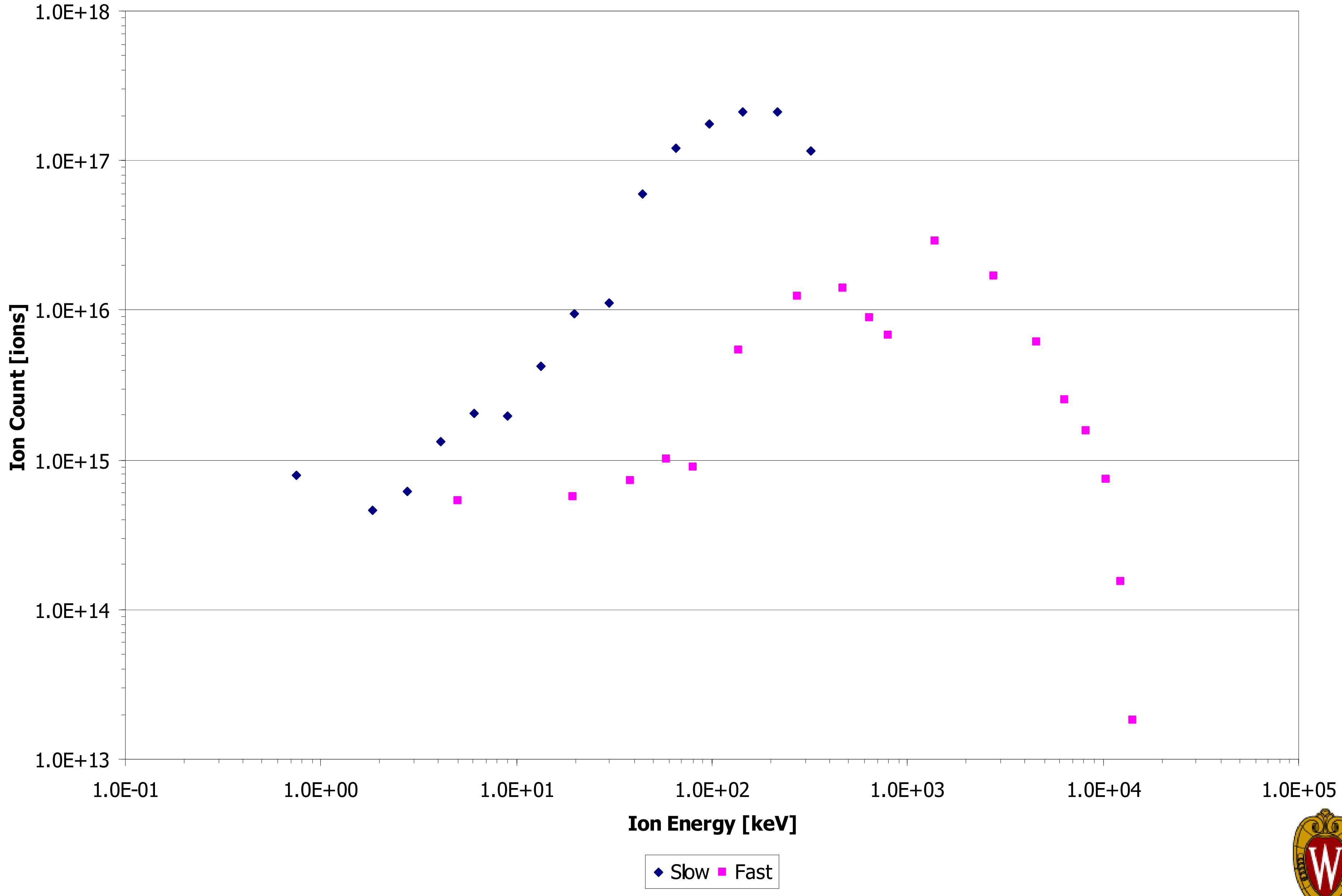

BUCKY Proton Tally
1.00E+20
1.00E+19
1.00E+18
1.00E+17
1.00E+16
1.00E+15
1.00E+14
1.00E+13
Ion Count [ions]
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
Ion Energy [keV]
Slow
Fast



