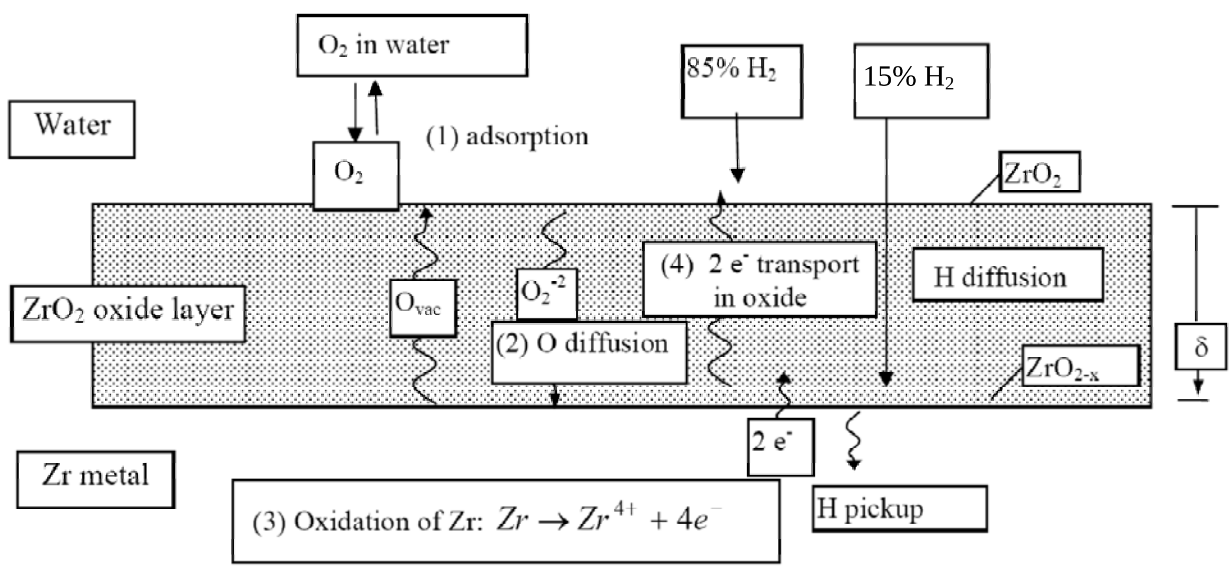
NUEN Qualifying Exam
Nuclear Materials Engineering
Spring 2008

1. (10 minutes) Sketch the crystal structures for the following materials: a) BCC α-Fe (ferrite), b) FCC γ-Fe (austenite), and c) HCP α-Zr. Show the lattice parameter(s) and atoms per unit cell for each sketch.

2. (10 minutes) Estimate the theoretical density of BCC α-Fe at room temperature (Z=26, a=0.124 nm, M=55.854 g/mol).

3. (20 minutes) The schematic diagram below shows the zirconium oxide layer formed on the exterior surface of Zircaloy during LWR operation.



a) (10 min) The diagram shows a 4-step process for oxide layer growth. Describe each step. Which step controls the oxide layer growth rate?

b) (10 min) Sketch a plot describing the oxygen content in the Zircaloy cladding as a function of depth. Assume the oxide layer is ~10 µm thick and the oxygen content in the middle of the cladding is still below 1000 ppm.

4. (15 minutes) Stainless Steel

   a) (5 min) What makes stainless steel "stainless"?

   b) (5 min) Sketch a cross section diagram showing the side view of a stainless steel surface in contact with pressurized water at ~150°C with a passive surface layer and evidence of pitting corrosion. What is the nominal composition of the oxide passivation layer?

   c) (5 min) Sketch a typical stress-strain diagram for austenitic stainless steel showing the relative behavior before and after a moderately high irradiation dose (e.g., 10 dpa). Why is there a change?

