NE 795 Advanced Reactor Materials and Materials Performance

Exam 3

The associated point values provide an indication of the expected thoroughness of response.

1. What are the types and benefits of molten salt reactors? (7pts)

Three types: solid fueled molten salt cooled; flowing salt fueled and salt cooled; static salt fueled and flowing salt cooled. High heat capacities, high thermal conductivity, atmospheric pressures, large margin to boiling, negative reactivity coefficient, flexibility of composition, reprocessing can proceed directly, etc.

1. What are three key properties needed for molten salt fuel and why are they important? (7pts)

Low melting point, high thermal conductivity, fission product solubility (other answers apply). Allows for lower temperature operation and is linked to lower viscosity and larger margin to boiling; allows for high power density cores, larger safety margins; soluble fission products will not plate out in the cladding tubing, but will be contained in the salt.

1. What role does the cover/sparge gas serve in MSRE type reactors? (7pts)

Primary control of impurities and redox conditions. Allows for tailoring the fluorine concentration, can assist in removal of fission gases, fission product precipitates, and corrosion products. Critical in corrosion rates, dissolution, and deposition.

1. Discuss corrosion of the cladding in a molten salt environment. (14pts)

Corrosion primarily occurs via dissolution/deposition reactions. Flowing molten salt will have a hot and a cold side of the flowing loop, and the solubilities of impurities are dependent upon the temperature, with higher solubilities at higher temperature. This leads to deposition of corrosion products on the cool side of the loop. For typical Ni-based cladding materials, Cr is the most common alloying element that participates in the corrosion process. The redox potential, effectively the amount of free fluorine/chlorine that is present, affects the prevalence with which corrosion products will form fluorides. Oxide layers do not inhibit corrosion but can actually accelerate corrosion via the generation of intermediate oxide phases that can be more readily converted to fluorides than the metallic species. Impurities can further accelerate corrosion through the formation of intermediate fluoride compounds, which can then be converted into CrF2. The redox potential is analyzed by the UF4/UF3 ratio, which is a measure of the amount of free fluorine in the system. Additional fluorine present will convert UF3 to UF4, which can then convert Cr metal to CrF2. Cr corrosion has been observed to be rate limited by the diffusion of Cr to the surface of the structural materials.

1. Why are we interested in carbide and nitride fuels? (8pts)

These fuel types represent a ‘best of both worlds’ area of fuel properties, with high fissile density, high thermal conductivity, and high melting points. This allows for high burnup fuels, operating at higher powers and higher temperatures, and thus reduced costs. UC and UN are being considered for a number of advanced reactors, including HTGRs, Pb-cooled reactors, and space reactors.

1. What are the two types of pin designs for C and N fuels? Discuss design and operational ramifications of the designs. (12pts)

Na-bonded and He-bonded. He-bonded designs are the standard choice with a low pressure He gas filling the cladding tube. He has a low thermal conductivity, and thus these fuels operate at higher temperatures. The theoretical density of these fuels must also be low, while reducing the gap thickness, the prevent excessively high centerline temperatures. He-bonded pins have relatively high fission gas release due to the high temperatures. Na-bonded pins can have high theoretical densities and larger gaps due to the high thermal conductivity of Na. These pins typically have lower centerline temperatures and thus have less fission gas release. Na-bonded pins correspondingly have higher swelling. C transport through the Na accelerates carburization of the cladding compared to He-bonded pins. Potential issues of using Na as bond due to pyrophoricity.

1. What are the three stages of temperature evolution in C and N fuels? (6pts)

A) Initial temperature ramp-up, leads to thermal cracks which further reduce the effective thermal conductivity and cause an increase in the temperature. B) Densification and unrestrained free swelling proceed, which initially increases the gap and then proceeds to close the gap, leading to a steady decrease in fuel temperature. C) Closure of gap, pseudo steady-state temperature, restrained swelling and FCMI occurs.

1. How do carbides and nitrides restructure as a function of burnup? (8pts)

Typically restructure into 3 zones. Central high temperature zone is highly porous, releases fission gases. Intermediate zone consists of equiaxed grain growth. High temperatures lead to large fission gas swelling, but temperatures not sufficiently large to allow for large bubble interconnection and release. Outer zone is the coolest zone, small fission gas bubbles, no fission gas release, minimal swelling contribution, as-fabricated microstructure. All three zones form for both carbides and nitrides. In carbides, a fourth zone can develop which is similar to the columnar grain growth region in MOX fuels if the linear power is sufficiently high.

1. Discuss FCCI for carbide fuels. (8pts)

Primary concern is carburization. Carbon is transported to the cladding and can form Cr23C6 precipitates. Precipitates form first on grain boundaries and can then propagate along crystallographic planes intragranularly. Carburization leads to embrittlement of the cladding, as carbides impede dislocation motion. Carburization is worse in Na-bonded pins. Also of concern are the formation of low melting phase metallic precipitates if too little C is present. C/M ratio decreases with time and can form these phases. Thus, carbides are made with excess C, which then contributes to carburization.

1. Why is fabrication of carbides and nitrides difficult? Why is nitride fuel fabrication more expensive than carbides? (8pts)

Proceeds primarily through carbothermic reduction process. Key difficulty is from pyrophoricity, requiring glove box/controlled atmospheric conditions. High fissile density restricts batch size. Very high temperatures required for sintering. Concerns with impurity pickup. Nitrogen requires N15 enrichment due to N14 neutron absorption.

1. How do the C/M and N/M ratios change with burnup? Why is this important? (9pts)

C/M ratio decreases with burnup, as fission products react with C. This potentially allows for the formation of intermetallic precipitates which have low melting points. Thus, carbides are usually fabricated as hyperstoichiometric. N/M ratio increases with burnup, as fewer fission products can form stable nitride phases. This can lead to the formation of U2N3 phases.

1. Why are lead-based coolants of interest? What is an area of concern for them? (6pts)

Low melting point, large margin to boiling, high thermal conductivity, low neutron moderation, and removes the issues of pyrophoricity of liquid Na coolant. Liquid metal embrittlement and solubility-based corrosion are the primary concerns.