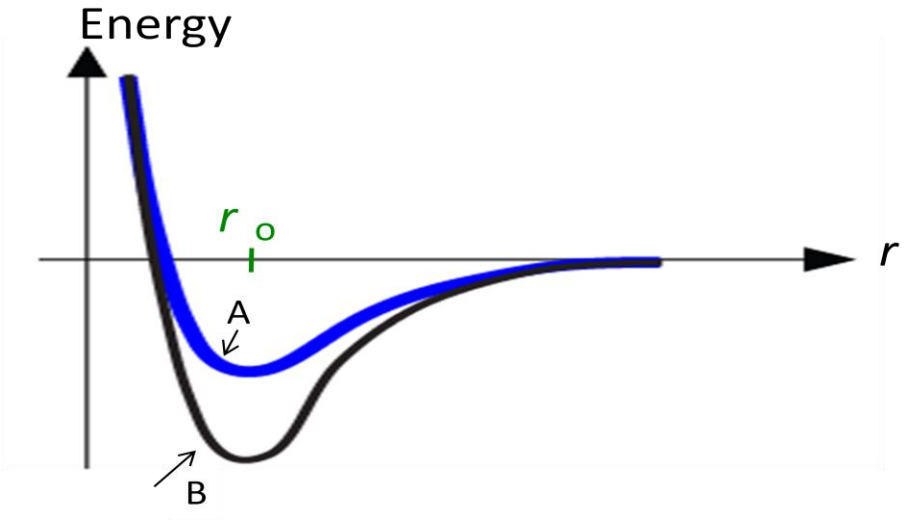
NUEN Qualifying Exam
Nuclear Materials
Fall 2010

1. (20 points) The figure below shows the interatomic potential as a function of separation distance between two isolated atoms in metals A and B, respectively.

    a) Which metal has a higher melting temperature? Briefly explain why.
    b) Which metal has a higher thermal expansion coefficient? Briefly explain why.
    c) Which metal has a higher value of Young's modulus? Briefly explain why.
    d) Upon neutron irradiation, which metal requires a higher temperature to develop maximized void swelling? Briefly explain why.

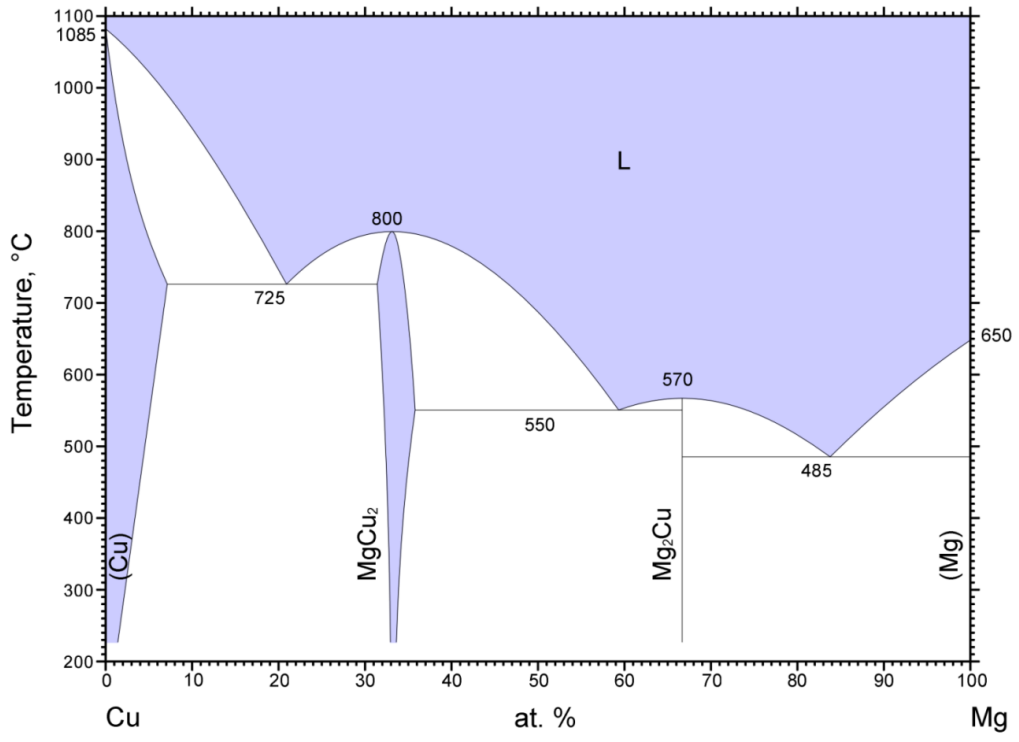


2. (20 points) Delta (δ) phase plutonium has a FCC structure. Its atomic radius is 0.13 nm and its atomic weight is 240 amu.

    a) Schematically draw a FCC unit cell.
    b) Calculate the atomic packing factor, which is defined as the fraction of volume occupied by atoms in a unit cell.
    c) Calculate theoretical density, which is defined as the mass to volume ratio in a unit cell.
    d) Re-draw the FCC unit cell and label one atomic plane belonging to (100).

3. (25 points) Krypton is created upon neutron irradiation of a uranium metal fuel. The atomic radius of uranium is 0.14 nm and the atomic radius of Krypton is 0.19 nm.
    a) What is the strain relaxation direction around a substitutional Kr atom in U lattice?
    b) If Kr diffusion involves defects, which type of defect (U vacancy or U interstitial) is more favorable to interact with Kr?
    c) If U has a grain boundary, can you predict the boundary segregation for Kr (whether Kr is enriched or depleted at the boundary)?
    d) If Kr is trapped by an edge dislocation in U, plot the region of the trapping. You need to draw the cross sectional view of an edge dislocation and mark the region.
    e) Will such a Kr trapping change mechanical properties of U? If so, name one such property and briefly explain the mechanism.

4. (20 points) Use the Cu-Mg binary phase diagram to answer the following questions:
    a) Identify the three 3-phase equilibrium points shown in the diagram (list the temperature, composition, and phases in equilibrium for each invariant point)?
    b) For a Cu-10 at %Mg alloy, sketch an approximation of the room temperature microstructure.
    c) For a Cu-75 at %Mg alloy, use the lever rule to estimate the following values for a room temperature alloy (M_{Cu} = 63.55 amu and M_{Mg} = 24.30 amu):
        - Total mass fraction of Mg_2Cu.
        - Mass fraction of primary Mg.



5. (20 points) Uranium dioxide (UO_2) nuclear fuel restructures during operation and the fuel cladding becomes degraded over time.

   a) (5 points) Sketch the cross section showing the structure of a high burnup UO_2 fuel pellet in contact with Zircaloy cladding. Label all key features.
   b) (15 points) Describe at least 3 key phenomena that cause cladding degradation. (In other words, name each phenomenon and describe their causes and driving mechanisms.)

6. (15 points) Type 304 stainless steel has the following room temperature properties:

   - Young's modulus 195,000 MPa
   - Yield Strength 1,400 MPa
   - Tensile Strength 1,180 MPa
   - Ductility 5%

   a) Sketch a nominal stress strain diagram for 304 SS.
   b) A 304 SS rod is originally 20 cm long. It is subjected to a tensile load of 1,000 MPa. How long is it while it is under stress? How long is it if the stress is removed?
   c) How would long exposures to irradiation affect each of the properties listed above?