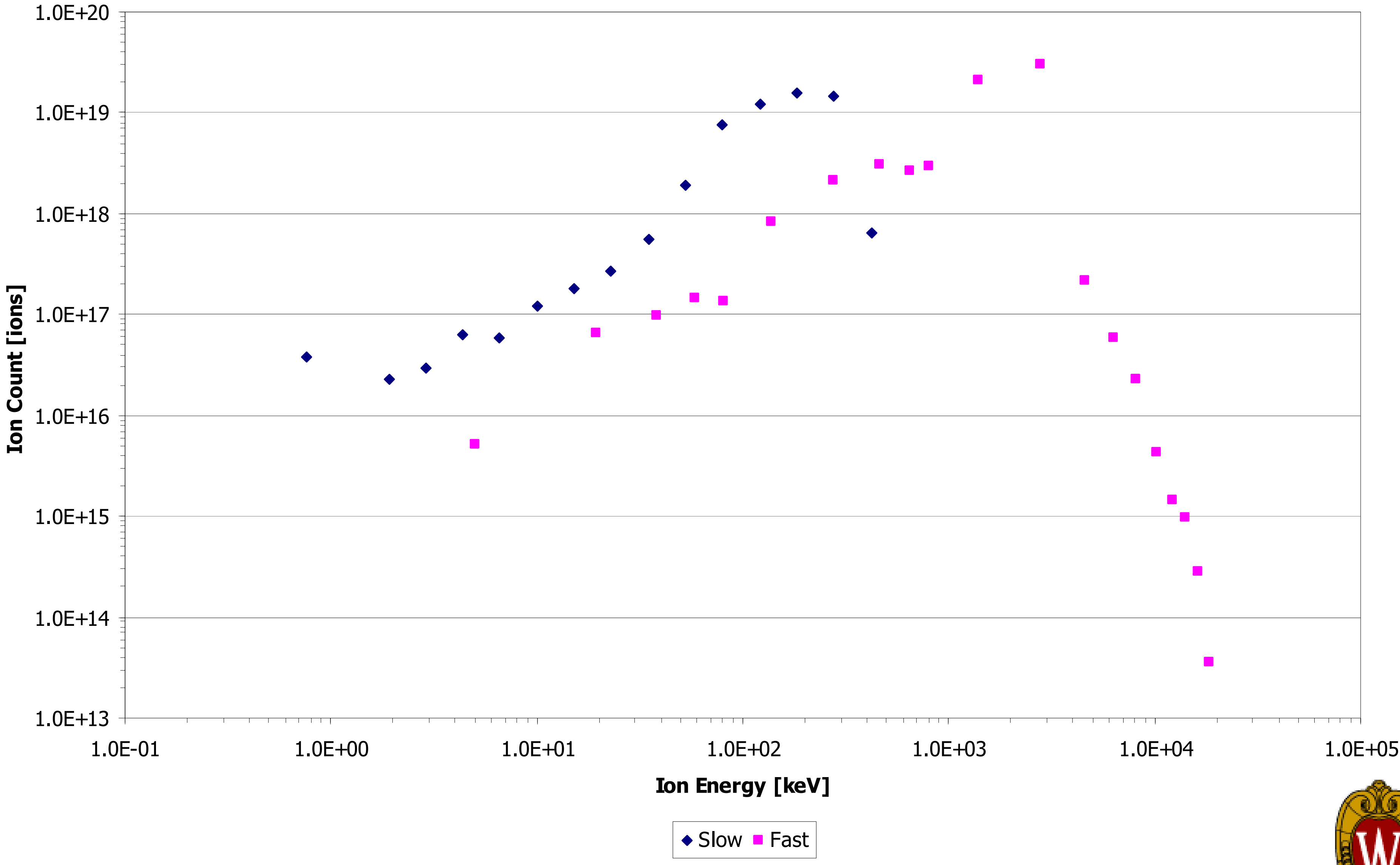
BUCKY Deuteron Tally
1.0E+21
1.0E+20
1.0E+19
1.0E+18
1.0E+17
1.0E+16
1.0E+15
1.0E+14
1.0E+13
1.0E+12
Ion Count [ions]
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
Ion Energy [keV]
Slow
Fast

