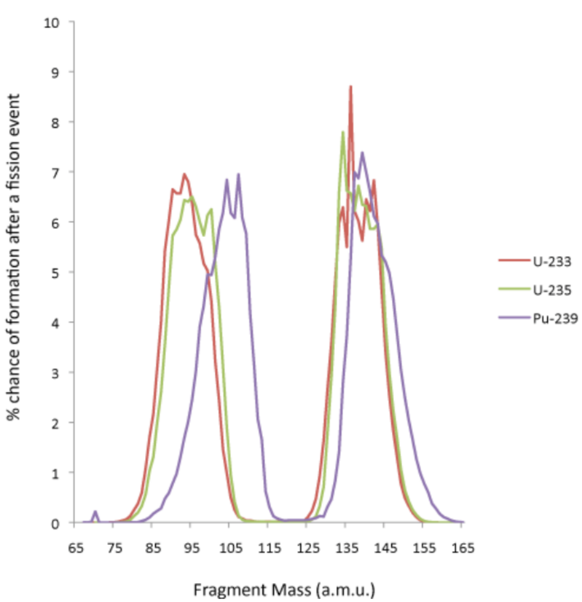
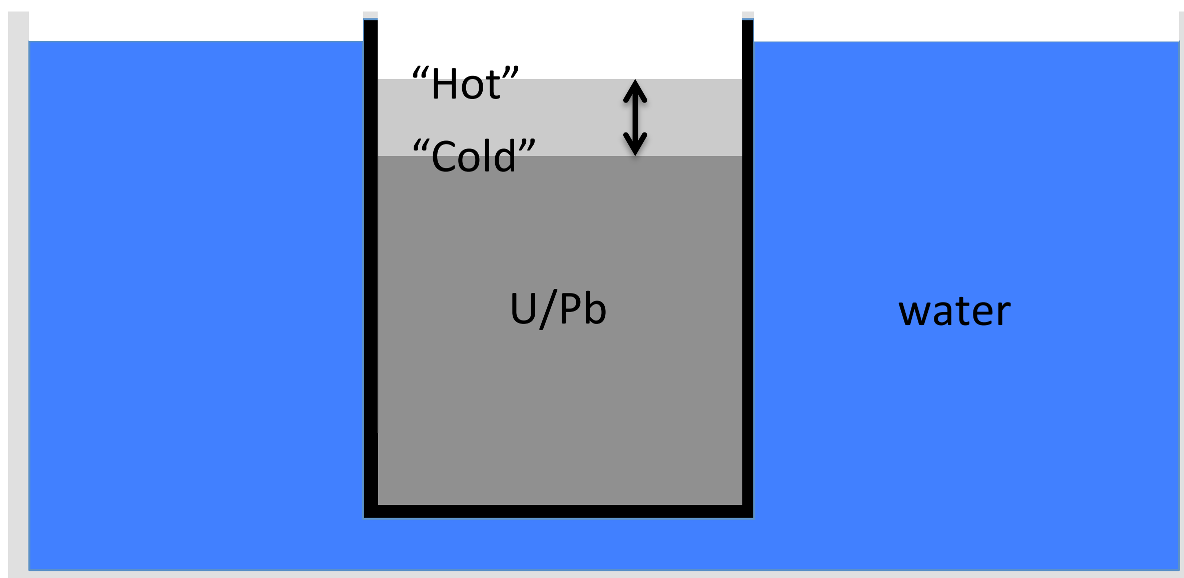
MIT Ph.D. Qualifying Oral Exam Question in Reactor Physics

PUBAR





Kim Jong-un will soon operate the PUBAR, Pu Bathtub Reactor, in the backyard swimming pool at his residence in Pyongyang. Special cooling coils/circulators have been installed in the swimming pool so water can be maintained at a uniform hot-tub temperature of 45C when the reactor is operated at 5 MW thermal. The core is a cylindrical platinum tank (with 10.0 cm thick honeycomb-walls, thermal conductivity of 9.0 W/m-K, and melting point of 2100K) filled with a homogenous solution of uranium metal melted into liquid lead (solubility limit is 45 weight percent uranium) – whose high thermal conductivity was chosen to maintain a nearly uniform fuel temperature distribution during steady-state reactor operation. The designers claim the reactor can operate without external control because as power and temperature increase, the high thermal expansion reduces the density of the U/Pb solution and automatically controls core reactivity. The reactor tank is open so all fission products are immediately volatilized and released into the atmosphere – eliminating any fission product poisoning.

The reactor has been designed so long term reactivity control is achieved by the Great Marshall himself, who will arise each morning and throw 93% enriched uranium (EU) metal pellets (5 grams each) into the reactor from his bedroom balcony.

