**NE 795-014 Advanced Reactor Materials and Materials Performance**

**Exam 2**

Please provide your responses to the following questions. Point values indicated expected depth of response.

1. Describe some of the beneficial safety features of SFRs. (8 pts)

Large margin to boiling of Na. High thermal conductivity of fuel leads to less stored energy. High thermal conductivity coolant. Negative reactivity feedback coefficient can lead to passive shutdown, even under severe accident scenarios.

1. Why do we alloy uranium for fuels? (8 pts)

Alpha U has an anisotropic structure which displays anisotropic irradiation growth and anisotropic thermal expansion and can swell excessively. Alloying stabilizes the high temperature body centered cubic phase, which has isotropic properties. Alloying also serves to improve certain properties, such as increasing the melting point. Alloying has also been shown to potentially reduce swelling and limit FCCI.

1. Why must metallic fuel systems include a relatively low smear density and large plenum? (10 pts)

Metallic fuels swell dramatically due to fission gases being generated and accumulating into bubbles. If a high smear density is utilized, the fuel will come into contact with the cladding and exert strong outward forces, increasing the likelihood of cladding failure. If a sufficiently low smear density is utilized, the fuel will swell until fission gas bubbles interconnect, allowing fission gas release and a significantly reduced rate of swelling, limiting the outward force induced on the cladding by the fuel. A large plenum is required to accommodate the released fission gases without excessively increasing the pressure inside the cladding.

1. What is constituent redistribution in metallic fuels? Why does it occur? What are the concerns associated with it? (15 pts)

The composition of the fuel slug changes radially under irradiation. This typically leads to three distinct regions: 1) an inner region enriched in Zr, 2) an intermediate region depleted in Zr, and 3) an outer region with an as-fabricated composition. This is believed to occur due to a combination of thermodynamics (different solubilities of Zr in different phases) and Soret diffusion (Zr diffusing up the temperature gradient, U diffusing down). This can modify the radial fission rate profile, which impacts the temperature profile, in addition to generating a low melting point phase in the intermediate region.

1. How does the thermal conductivity vary as a function of burnup in metallic fuels? What phenomena drive this behavior? (8 pts)

The thermal conductivity decreases as a function of burnup due to the accumulation of porosity in the form of fission gas bubbles. Upon fission gas bubble interconnection and release, sodium infiltration can occur to partially back-fill the open porosity connected to a free surface. The replacement of fission gas with liquid sodium in the porosity serves to increase the thermal conductivity of the fuel. Subsequently, the thermal conductivity decreases as additional porosity is accumulated.

1. For metallic fuel: What is FCCI? What are the adverse effects of FCCI? What are the primary fuel and cladding species participating in FCCI? (15 pts)

Fuel cladding chemical interaction. The fuel comes into contact with the cladding due to swelling, fuel constituents and fission products can chemically interact with the cladding to form a variety of phases. These phases are often intermetallic, brittle, with low melting points, wasting away the cladding and increasing the likelihood of cladding failure. Low melting phases can potentially redistribute the fuel, leading to safety concerns. Nd and Ce are the primary fission products, U and Zr are the primary native fuel species, and Cr and Fe are the primary cladding species which participate in FCCI.

1. Describe restructuring in MOX fuels, including why it happens. (12 pts)

Restructuring results in four distinct regions. Due to the high temperatures in MOX fuel, porosity migrates up the temperature gradient in an evaporation/condensation process, restructuring the fuel. This leads to a central void region where accumulated porosity resides, and a columnar grain region generated by the diffusion of elongated voids up the temperature gradient, destroying the prior microstructure and depositing new grains. At temperatures below which porosity migration can occur, grain growth occurs. Finally, on the periphery of the fuel the microstructure is effectively as-fabricated.

1. How does Pu and O concentration vary spatially in a MOX pin? (8 pts)

Pu diffuses up the temperature gradient due to the preferential evaporation/condensation of U as porosity migrates. Thus, Pu is often concentrated around the central pore. Pu also forms in agglomerates due to imperfect mixing of initial powders. The O concentration typically increases as a function of radius in the pellet, as O wants to diffuse down the temperature gradient. Thus, the O/M ratio near the periphery is nearly 2.0, which in the center of the fuel pin the system is very hypostoichiometric.

1. What is JOG? Why does it occur? (8 pts)

Joint oxyde gaine. This is an oxide layer that forms on the outer surface of the fuel pellet in between the cladding and the fuel. The diffusion of volatile fission products down the temperature gradient, combined with extra oxygen available at the fuel pellet rim, leads to the formation of Cs-Mo-O phases. JOG can improve the effective thermal conductivity of the fuel system by filling in the gap and can serve as a mechanical buffer to PCMI. However, the fission products can contribute to cladding corrosion.

1. Discuss the means which sodium corrosion occurs in SFRs. (8 pts)

Sodium corrosion primarily occurs due to difference in the solubility of various cladding species as a function of temperature. Solubilities are higher at higher temperatures, leading to leaching at high temperature regions and deposition at low temperature regions. Impurities, such as oxygen, exacerbate this process by increasing the effective solubility of cladding species through the intermediate formation of oxide phases.