MIT NSE Ph.D. Qualifying Exam:
Reactor Physics Oral Question, February 2017

The MIT Graphite Exponential Pile (MGEP), constructed in 1958, is to be restarted after forty years in hibernation. The pile (Fig. 1) is a large rectangular parallelepiped of **1.70 g/cc nuclear-grade graphite** with 144 horizontal cylindrical holes - into which either graphite rods or natural uranium metal rods are placed. The outer surface of the graphite pile is covered with cadmium metal sheets.

The pile is subcritical when loaded with uranium, so a ^{252}Cf source (emitting 2.0 MeV neutrons) is placed at the midpoint of the pedestal's central hole to generate a neutron flux distribution within the pile. Foils are distributed throughout the pile to measure neutron activation and infer flux distributions.

For some experiments, a sheet of cadmium (the shutter) is inserted at the top of the graphite pedestal.

Basic Neutron Physics of a pure graphite pile

1. Explain the physics phenomena that are most important in determining the spatial and energy distribution of neutrons throughout the pile.
2. Using the cross section data given in Fig. 2, estimate the diffusion length of neutrons in the pile at the most probable neutron energy.
3. What is the flux extrapolation distance at the outer graphite surface (e.g., at the graphite/cadmium interface) for neutrons of the most probable neutron energy?

2-D Lattice Physics of the graphite pile filled with NU rods

4. Using one-group homogenized diffusion theory, derive the mathematical expression for the relationship between the lattice material buckling and the lattice k-infinity.
5. Discuss the impact of altering a pile's rod diameter and rod spacing on the lattice k-infinity.
6. Estimate the 0.001 eV neutron escape probability from an isolated natural uranium fuel rod
7. Explain how you would estimate the infinite lattice black Dancoff factor.

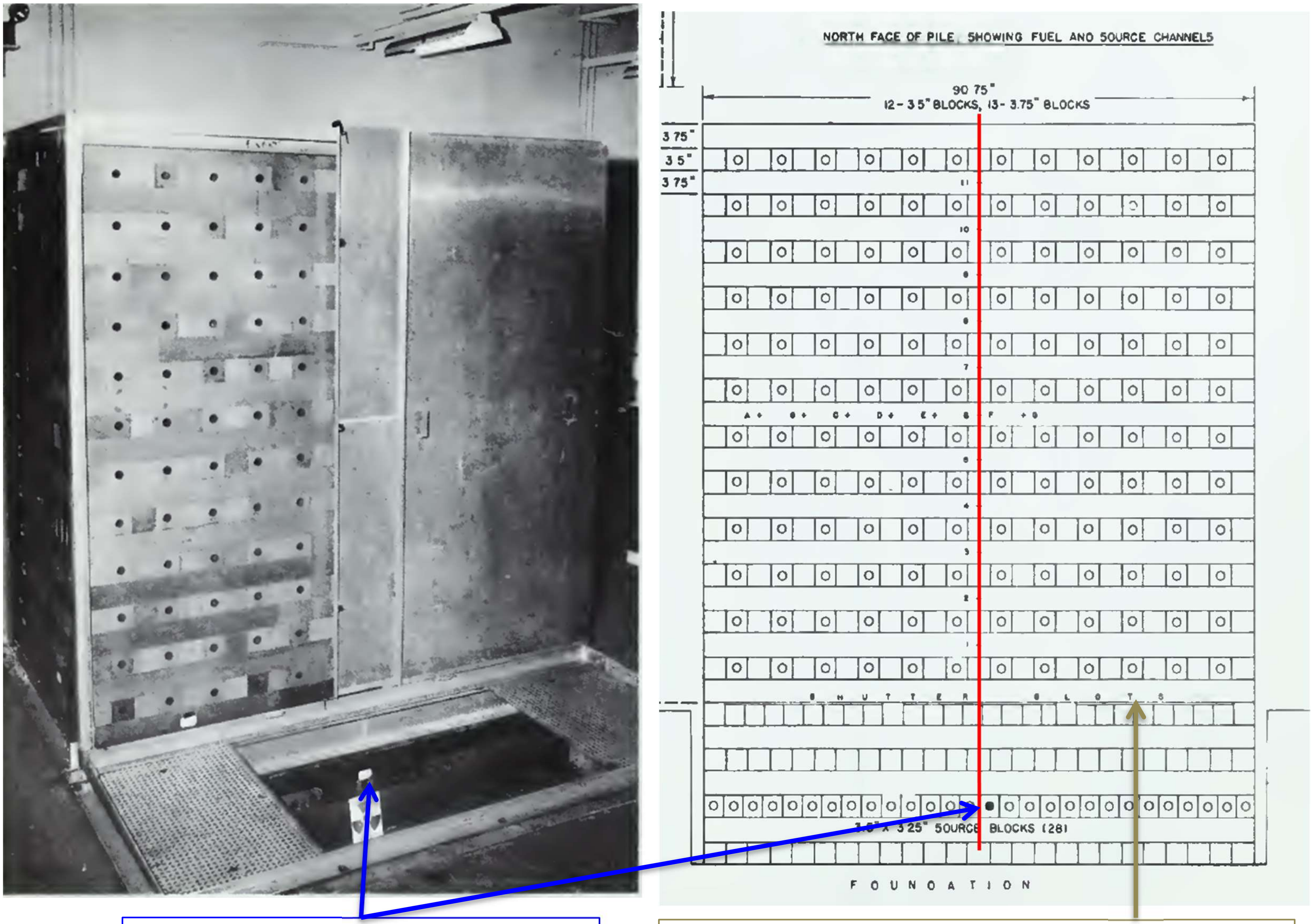
3-D Homogenized Diffusion Theory flux distributions in the graphite pile filled with NU rods

