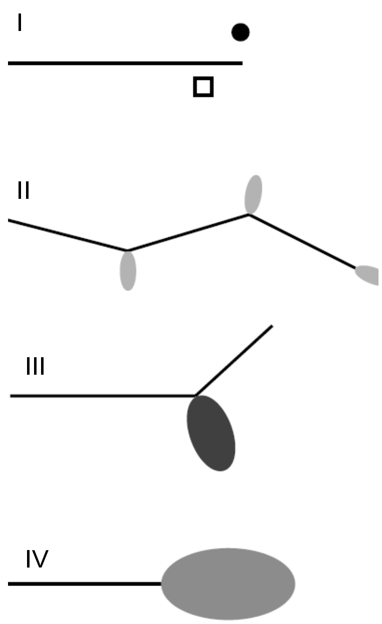
Nuclear Engineering
Qualifying Exam – Fall 2009
Nuclear Materials

1. (15 min)

Different ion-solid interactions will lead to different damage patterns. Below are schematic drawings of a series of radiation damage in a solid caused by different particle bombardments. In the first figure, the small circle refers to an isolated interstitial and an open square refers to an isolated vacancy. In the other figures, the shadowed regions refer to damage cascades (high density interstitials and vacancies).



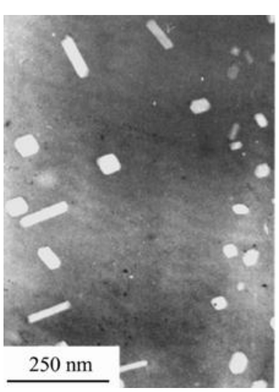
(1) Identify the corresponding plot to each of the following: (a) 1 MeV neutron, (b) 1 MeV helium ion, (c) 1 MeV heavy ion and (d) 1 MeV electron.

(2) Most studies in the literature used MeV helium ion bombardment to simulate radiation damage caused by fast neutrons. Based on your answer in (1), discuss the disadvantage of this approach.

2. (15 min)

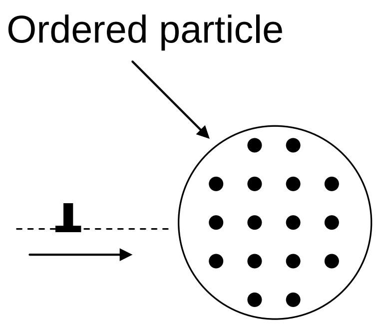
The picture below is a bright field transmission electron microscope image obtained from a stainless steel that has been bombarded by helium atoms.

- Describe the features observed in this image and briefly explain the mechanisms leading to these defects.
- Explain why the defects have irregular shapes.



3. (15 minutes)

With defects created by irradiation, nuclear materials can form precipitates. The diagram below shows a dislocation moving from the left to the right. The dashed line refers to its slip plane. The circle refers to an ordered particle formed due to precipitation.



- Schematically sketch what happens when the dislocation cuts the particle and moves through it. The diagram needs to clearly show the new interfaces created.
- If the particle's size is so large that dislocation is forced to stop in front of the particle, what happens to the materials' mechanical properties?

4. (15 min)

Fuel swelling can close the gap between cladding and fuel. This will lead to significant diffusion of fission products from the fuel into the cladding. One research group proposes to use a high strength ceramic layer as a buffer layer between the fuel and cladding to alleviate the issues. They further propose to use a nanograined ceramic layer.

- From the view-point of the damage accumulation, what is the advantage of using a nanograined buffer layer?
- From the view-point of fission product migration, what is the disadvantage of using a nanograined ceramic layer?

5. (10 min)

A sheet of BCC iron, 1 mm in thickness, was exposed to a carburizing gas atmosphere on one side and a decarburizing atmosphere on the other side at 725°C. The iron was quickly cooled to room temperature after reaching steady state. The carbon concentrations at the two surfaces of the sheet were determined to be 1 and 0.5 kg/m^3. For C in α-Fe, D_0=6.2×10^{-7} m^2/s, Q_d=80,000 J/mol, and R=8.314J /mol-K.

What was the steady state diffusion flux (in kg/m^2-s) of carbon in iron for these conditions?

6. (10 min)

Name and briefly describe the three primary types of atomic bonds

7. (10 min)

Why are interstitial and substitutional solid solution alloys stronger than pure metals?

8. (20 min)

- (5 min) Write the Arrhenius-type expression for the number of vacancies, N_v, formed within a crystal (define all terms).
- (5 min) Sketch the typical ln(N_v) vs. 1/T representation for this thermally-activated behavior. Label the axes carefully and identify the meaning of the slope of the curve.
- (10 min) The equilibrium number of vacancies in a hypothetical metal increases by a factor of 2.7 when the temperature is increased from 1000 K to 1200 K, calculate the activation energy, Q_v (in kJ/mol), for vacancy formation.

  Assume density changes are negligible over this temperature range.
  R = 8.314 J/mol-K

9. (10 min)

Sketch a hypothetical simple eutectic diagram with components A and B. Label the axes and all phase fields on the diagram. Pick a temperature on your diagram and identify the solubility limits of A in B and B in A. For a hypoeutectic alloy, sketch and label the structural stages present at unique stages during cooling (not including the liquid-only structure).