Reactor Design:

North Korean reactor physicists have no computers, and they have relied on analytic solutions of one-group neutron diffusion equations for the reactor's design.

1. How does the fuel solution k-infinity and neutron migration area change with the U/Pb ratio?
2. If maximizing the Pu^{239} production rate is the primary reactor goal, explain the physics principles that will determine the optimum U/Pb ratio and core height & diameter?
3. If the core was designed to operate at a average solution temperature of 1900K at full power (with a fuel temperature coefficient of -1.0 pcm/K), how would designers go about computing the appropriate k-infinity for the U/Pb solution when melted at 1400K for the initial core tank filling?
4. The morning following the reactor's first full-power day of operation, approximately how many EU pellets will the Great Marshall have to throw in - so the reactor will return to full power?

Cross Section Generation Methods:

You have access to western-world reactor physics tools.

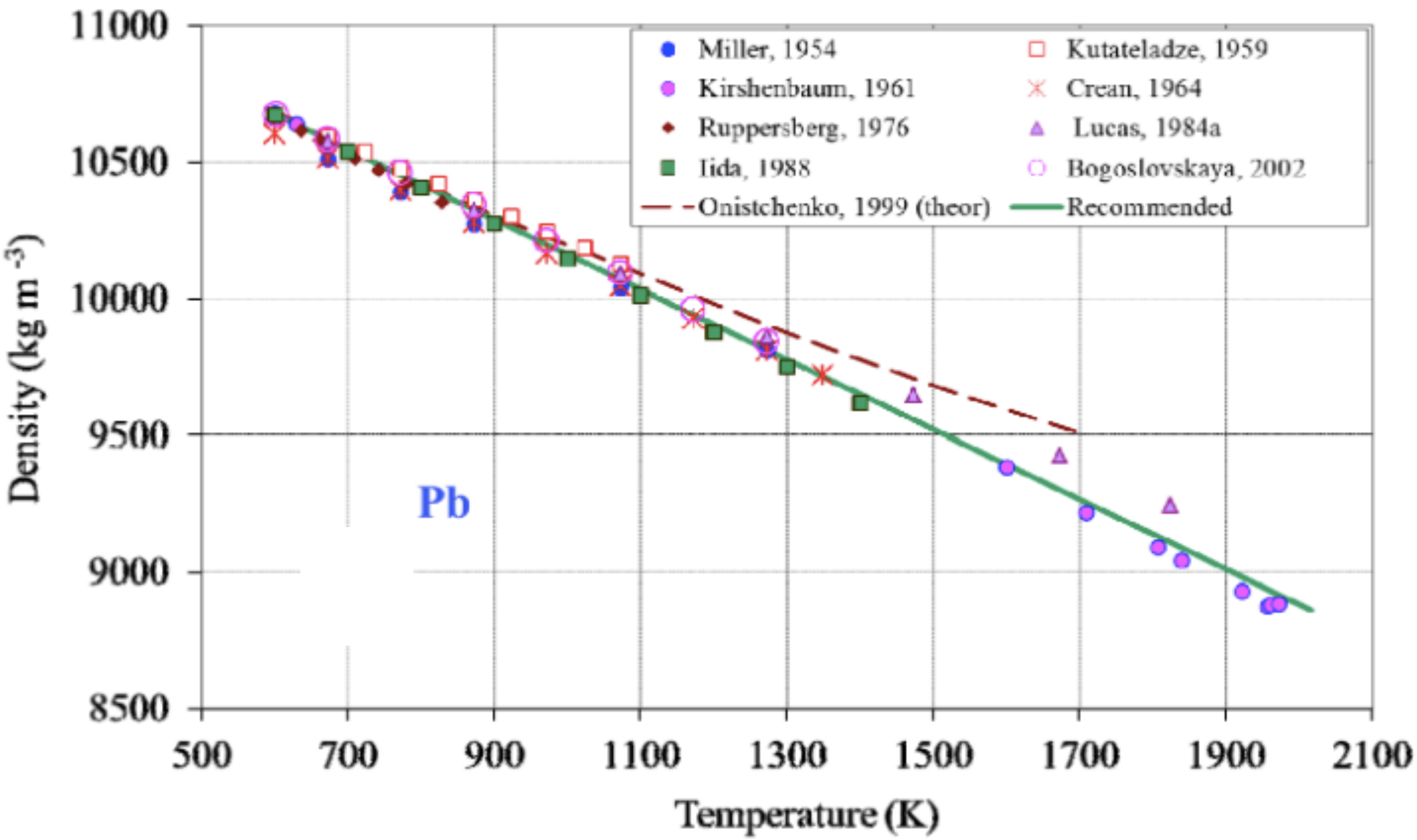
5. How would you go about generating accurate 1-group and 2-group cross sections for core and reflector regions?
6. How would you evaluate the importance of resonance overlap (or interference) in generation of cross sections for the mixed U/Pb solution?

