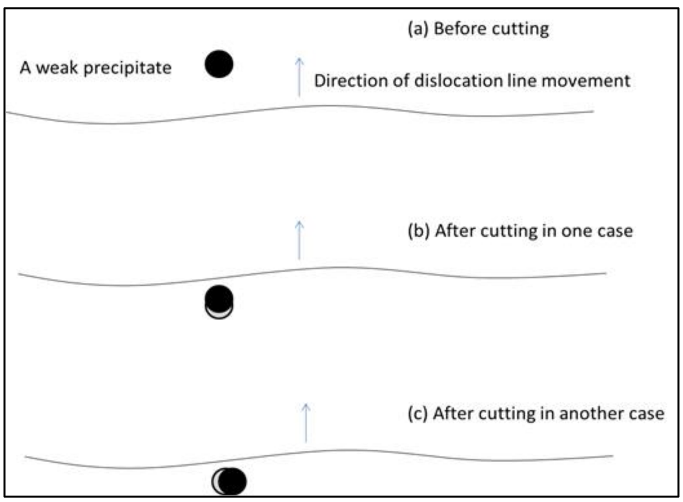
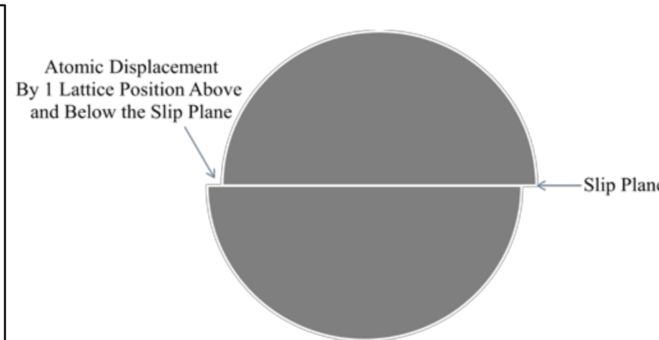
**Fall 2013 NUEN PhD Qualifying Exam**
**Nuclear Materials Engineering**

1. *(10 min)* The figure below shows the top view (above the plane of motion) of a single dislocation segment before and after it cuts through a precipitate. Figures (b) and (c) show what happened to the precipitate; the precipitate is cut by half and the open circle region represents the precipitate's newly created surface.
   (a) What type of dislocation (edge or screw) is shown in Figure (b)? Why?
   (b) What type of dislocation (edge or screw) is shown in Figure (c)? Why?



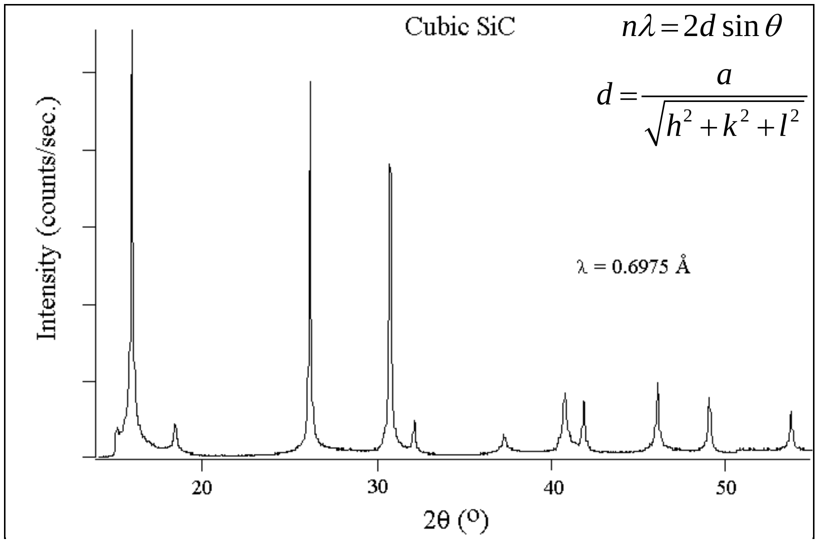

Side View of Small Precipitate
After Displacement (not to scale)

2. *(20 min)* Answer the questions below about creep:

   (a) What is creep? Specify the necessary conditions under which creep occurs.
   (b) Sketch a typical strain vs. time creep curve and label the features.
   (c) On the same sketch, superimpose a second creep curve for the same material after significant neutron damage.
   (d) What is the impact on creep behavior if a material develops voids (e.g., will creep be increased or decreased)? Provide a brief explanation of the mechanism for this effect.

3. *(20 min)* Sketch the cross sections of a nominal fuel pin or fuel particle at the "beginning of life" (BOL) and at the "end of life" (EOL) for a (a) light water reactor, (b) a fast reactor, and (c) a gas-cooled reactor. Label the features and identify the materials present (include materials that fill gaps, if any).

4. *(20 min)* The image below shows an X-ray diffraction pattern for cubic silicon carbide.




(a) Explain how x-ray diffraction works and how the above pattern may have been generated.

(b) Estimate the lattice parameter of the crystal if the highest intensity peak represents the (1 1 1) plane.

5. *(30 min)* Answer the following questions relevant to radiation damage effects.

(a) *(5 min)* The unit "dpa" is widely used to quantitatively describe radiation damage effects in solids. What does "dpa" stand for and what does it physically represent?

(b) *(5 min)* For BWR fuel assemblies after one fuel cycle of use, state the nominal dpa range (<1 dpa, 1-100 dpa, >100 dpa) present in both cladding and nuclear fuel. Comment on the differences, if any.

(c) *(5 min)* Failure phenomena begin to become active in BWR fuel cladding after certain dpa values are reached. Consider stress corrosion cracking and swelling. State which phenomenon becomes active at a lower dpa threshold? (explain your selection)

(d) *(5 min)* An accelerated test is being designed to achieve 100 dpa in a material of interest within a few days. Select the one particle beam that is most capable of achieving this goal: (1) 1 MeV electron beam; (2) 1 MeV proton beam; (3) 1 MeV heavy ion beam. (explain your selection)

(e) *(10 min)* For steel bombarded by 1 MeV Fe ions, the projected range of Fe ions is 0.2 μm. Each Fe ion creates about 1000 displacements in the steel. Assuming these displacements are uniformly distributed within the projected range, what is the ion fluence (in the unit of atoms/$cm^2$) required to achieve 10 dpa? Assume the atomic density of the steel is $1\times10^{23}$ atoms/$cm^3$.

6. *(20 min)* Alpha uranium metal (R = 0.156 nm) has an unusual orthorhombic crystal structure shown in the figure below.
   (a) Estimate the atomic packing factor of the unit cell.
   (b) Explain why alpha uranium generally tends to deform by twinning instead of through dislocation glide.
   (c) If pure uranium metal is irradiated in a neutron flux between 350°C and 550°C, it swells dramatically through the generation of micro-tears between grain boundaries long before fission gas bubbles begin to nucleate. Explain the mechanism that creates this tearing-induced swelling.
   (d) Why does this tearing not occur as readily at 300°C, 650°C, and 800°C (Hint: the reason is different at each temperature.