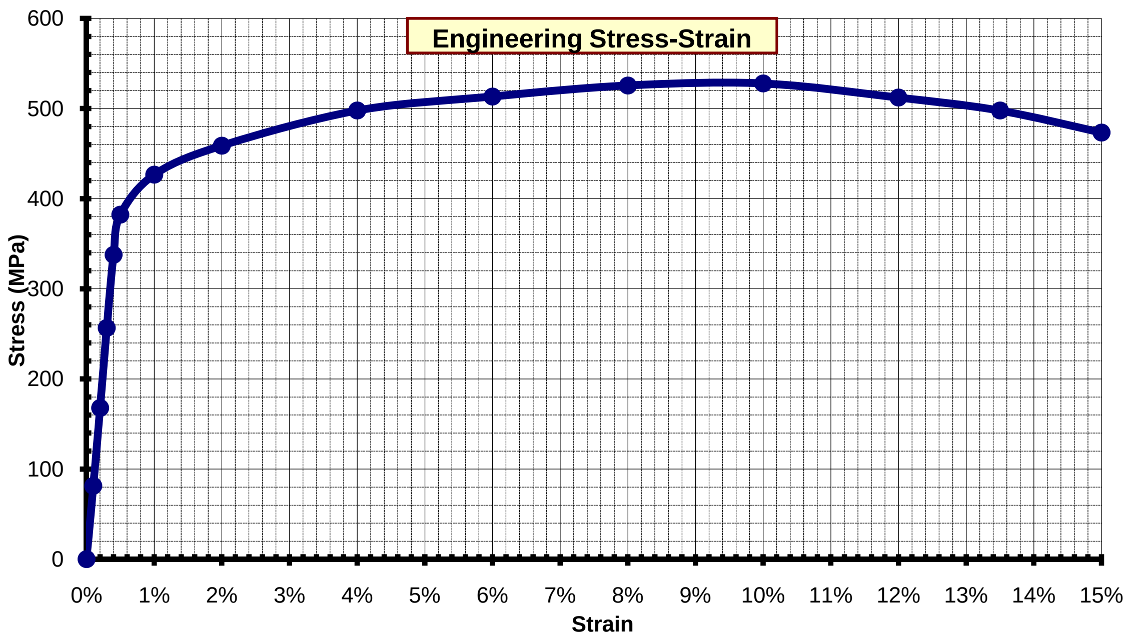
5. (10 minutes) A stress-strain curve is given below for a hypothetical alloy.

   a) Estimate the modulus of elasticity, yield stress (0.2% offset), and ultimate tensile strength of this material.

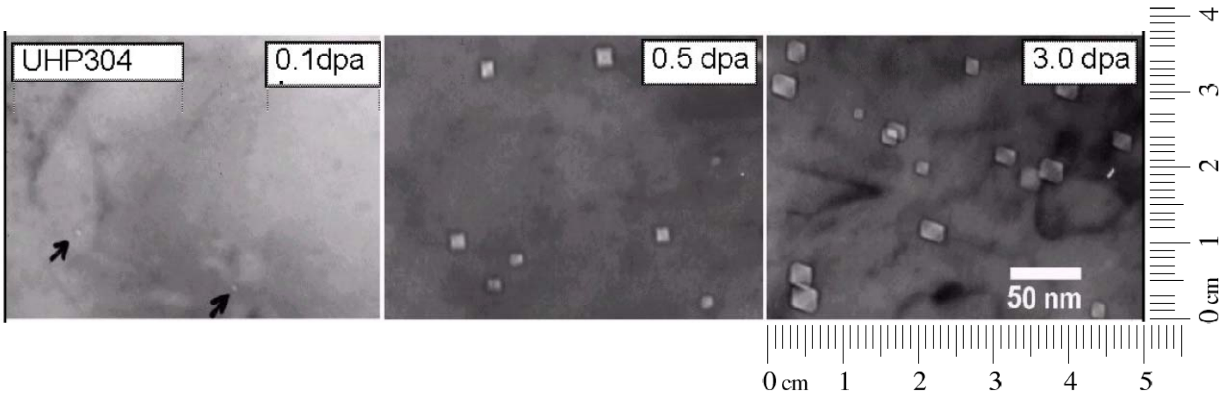
   b) Describe what is happening to the alloy microstructure in the elastic region.

   c) Describe what is happening to the alloy microstructure just beyond the yield point.

   d) Describe what is happening to the alloy microstructure at the point of maximum stress.