3D Transport Methods:

Unbeknownst to the Great Marshall, the CIA operates a surveillance drone that flies a 25-km circular pattern that passes vertically over the reactor at one point in its circle, and it operates at a height of 25 km. This drone has recently been modified with gamma detecting bottom wing coverings that can measure the intensity and energies of incoming gammas. The CIA has the world's largest computers, has nearly infinite monetary resources, and wants desperately to determine the amount of Pu^{239} at all times in the PUBAR.

7. What is the ratio of peak-to-minimum total un-collided gamma intensity observed as the drone makes its circular path?
8. What 3-D transport method would you recommend for computationally studying the potential for detecting un-collided gammas produced from various Pu and U fission products produced by PUBAR?
9. What physics principles would you use to select the most appropriate Pu and U fission product gammas to interrogate, with a goal of minimizing the uncertainty in deducing the reactor's Pu^{239} inventory?

Some Liquid U and Pb Thermal Properties



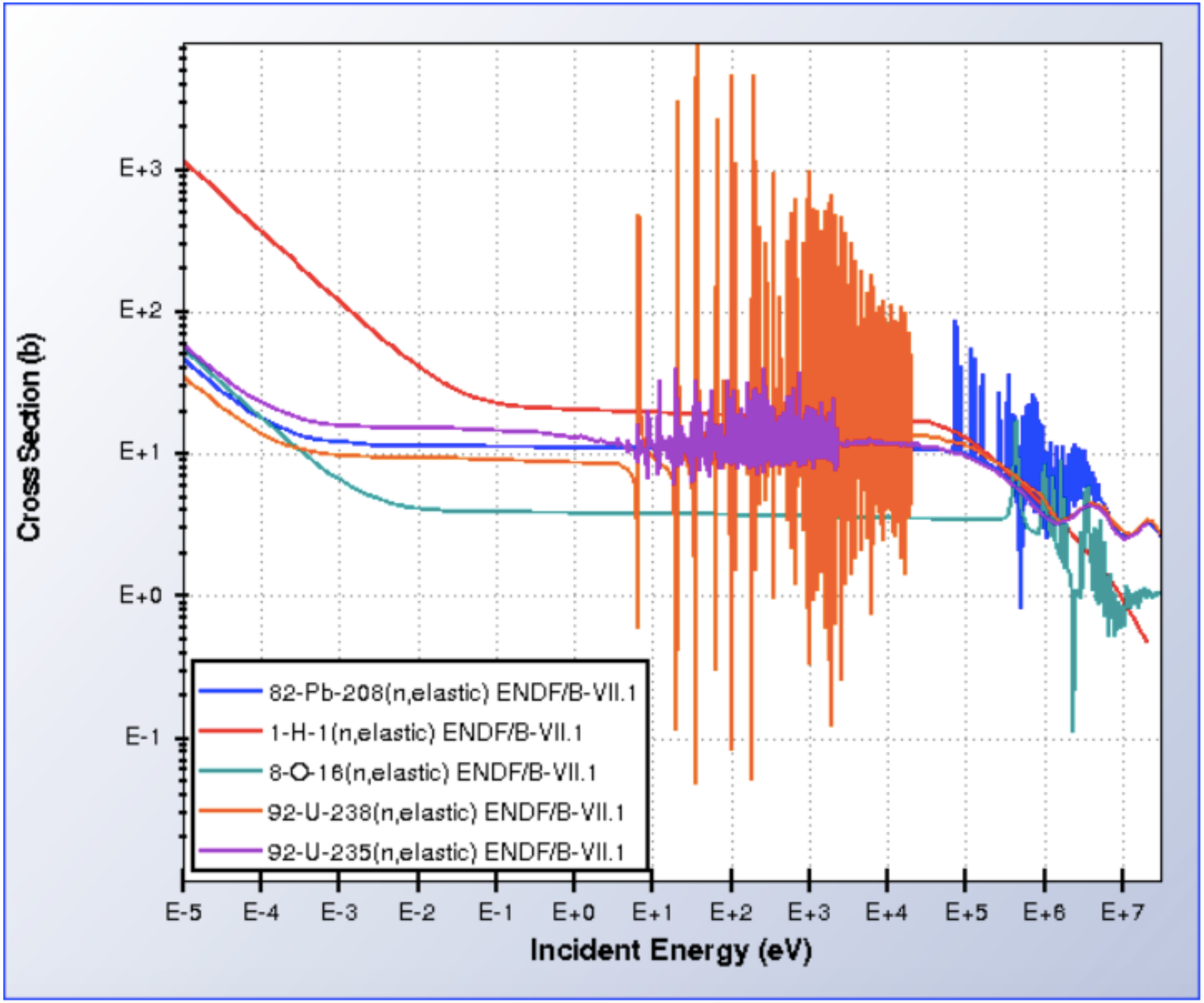
$$\rho_{Pb}\left[\mathrm{kg\ m^{-3}}\right] = 11441 - 1.2795 \cdot T$$

