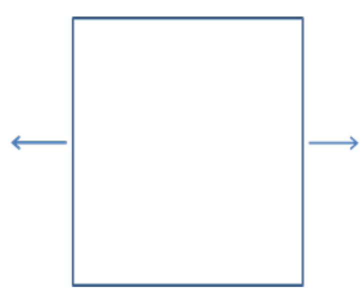
Fall 2012 NUEN PhD Qualifying Exam
Nuclear Materials Engineering

1. *(20 min)* Draw a set of six cubic unit cells and label their axes.
    (a) Sketch and label the following crystallographic planes within your first three unit cells: $(\bar{1}\ 0\ \bar{1})$, $(2\ \bar{1}\ 0)$, and (3 2 1).
    (b) Sketch and label the following crystallographic directions within your remaining unit cells: $[\bar{1}\ 0\ \bar{1}]$, $[2\ \bar{1}\ 0]$, and [3 2 1].

2. (*10 min*) Consider a dislocation within a crystal structure.
    (a) Why must it exist as a loop?
    (b) Describe a condition that may cause a dislocation to move within a slip plane.
    (c) Describe a condition that may cause a dislocation to move out of a slip plane.
    (d) Why can a dislocation move in all directions within a slip plane even though its Burgers vector only points in one direction?

3. (*10 minutes*) Explain the structural differences and similarities of ferritic, austenitic, and martensitic steels. Name one alloying element which may be used to adjust the amount of austenite in a mixed ferritic-austenitic steel.

4. (15 minutes) Create a duplicate of the sketch below showing a rectangular metal bar that is being stretched under uniaxial tension.



    (a) On your sketch, show the preferred orientation of an interstitial dislocation loop and a vacancy dislocation loop. Explain why your sketch is correct.
    (b) On your sketch, show the dominant directions for interstitial and vacancy point defect migration under such tensile stresses. Explain why your sketch is correct.

5. (*15 minutes*) At higher burnup and in high power density pins, oxide fuel may develop a central hole and experience major restructuring. Examine the figure below showing a cross section of UO_2 fuel after 7 atom % burnup and a radial fission gas profile. Answer the following questions:
   (a) Describe the primary features of the radial fuel zones indicated in the picture and the mechanisms that cause their formation.
   (b) Why do the fission gas profiles show a significant Cs and Xe content in the outer region, but there appears to be no fission gas present in the central region?
   (c) Explain the impact of the central hole on the centerline fuel temperature (compare T_{cl} before and after hole formation)?