8. Using one-group homogenized diffusion theory, derive the general mathematical expression for the source-driven 3-D flux distribution in the pile
9. Explain how one could use axial measurements of Indium foil activation rates to estimate the pile's material buckling.

Critical Pile Dimensions

10. Explain how you would use one-group theory and MGEP foil activation data to predict the dimensions of a pile that would be critical for the MGEP rod diameter and pitch.
11. Explain how you might use modern core analysis methods to improve upon traditional one-group predictions of critical pile dimensions.

Fig. 1 MIT Graphite Pile (~ 91” x 91” x 115” or 230 cm x 230 cm x 292 cm)



^{252}Cf Source Channel

0.020” thick Cd Sheet (removable)

Pile Unit Cell (7.25” x 7.25”)
Graphite Blocks & Bare Natural Uranium Metal Rods (3.175 cm Dia.)

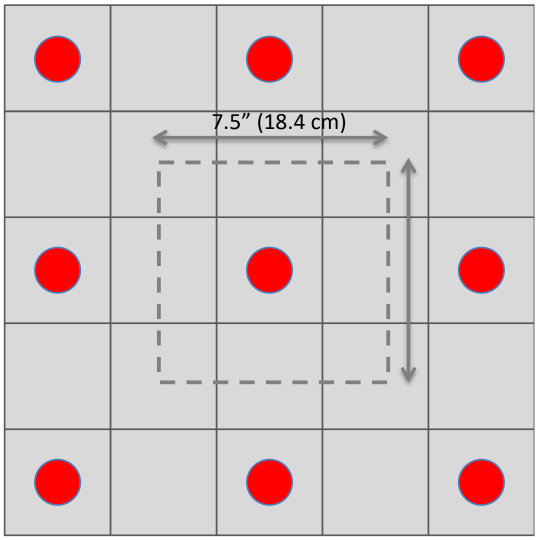


Fig. 2 Neutron Cross Sections

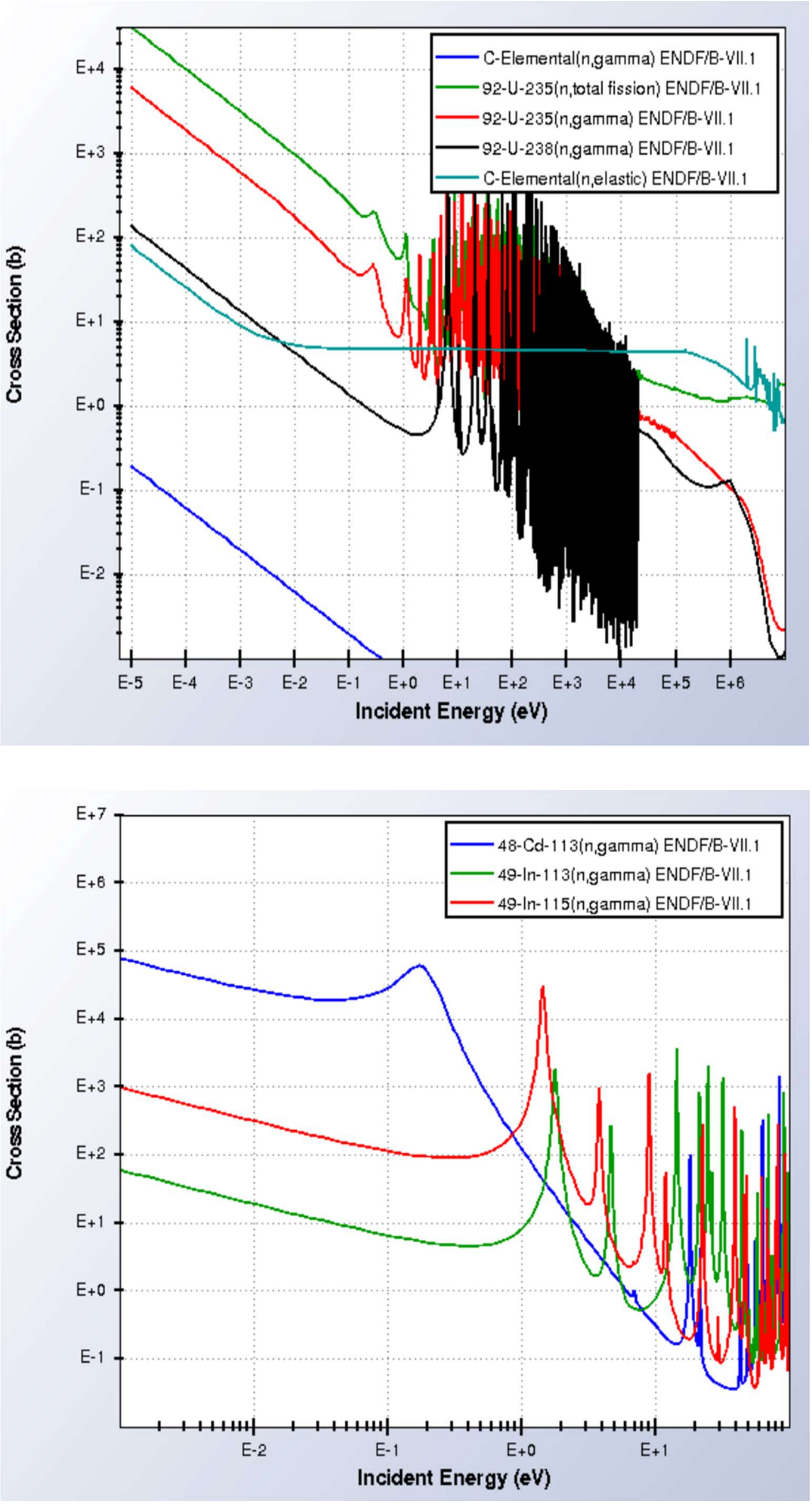
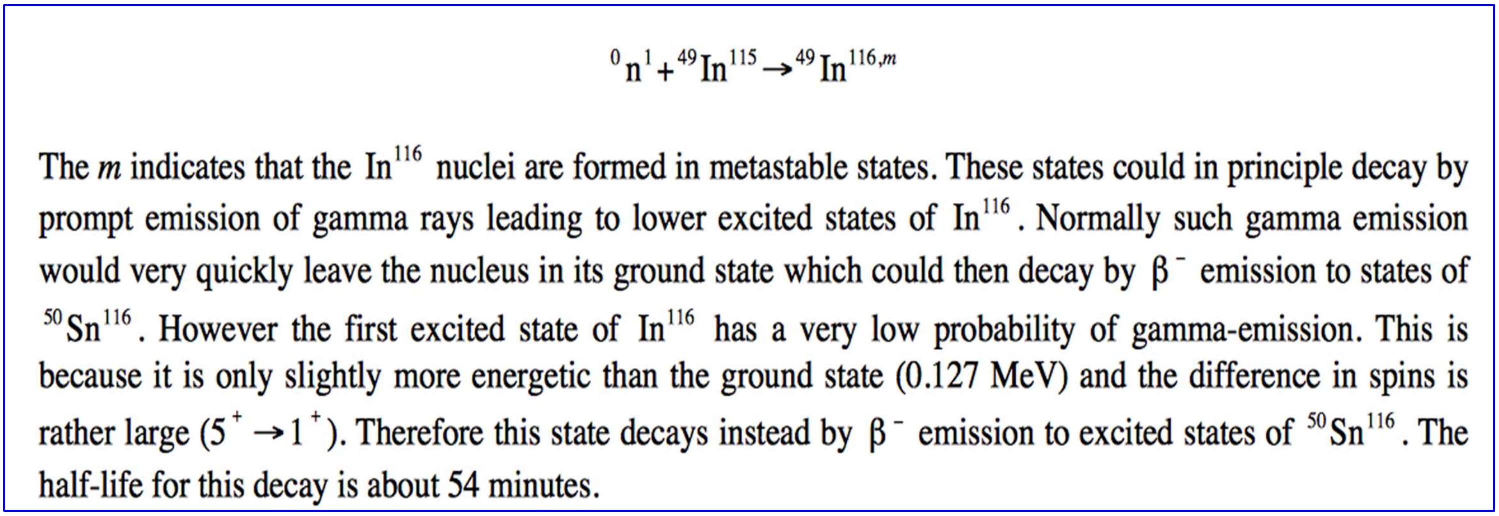


