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Irradiation of Advanced Neutron Absorbing Material to Support Accident Tolerant Fuel

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ABSTRACT:

A strong focus of the nuclear industry is to develop enhanced accident tolerant fuel (EATF) concepts. Extensive levels of funding are being spent industry-wide on development of these concepts with the goal to deploy lead assemblies by 2021. Deployment of EATF products supports the Department of Energy's (DOE) Office of Nuclear Energy's (NE) mission to sustain the safety of current reactors.

Once EATF cladding and fuel concepts are utilized in reactors, the limiting components during Design Basis Accidents (DBAs) and Beyond Design Basis Accidents (BDBAs) will be the control components. Current absorber materials have proven insufficient at providing reactivity control during the Three Mile Island and the Fukushima Daiichi accidents. During DBA conditions at peak fuel rod cladding temperatures, control rod temperatures are predicted to be high enough that current absorber materials (Ag-In-Cd) will melt with vaporization of portions of the material. Additionally, the densities of these materials prevent inter-mixing of the material when molten material forms during a full core melt-down.

Thus a research program was initiated to development new absorber materials which would not degrade at the temperatures predicted for DBA and BDBAs. The materials developed are reported to have melting points more than three times that of the current absorber materials. Phase stability of these new absorbers is ensured to at least 1800°C, well above the temperatures expected during DBA/BDBAs. The materials are expected to show slow oxidation kinetics in these conditions and to not result in the evolution of hydrogen during oxidation. Further, no eutectics occur between the absorber materials and the stainless steel cladding in the temperature ranges predicted for normal operation and accidental conditions.

The new absorber materials can be designed to perfectly replace control rod worth and maintain reactor critical drop times, providing a transparent replacement for current materials. Manufacturing of the materials is straightforward and uses current industrial equipment and methodologies. The proposed absorber materials are expected to also offer benefits during normal operation, with a predicted reduction in irradiation-induced swelling and thus the ability to better support flexible power operations.

Extensive out-of-pile testing of these absorber materials is underway. To validate performance under irradiation, the absorber materials must be irradiated to dose levels reflective of middle- and end-of-life fluence. Four pellet types will be irradiated and compared to control pellets representing current industry absorber material. Four samples of each type will be irradiated. Of these, two will be removed at an approximate fast fluence (0.1 MeV – 10 MeV) of 1.3 x 10^{22} n/cm^2 and two will be removed at approximately 2.7x 10^{22} n/cm^2 which is representative of an end-of-life dose and can be reached in less than three years through irradiation in the High Flux Isotope Reactor (HFIR). Samples are manufactured as rectangular bars that are nominally 1.8 mm x 3.6mm x 12mm, with a sintered density > 95% theoretical density.

Following irradiation, samples will be transferred to Oak Ridge National Laboratory (ORNL) Building 3025E for post-irradiation examination (PIE) to evaluate the performance of the samples. Examinations will focus on sample integrity using optical microscopy as well as dimensional measurements to facilitate irradiation induced swelling calculations. The major project deliverable will be a final technical report summarizing the samples, irradiation experiments, and post-irradiation examination results.

Development of accident tolerant neutron absorbing materials is a key aspect necessary to ensure the accident tolerance of the commercial nuclear fleet. Once irradiation of these materials is complete and the results incorporated into design models, the neutron absorbing materials can be deployed to commercial reactors worldwide. When used in conjuction with accident tolerant fuel designs, the accident tolerant control rods will further enhance safety of the nuclear reactor.