MIT NSE Ph.D. Qualifying Exam:
Reactor Physics Oral Question, February 2019

A small startup company is proposing to build a reactor to produce Mo^{99} (with subsequent decay to $Tc^{99m)}$ for medical imaging applications. Their concept is to fill an insulated (non-heat-conducting) tank with alternating layers of 20% enriched uranium metal plates (19.0 g/cc) and layers of ice (frozen light water). The reactor designer claims that by properly selecting the **thicknesses of ice and uranium layers** that the reactor can start out as a critical thermal-spectrum reactor and slowly transition to a critical fast-spectrum reactor - as layers of ice slowly melt from heat production and water migrates to the top of the core tank. The reactor designers expect the reactor to then naturally shut itself down as the nuclear fuel becomes more depleted. After shutdown, the operators will then extract Mo^{99} by processing the fission-product-bearing water solution.

The reactor designers have patented their precise design specifications, and you are tasked (while in a meeting with potential startup investors) to analyze their reactor design by following their published design steps and using neutron cross section data from the attached plots:

A. The diameter of the cylindrical core was chosen by requiring that the fast-spectrum core be exactly critical as a bare square cylinder (e.g., height=diameter).

1. How would you estimate k-infinity of the fast-spectrum uranium metal material?

2. How would you estimate the required core diameter?

B. The thicknesses of the ice and uranium layers were chosen to minimize the U-238 resonance absorption of an infinite-slab model of uranium metal and ice.

3. How would you go about estimating the required thickness of the uranium/ice layers?

4. How would you estimate the relative neutron absorption in U^{235} vs. U^{238}?

C. The height of the cylindrical core was chosen to be exactly critical with uniform initial uranium/ice layers and a Be reflector with a thickness of 10 cm.

5. How would you estimate the required core height if the reflector were ignored?

6. How would you estimate the core height with the Be reflector included?

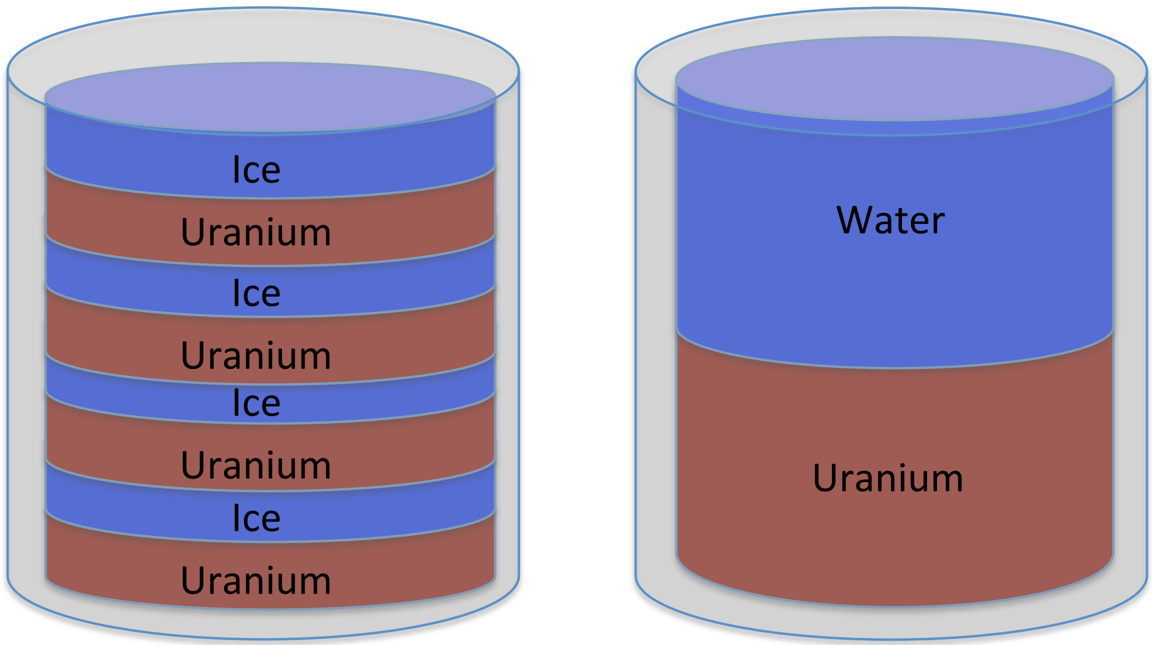
D. The reactor is assumed to remain critical during the entire transition from the thermal to the fast-spectrum system, by assuming uniform melting of all ice layers.

