NUEN Qualifying Exam
Nuclear Materials Engineering
Spring 2011

1. (10 min) For a given metal at 1000^{o}C, N represents the equilibrium number of vacancies present in the crystal lattice. At 800^{o}C, the number of equilibrium vacancies drops by half (N/2). How many vacancies are expected at 600^{o}C, expressed as a fraction of N? (The Boltzmann constant is 8.62×10^{-5} eV/atom-K.)

2. (15 min) Consider a 3 MeV heavy ion as it interacts with a solid.
   (a) (5 min) Schematically plot the electronic stopping power and nuclear stopping power changes as a function of ion penetration depth.
   (b) (5 min) Briefly explain the mechanisms causing "electronic stopping" and "nuclear stopping."
   (c) (5 min) Sketch a schematic of a damage cascade and mark the region of high density cascade creation in your plot from part (a).

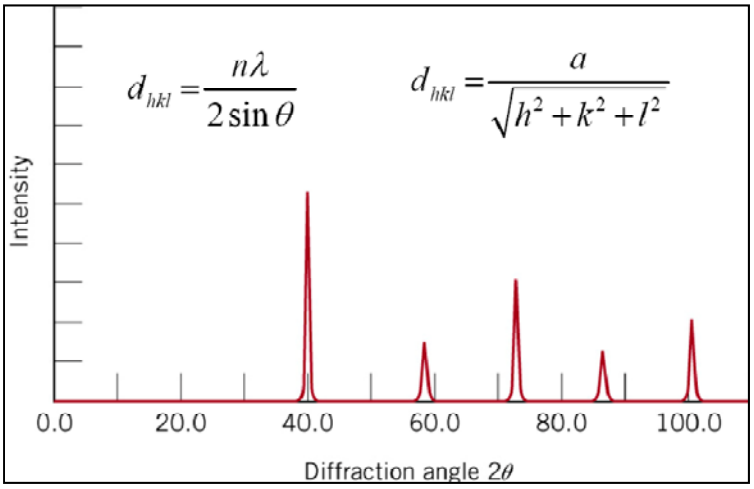
3. (20 min) The basic crystal structure of uranium dioxide (UO_2) is the "fluorite" structure.
   (a) (5 min) Sketch the unit cell for UO_2; identify the uranium and oxygen atomic positions.
   (b) (5 min) What type of bonding exists between the uranium and oxygen atoms (ionic, covalent, metallic)? Explain the nature of this bonding.
   (c) (10 min) Given that the molar mass of uranium is 238 g/mol, the molar mass of oxygen is 16 g/mol, and the density of UO_2 is 10.96 g/cm^3, calculate the nearest atomic distance between two uranium atoms in UO_2.

4. (15 min) Consider the thermal conductivity of UO_2.
   (a) (5 min) Sketch a plot of the thermal conductivity of fully dense UO_2 as a function of temperature in the region of 300^{o}C to 2500^{o}C.
   (b) (5 min) What is (are) the primary mechanism(s) of thermal transport in UO_2 over this temperature range? Explain any changes in the dominant mechanism with temperature.
   (c) (5 min) As UO_2 is irradiated, how does the thermal conductivity change? Explain why.

5. (20 min) A nuclear fuel alloy has a composition of U-10 wt% Pu-10 wt% Zr.
   a. (10 min) What is the composition of this fuel alloy in atom percent?
   b. (10 min) What would the alloy composition be (in wt%) if the atom fraction of Pu of the original alloy was doubled while the U:Zr atom ratio was held constant?

M_{Zr} = 91.22 g/mol
M_{Pu} = 244 g/mol
M_{U} = 238.03 g/mol

6. (15 min) The figure below shows the first five peaks of the x-ray diffraction pattern for tungsten, which has a BCC crystal structure and an atomic radius of 0.137 nm; monochromatic x-radiation having a wavelength of 0.1542 nm was used to generate this pattern. Which of the peaks shown below comes from the (110) plane? Justify your answer (*assume n=1*).



7. (15 min) Sketch an orthorhombic unit cell and complete the following:
   a. (5 min) Sketch and label the [111], [101], [021] and [231] crystal directions. (It may be helpful to sketch a separate unit cell for each individual direction)
   b. (5 min) Sketch and label the (111), (101), (021) and (231) crystal planes. (It may be helpful to sketch a separate unit cell for each individual plane)
   c. (5 min) If the actual unit cell is face-centered orthorhombic with a=2b and b=2c and the atomic radius is equal to c/2, calculate the atomic packing fraction of the unit cell.

8. (10 min) Consider a hypothetical metal with a reported yield stress of 400 MPa. You need to design a long cylindrical beam using this alloy that can support a vertical hanging load of 25,000 pounds (1 lb = 4.082 N). What is the minimum diameter (in cm) of the beam if your safety factor is equal to 2.5?