URANIUM NITRIDE-SILICIDE ADVANCED NUCLEAR FUEL: HIGHER EFFICIENCY AND GREATER SAFETY

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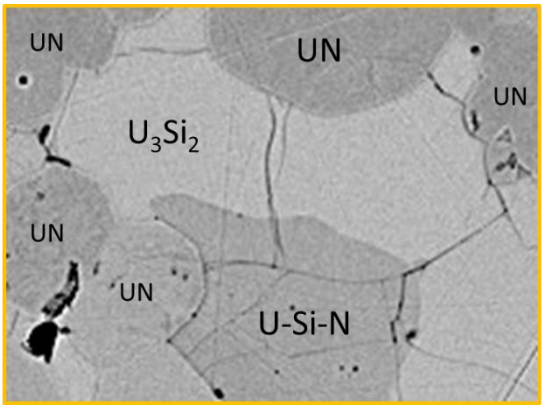
The development of new nuclear fuel compositions is being driven by an interest in improving efficiency/lowering cost and increasing safety margins. Nuclear fuel efficiency is in large measure a function of the atomic density of the uranium, that is, the more fissionable uranium available per unit volume the less fuel volume that is required. Proliferation concerns limit the concentration of fissile ^{235}U, and thus attention is directed to higher overall uranium content fuel. Among the options are the high temperature phases U_3Si_2 and composite UN-U_3Si_2 where the design would have the more water-stable U_3Si_2 surround the more soluble, but higher uranium density UN grains. (Uranium metal of course has the highest atomic density, however its low melting point, high degree of swelling under irradiation, and chemical reactivity eliminate it from consideration.) Another advantage of the nitride and silicide phases are their high thermal conductivity, greatly exceeding the current standard UO_2 fuel, with the high conductivity potentially allowing the fuel to operate at a higher power density.

The accident at Fukushima dramatically demonstrated that the current fuel system of UO_2 pellets encased in zirconium alloy cladding will rapidly oxidize in high temperature steam or air present once cooling water is lost. Zirconium has been the standard base alloy for fuel cladding due to its very low neutron absorption cross-section allowing for very efficient nuclear processes, and good corrosion resistance in water. Yet, zirconium is particularly problematic in severe accidents as it undergoes runaway oxidation with a very high reaction enthalpy that contributes significantly damaging energy to the system. There are thus current programs to develop alternative cladding materials, including options such as ferritic alloys and SiC composites. Work on ferritic alloys has been particularly promising for near term introduction, however the neutron absorption cross-sections for the alloy constituents are substantially greater than that of zirconium. Thus to compensate for the neutrons lost to ferritic alloy elements, higher uranium concentration fuels such as nitrides and silicides are needed.



The current research focuses on the high temperature behavior of silicides and composite nitride-silicide. Thermochemical models and values for the U-Si and U-Si-N systems are being computationally determined by first principles and CALPHAD techniques, supported by experimental measurements. Phase equilibria in important compositional regions of the U-Si system and the nature of recently observed U-Si-N ternary phase(s) are being determined. In addition the high temperature phase equilibria and compatibility of the fuel systems with the novel cladding materials, interpreting initial observations, for example, of U-Fe-Si ternary phase formation from U_3Si_2 fuel in contact with ferritic cladding alloy are being explored. These and other recent efforts on the high temperature behavior of advanced fuels will be discussed.

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