U3Si2 Fabrication and Testing for Implementation into the BISON Fuel Performance Code

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ABSTRACT:

A three-year research program is proposed to fabricate, test, and model a high uranium density, advanced nuclear fuel (U3Si2). This work is designed to deliver key research data on creep and grain growth that is complementary to earlier and ongoing programs focused on advanced fuels for greater safety and economics (i.e. power uprates) and supports DOE programs in LWR Sustainability.

U3Si2 fuel in combination with an advanced cladding material is important to advance more accident tolerant fuels to address issues related to possible loss of coolant accidents. U3Si2 has a number of advantageous thermophysical properties, including; high density (12.2 g/cm3, 11.3gU/ cm3), high thermal conductivity at room temperature (15 W/mK), and a high melting temperature (1665^{0} C). Other advanced fuels such as carbides and nitrides similarly have higher uranium atom densities (greater than UO2), high thermal conductivity, and even higher melting temperatures but are not compatible with water. Because of its high thermal conductivity it operates at a much lower temperature and stores less energy. The fuel's lower temperature leads to a smaller temperature gradient and lower thermal stresses. This helps mitigate issues of pellet cracking and relocation, both of which are common to standard UO2 fuel. The impact of fuel swelling and relocation are important factors in evaluating pellet clad interaction (PCI), a chief cause of fuel failures. Consideration of advanced ceramic claddings which are non-yielding (lack of plastic deformation) means accurate information for fuel thermal and mechanical responses are needed. A gap in such information exists with respect to the creep of U3Si2. To address this need, a series of flexure creep tests are proposed to collect the needed data for modeling.

The proposed effort will fabricate single phase U3Si2 specimens for grain growth and creep testing. Characterization will include a complete understanding of feedstocks and as fabricated microstructure for the most complete "understanding of mechanistic material behavior in fuels, including how relevant microstructures affect the mechanical, thermal, and chemical performance" as called for in Workscope FC-2.

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It is proposed to implement an improved four-point bend creep test by leveraging a non-contact full-field strain measurement method with the goal of tracking local stress and local strain simultaneously. During the flexure creep test, digital image correlation (DIC) will be utilized to measure the strain distribution of the side surface of the flexure sample. It is expected that the additional DIC measurement will enhance the analysis of flexure creep data and allow for the acquisition of accurate creep data using a low-cost flexure test method. Data for creep rate of U3Si2 will be used in development of models for implementation into Idaho National Lab's fuel performance code, BISON and grain growth information will be modeled in the related code MARMOT. This combined effort of testing and modeling would thus support and have programmatic relevance as described in Workscope FC-2.2: Separate Effects Testing to Support Model & Material Science Development. The collection of information on creep in fuels with varying grain sizes will enhance models to account for grain size effects. Such fidelity of models for accurate fuel condition is important as feedback from related codes such as MARMOT which provide for grain growth during fuel burnup. By testing and modeling samples with different microstructures/grain sizes, this enables and supports development of more mechanistic fuel performance models as called for in Workscope FC2.2.