6. (20 minutes) <u>Metal alloys under neutron or ion irradiation</u>.



a) (5 min) Explain (step-by-step) how the voids shown in the figure above are formed.

b) (5 min) Estimate the void density in UHP304 at 0 3.0 dpa (assume a sample depth of ~50 nm).

c) (10 min) Assume that a spherical void with a radius r is formed in a metal. Use the symbols G_V (<0) for the Gibbs free energy per unit volume to form a cavity and σ (>0) for the interface energy per unit area between the cavity and the matrix.

   - Derive the equation for the total energy cost to form a void with radius r.
   - Derive the critical radius r^* beyond which voids readily grow.

7) (20 minutes) Solid State Diffusion

a. (10 min) State the governing equations for 1-dimensional diffusion (Fick's Laws). What is the difference between steady state and non-steady state diffusion.

b. (10 min) Calculate the diffusion coefficient for Cu in Al at 500ºC and 600ºC.

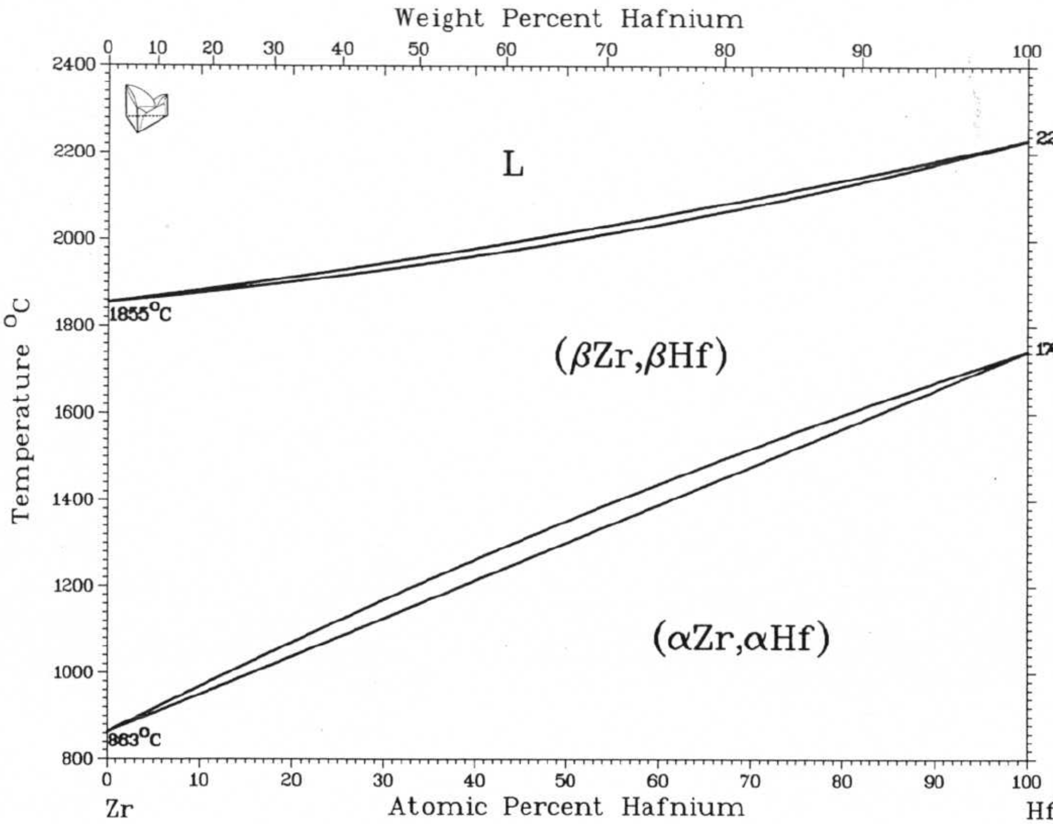
Pre-exponential constant = 6.5×10^{-5} m^2/s
Activation Energy = 136 kJ/mol
Boltzmann Constant = 8.317 J/mole • K

8. (15 minutes) Phase Diagrams (see following page)

