A High Current, High Energy Helium Beamline for Accelerated Nuclear Materials Development

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ABSTRACT:

Many advanced reactor concepts are proposing operational temperatures more than 500°C. These elevated operational temperatures pose difficulties for current and proposed structural materials as many of the materials, such as Fe-based alloys or steels, the operational temperature is near or above ≥ 0.45 T_m, where T_m is the melting point of the structural alloy. This temperature regime, in concert with an applied stress, can cause a phenomenon known as high temperature helium embrittlement (HTHE) which could significantly reduce the operational lifetime of components in advanced reactors. HTHE occurs when helium, produced via (n, α) reactions, migrates to microstructural features such as grain boundaries and precipitates as helium bubbles, causing a significant reduction in the mechanical properties of the material. HTHE is inherently difficult to systematically study in nuclear materials test reactors as the helium production rate is directly tied towards the specific reactor's spectrum and the alloy composition. In addition, elevated temperatures are inherently difficult to control when test specimens undergo dimensional changes due to creep and/or swelling in reactor. This works seeks to expand the domestic testing capabilities for HTHE and other helium-induced or accelerated degradation processes in nuclear materials by establishing a new high current helium ion source and corresponding beamline components at the Michigan Ion Beam Laboratory (MIBL) to form a new high current, high energy helium beamline. An ion-based approach enables decoupling of the alloy composition from the helium production rate thus enabling emulation of irradiation parameters for multiple reactor concepts (*e.g.*, fast, thermal, or mixed spectrums) in a single testing facility. Ion-based approaches have been used historically in the past, but many of the facilities for doing such irradiation tests no longer exist or are not open to the nuclear materials community. A new National Electrostatics Corporation (NEC) Toroidal Volume Ion Source (TORVIS) capable of producing negative ions of hydrogen, deuterium, and helium, and the corresponding beamline upgrades including a turbomolecular vacuum pump will be installed at MIBL to enable the proposed ion-based approach and will be made available to the nuclear materials community through user facility proposals. The new capability will be coupled to MIBL's in-situ ion creep testing capability as well as other test stations to enable a wide range of temperatures, helium production rates, damage rates, and stress states to be accessed. The result is a new capability that enables systematic and high-fidelity studies of HTHE and other helium effects in complex material systems for advanced nuclear reactor applications. The establishment of the HTHE capability will be open to user access via the Nuclear Science User Facilities (NSUF), and will thus serve all nuclear energy supporting universities, national laboratories, and industry.