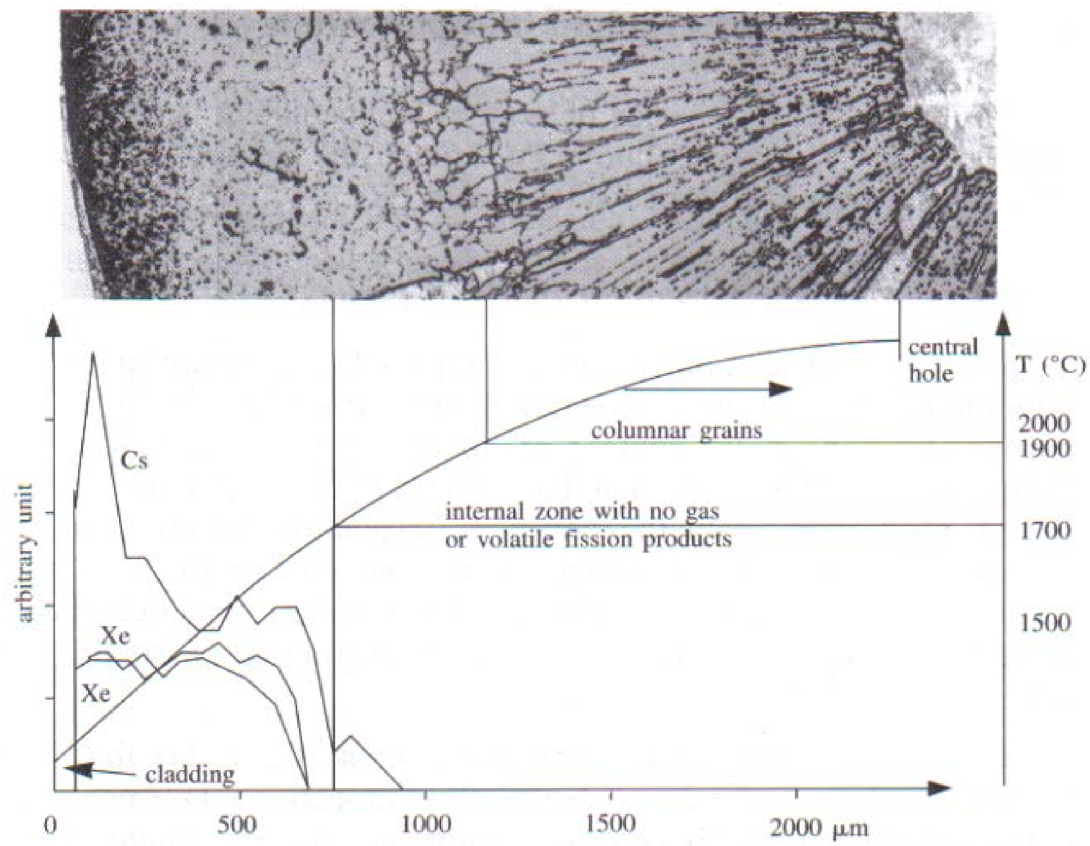
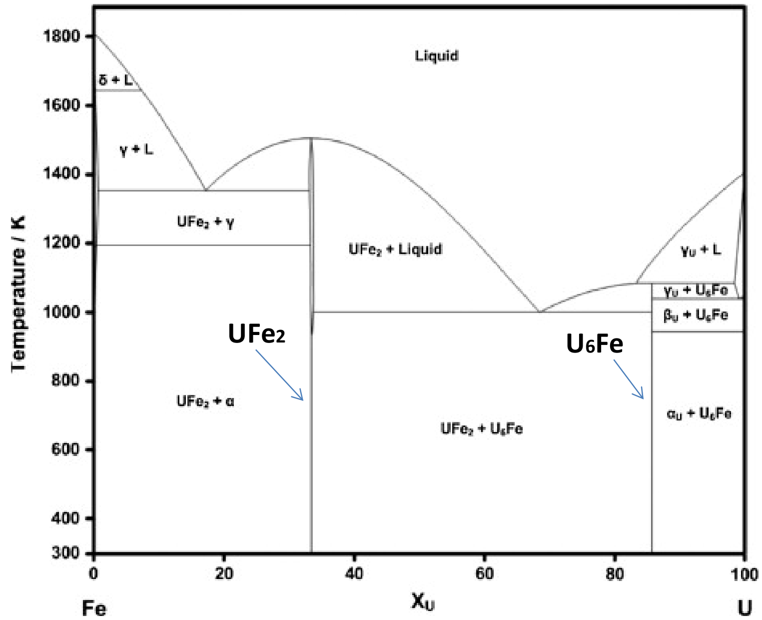
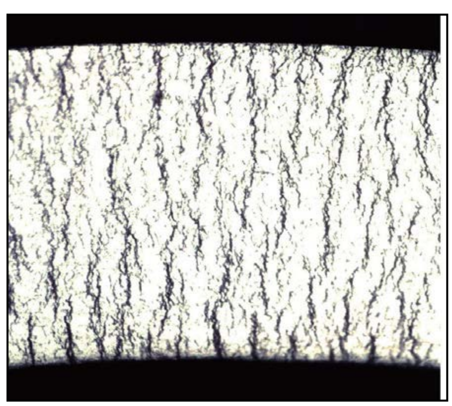


FIG. 3.22. – Radial profiles of fission gases and caesium in FR fuel.

6. (15 minutes) A metal fuel alloy is produced to have a composition of 80 atom percent uranium and 20 atom percent iron.
   (a) Create a sketch of the equilibrium microstructure that may be observed within the alloy after cooling very slowly from a molten state at 1400 K down to 400 K.
   (b) What is the composition (in weight percent) of each component phase in the microstructure?
   (c) What is a safe operating temperature limit for this fuel? Justify your answer.



7. (20 minutes) Answer the following questions regarding zirconium-based cladding alloys (e.g., Zircaloy).
   (a) Create a sketch of the crystal structure of pure Zr and specify the direction of c axis.
   (b) For the image below (obtained after hydride formation), what is the orientation of c axis?
   (c) Explain the mechanism governing delayed hydride cracking (DHC). (A sketch may be useful.)
   (d) Is DHC more likely to occur during reactor operation or after reactor shut down? Why?



8. (*15 minutes*) Consider the immobilization of Cs-137 in a monolithic di-cesium oxide (Cs_2O) ceramic waste form that is sealed in an air-filled canister (Cs-137 is sometimes separated from used nuclear fuel for various applications). Over a very long time, equilibrium suggests that Cs_2O may transmute into barium oxide (BaO) according to the following simplified reaction pathway:

$$^{137}Cs \xrightarrow[t_{1/2}=30.1y]{\beta^-} {}^{137}Ba + \bar{\nu}$$

$$Cs_2O \xrightarrow{2\beta^-} BaO + Ba$$

$$2Ba + O_2 \longrightarrow 2BaO$$

(a) Assuming rapid chemical kinetics, what is the expression for the initial rate of oxygen molecule (O_2) consumption within the storage canister?

(b) Using the data below and the information above, discuss the pros and cons of using Cs_2O as a storage form and the stated design package.

	Cs_2O	BaO	Ba
Density (g/cm^3)	4.65	5.72	3.51
Melting Point (ºC)	490	1973	977
Thermal Conductivity (W/cm•K) @STP	$\sim 10^{-5}$	$\sim 10^{-4}$	~0.2