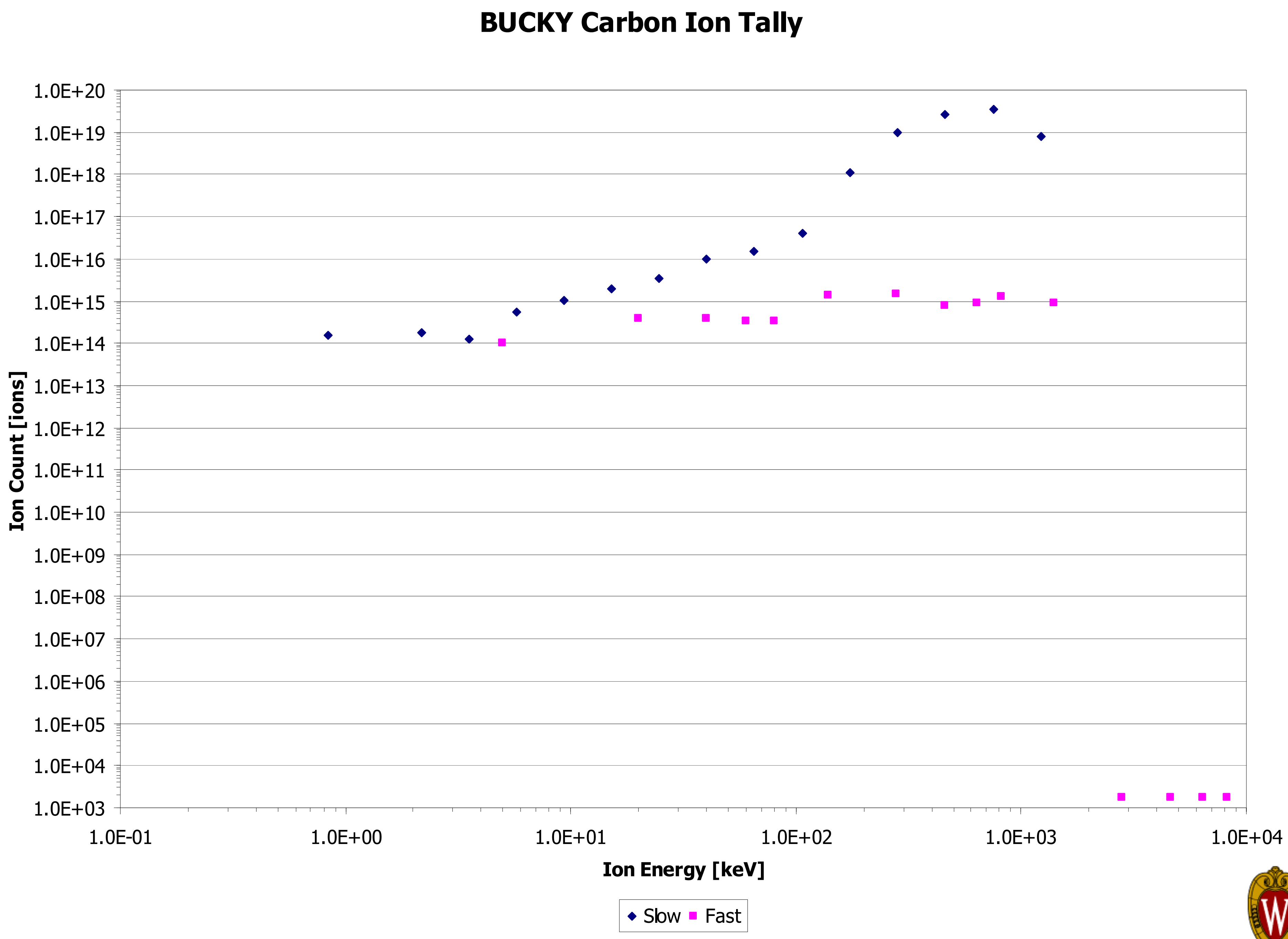

BUCKY Triton Tally
Ion Count [ions]
1.0E+21
1.0E+20
1.0E+19
1.0E+18
1.0E+17
1.0E+16
1.0E+15
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
Ion Energy [keV]
Slow
Fast

BUCKY Helium-3 Tally



BUCKY Helium-4 Tally




BUCKY Carbon Ion Tally
Ion Count [ions]
1.0E+20
1.0E+19
1.0E+18
1.0E+17
1.0E+16
1.0E+15
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
Ion Energy [keV]
Slow
Fast