7. If the uniform-melting assumption is valid, would the criticality assumption be credible? Explain why or why not?

After the investor meeting, you return to your office where you have access to the world's largest supercomputer to continue your criticality analysis:

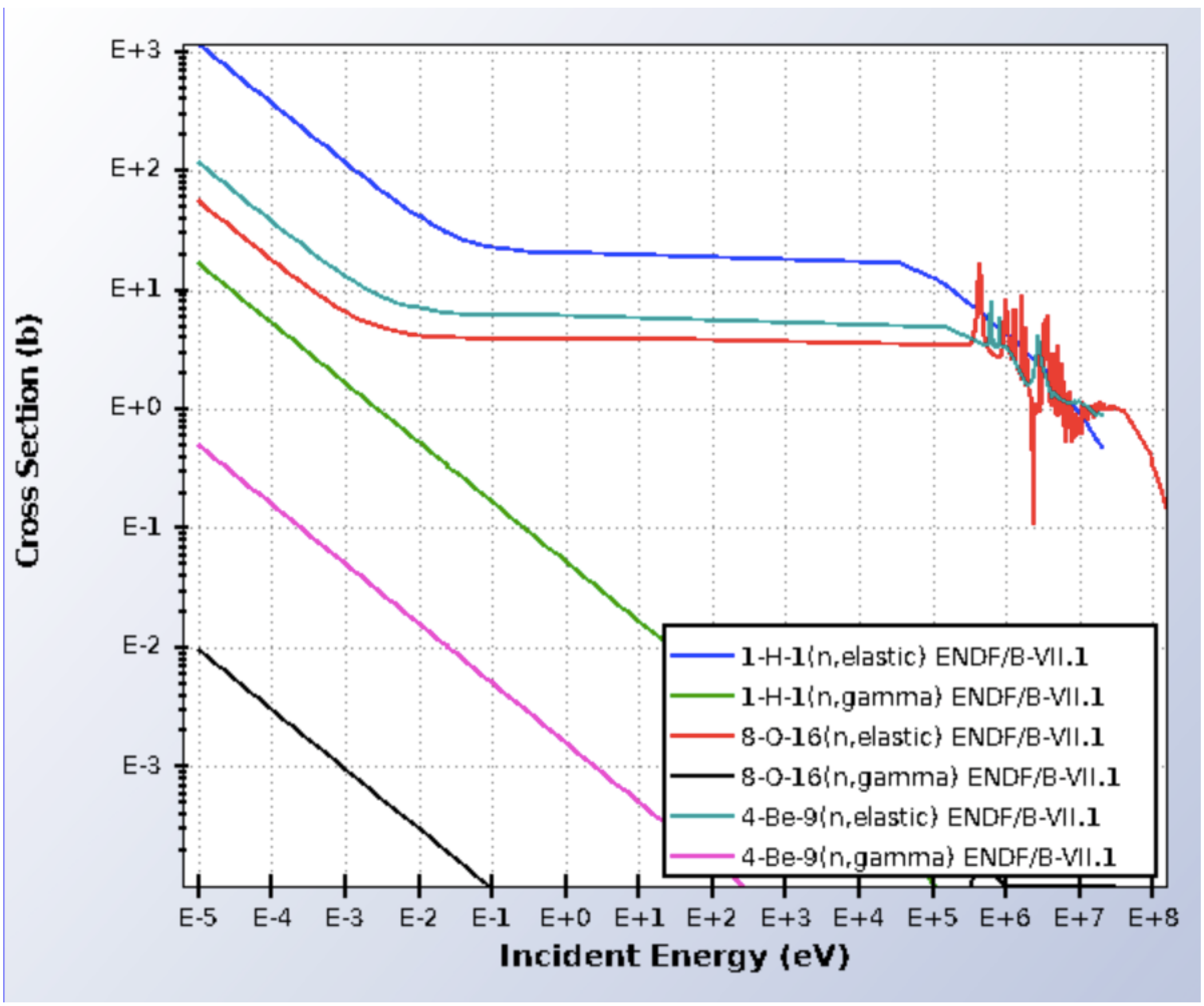
8. Describe your analysis approach if you were to use deterministic neutron transport methods.