k_{Pb} = 30 W/m-K

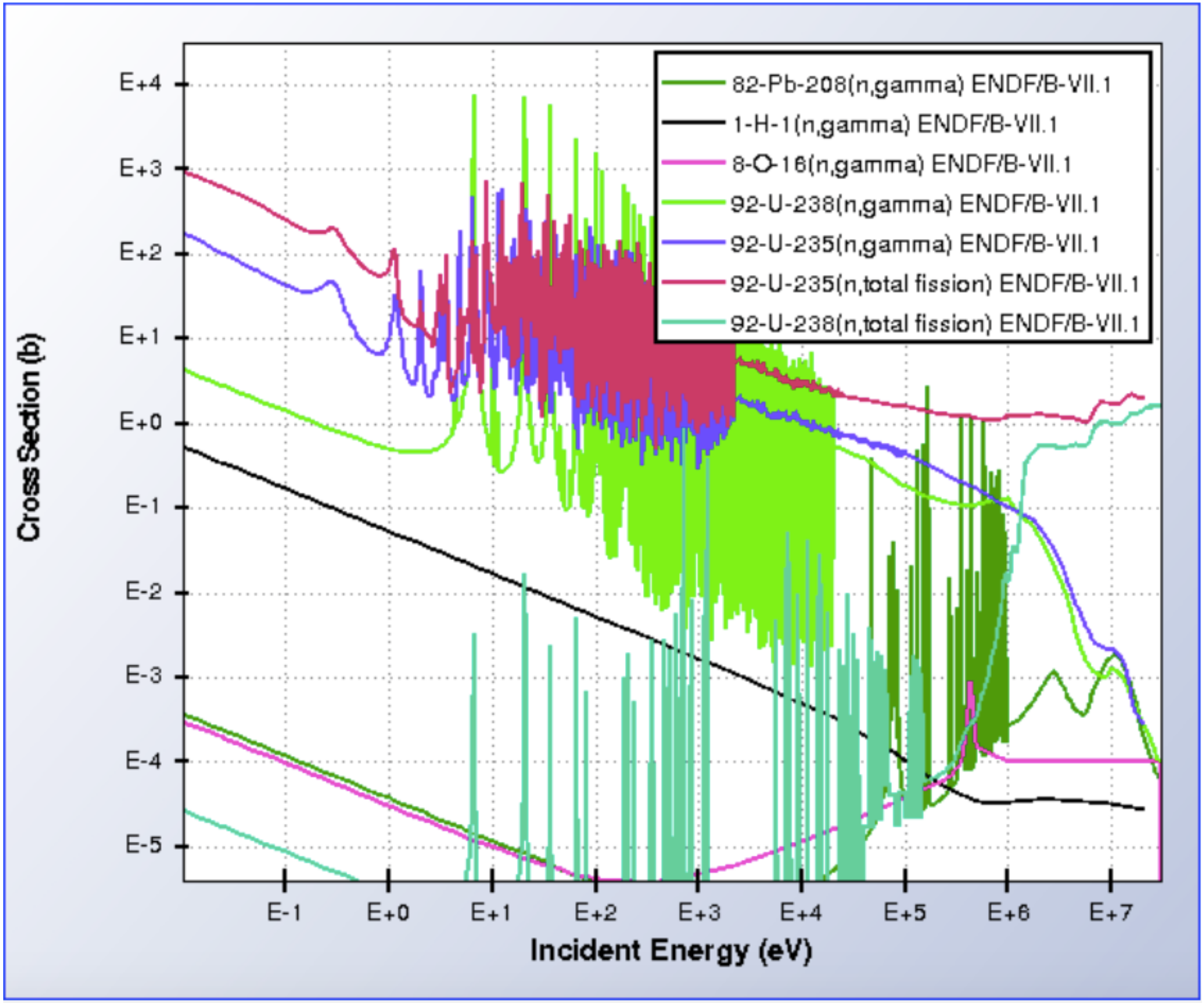
$$\rho U = 17269 - 1.6010 * (T - 1408) \quad (kg/m^3)$$

k_U = 29 W/m-K

Elastic Scattering Cross Sections



Capture and Fission Cross Sections



100 keV Neutron-Induced Fission Product Yields