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Chemical Interaction and Compatibility of Uranium Nitride Fuels with Liquid Pb and Alumina-forming Austenitic Alloys

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ABSTRACT:

UN is considered as a primary fuel form for lead-cooled fast reactors (LFRs), and displays enhanced fissile element density, higher thermal conductivity, better breeding ratios and neutronic economics as compared with oxide fuels. It is expected that UN fuel should display good compatibility with Pb coolants/sublayer of LFRs; however, limited data on chemical interaction between nitride fuels and liquid metals are available to verify this key materials compatibility characteristics. In addition, a key technological challenge in the development of LFR is the corrosive nature of liquid metal at high temperature. Typical alloy elements particularly Ni display high dissolution in liquid metal, and active oxygen control in liquid metal is not effective to control corrosion of cladding in liquid metal above 500 ^{o}C. Alumina-forming austenitic alloys (AFAs), currently being developed by ORNL, is the key to enable Westinghouse's LFRs with improved economic competiveness and safety margin. A critical technological need not being addressed is the fuel-cladding interaction with the presence of liquid metal.

We propose a comprehensive research program targeting critical issues of chemical interaction and compatibility among UN fuels, AFAs and liquid Pb. The overarching goal of this project is to obtain critical data of fuel-coolant-cladding chemical interaction and compatibility that will be useful for evaluating and defining key parameters of operation temperature, fuel impurities and coolant chemistry relevant to the deployment of this fuel-coolant cladding system for LFRs. Specific research objectives include: (1) to testify the hypothesis of good compatibility of UN with liquid metal Pb and AFAs; (2) to identify any possible interaction and compatibility issues of UN fuels and optimized AFAs with the presence of liquid metals at elevated temperatures; (3) to understand how different fuel chemistry, impurities, phases, and coolant chemistry (specifically oxygen control) impact fuel-cladding interaction and compatibility with liquid Pb coolant/sublayer; and (4) to achieve a comphrensive understanding of the interaction and compability of this fuel-coolant-clading system and recommendation of key operation window and parameters for practical applications.

Chemical interaction and compatibility of UN fuels with liquid Pb and AFAs are critical for the long term performance evaluation of the fuel, coolant and structural materials for LFRs. The interaction of the fuel with Pb metal will be useful in guiding the design of different fuel element configurations (liquid metal sublayer) and coolant chemistry control. A thoroughly investigation of the chemical interaction and compatibility among this fuel – coolant – cladding system and understanding of the impact of oxygen levels in coolants and temperature will enable us to define operation windows and optimize the controlling parameters including operation temperature, fuel chemistry and impurities, and coolant chemistry. The fundamental understanding of the impact of the oxygen and carbon impurities, liquid metal chemistry and fuel stoichiometry can be useful in understanding various key fuel phenomena and properties such as fuel swelling, fission product retention and release, elemental transport through liquid metal and degradation of the cladding such as liquid metal corrosion and embrittlement. The success of this project will represent a significant advancement in understanding UN fuel behavior, which is supportive of the DOE-NE's mission to provide an advanced reactor pipeline and to implement and maintain national strategic fuel cycle and supply chain infrastructure.