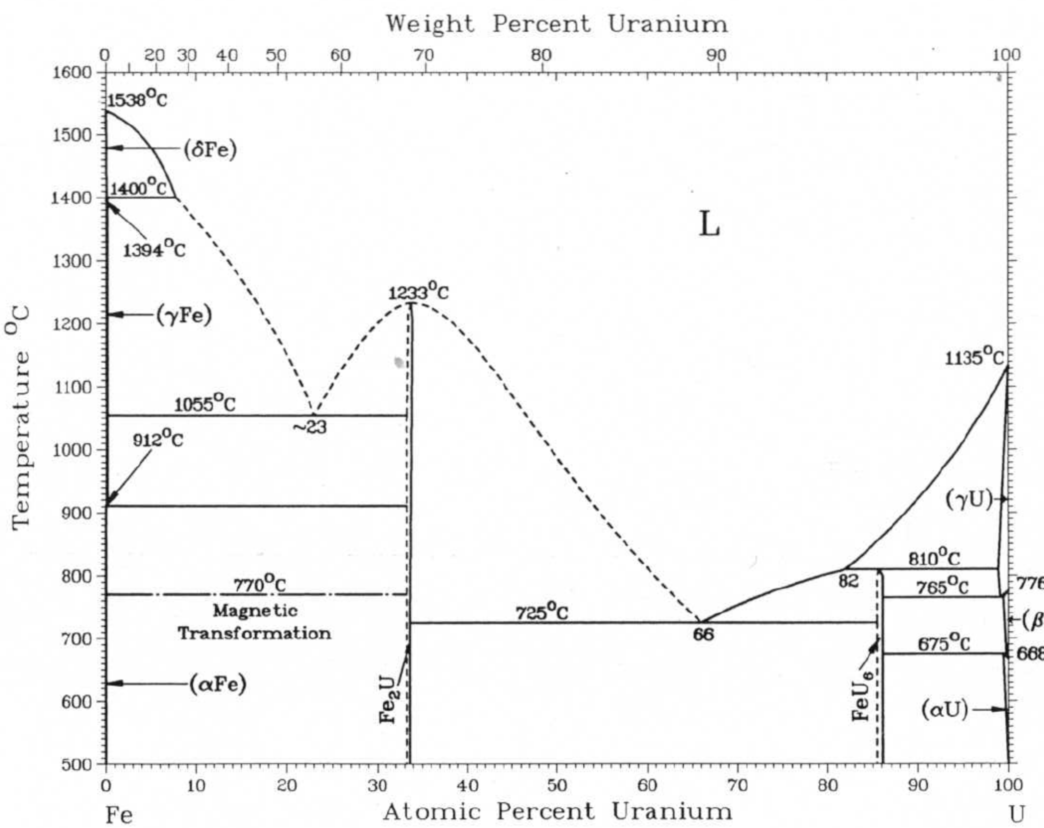
a) (5 min) What is the solubility limit (in atom %) of zirconium in hafnium at 1800°C? What is the solubility limit (in atom %) of iron in uranium at 700°C?

b) (5 min) If you are slowly cooling a solid alloy of 50 wt%Zr-50wt%Hf from 1600ºC to 500ºC, at what temperature will (αZr,αHf) begin to precipitate? What will the (αZr,αHf) composition be (in wt %) at that point? What will the (βZr,βHf) composition be (in wt %) at that point?

c) (5 min) On cooling liquid U-11 wt% Fe (U-34 at% Fe) alloy from 1200ºC, how many phase transitions will occur? What is the name for the type of transformation at 725ºC? Name the equilibrium phases present at room temperature for this composition.



Weight Percent Hafnium
Temperature °C
Atomic Percent Hafnium
Zr
Hf
L
(βZr,βHf)
(αZr,αHf)
1855°C
2231°C
1743°C
863°C



Weight Percent Uranium
Temperature °C
Atomic Percent Uranium
Fe
U
L
1538°C
(δFe)
1400°C
1394°C
(γFe)
1233°C
1055°C
~23
912°C
770°C
Magnetic Transformation
(αFe)
Fe2U
725°C
66
82
FeU6
1135°C
(γU)
810°C
765°C
776°C
(βU)
675°C
668°C
(αU)