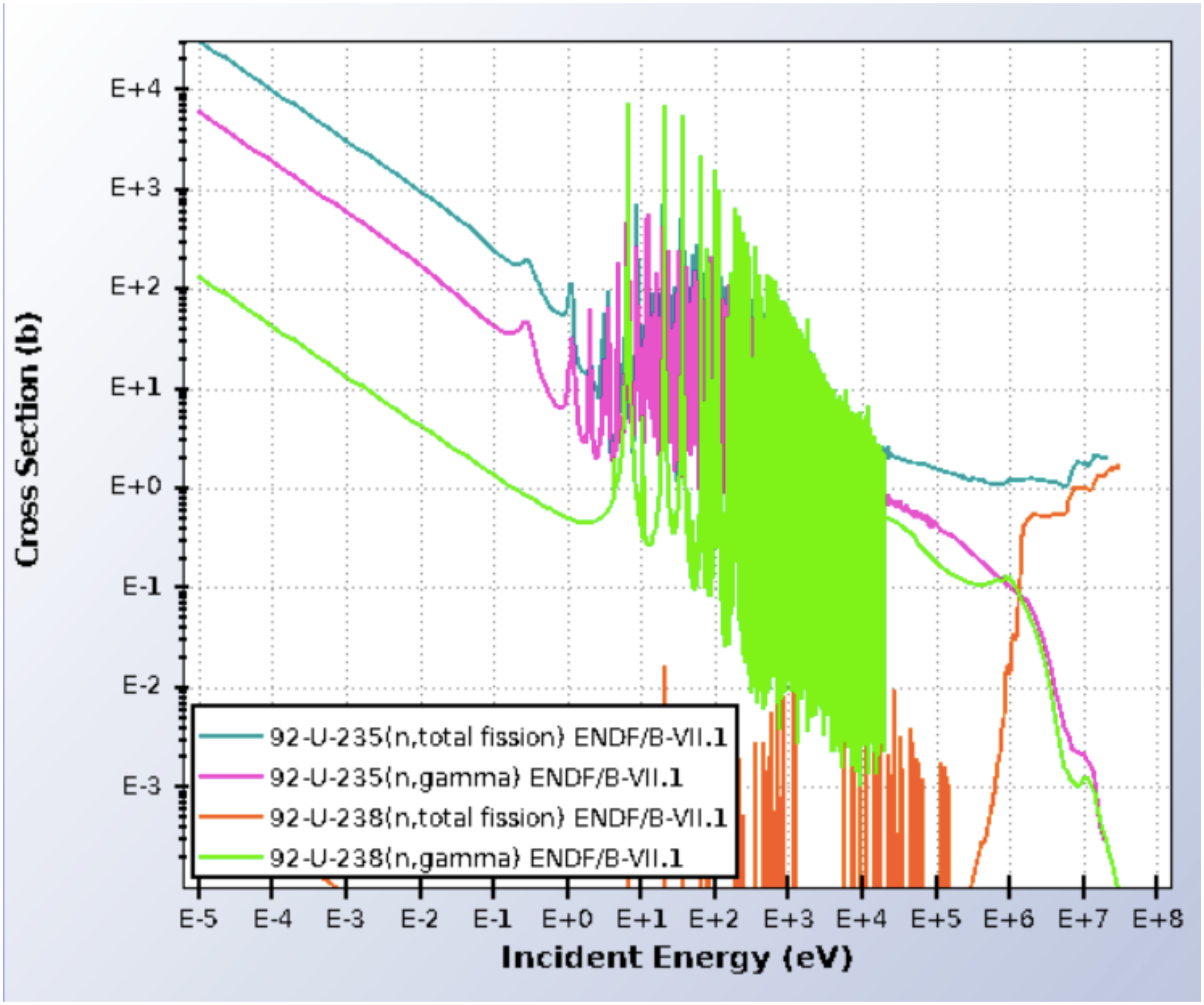
9. Describe your analysis approach if you were to use stochastic neutron transport methods.



Initial: Thermal Reactor

Final: Fast Reactor





Cross Section (b)
E+4
E+3
E+2
E+1
E+0
E-1
E-2
E-3
92-U-235(n,total fission) ENDF/B-VII.1
92-U-235(n,gamma) ENDF/B-VII.1
92-U-238(n,total fission) ENDF/B-VII.1
92-U-238(n,gamma) ENDF/B-VII.1
E-5
E-4
E-3
E-2
E-1
E+0
E+1
E+2
E+3
E+4
E+5
E+6
E+7
E+8
Incident Energy (eV)