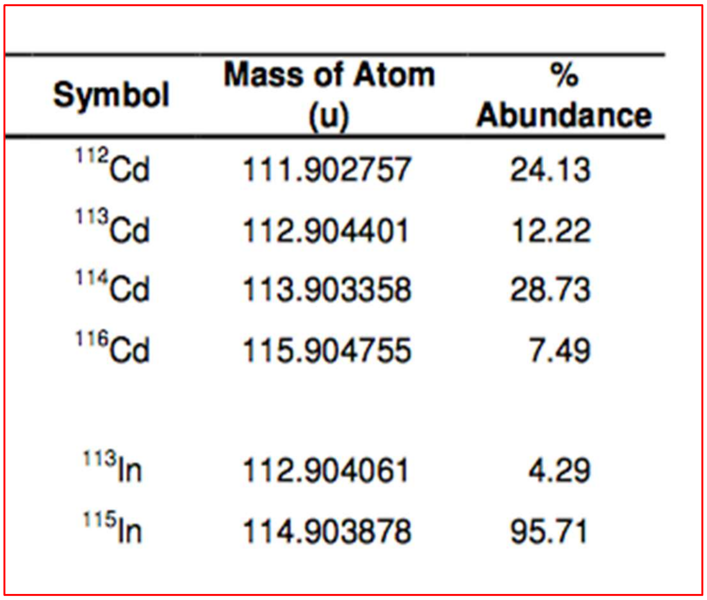
Fig. 3 Indium Neutron Absorption and Decay



$$ {}^{0}\mathrm{n}^{1} + {}^{49}\mathrm{In}^{115} \rightarrow {}^{49}\mathrm{In}^{116,m} $$

The *m* indicates that the In^{116} nuclei are formed in metastable states. These states could in principle decay by prompt emission of gamma rays leading to lower excited states of In^{116}. Normally such gamma emission would very quickly leave the nucleus in its ground state which could then decay by β^- emission to states of ${}^{50}\mathrm{Sn}^{116}$. However the first excited state of In^{116} has a very low probability of gamma-emission. This is because it is only slightly more energetic than the ground state (0.127 MeV) and the difference in spins is rather large ($5^+ \rightarrow 1^+$). Therefore this state decays instead by β^- emission to excited states of ${}^{50}\mathrm{Sn}^{116}$. The half-life for this decay is about 54 minutes.

Isotopic Abundances



Symbol	Mass of Atom (u)	% Abundance
^{112}Cd	111.902757	24.13
^{113}Cd	112.904401	12.22
^{114}Cd	113.903358	28.73
^{116}Cd	115.904755	7.49
^{113}In	112.904061	4.29
^{115}In	114.903878	95.71