DOE-ID NEPA CX DETERMINATION
Idaho National Laboratory

CX Posting No.: DOE-ID-INL-21-013

SECTION A. Project Title: Passive Strain Measurements for Experiments in Radiation Environments

SECTION B. Project Description and Purpose:

Understanding the mechanical response of materials under radiation is essential to qualifying any material for use within a reactor. In a radiation environment, such as in a reactor core, the radiation damage incapacitates many instruments and thus it limits the instrumentation options. Furthermore, the cost of instrumentation increases if parameters are monitored online. However, passive instrumentation can be used to evaluate critical parameters for fast and reliable screening tests. The accuracy of the instrumentation can be significantly high when benefited from modern computational methods. Thereby, we propose to develop passive instrumentation for the determination of permanent strains induced by irradiation and extract critical parameters using machine learning techniques. A reference material will be used as an irradiation-driven actuator. Specimen will be constrained by the actuator to force either the actuator or the specimen to deform under irradiation. After irradiation, dimensional changes of both materials will be compared to unrestrained control specimens and actuator material to extract the deformation behavior using physics-informed crystal plasticity modeling. The models will then be retrained using machine learning and the new data. Demonstration tests will be performed at North Carolina State University's nuclear reactor. Because machine learning is not affected by the source of the deformation, the algorithm will be developed first using fresh materials testing data and it will be extended to irradiated data.

Significance: Understanding the mechanical response of materials under radiation is essential to qualifying any material for use within a reactor. For non-radiation environments, the mechanical response of interest can be more easily measured using conventional and advanced techniques. In a radiation environment, such as in a reactor core, the radiation damage incapacitates many instruments, and thus it limits the instrumentation options. When testing materials for nuclear applications, it is very difficult to separate the thermal and radiation induced contributions to the mechanical behavior. This is necessary to support the development of physics-based modeling and predictive simulations of materials used in reactors. Evaluating materials in the reactor is also challenging as many tools used out of the reactor cannot withstand the environment and those that can make irradiation experiments prohibitively expensive for most projects.

One of the most used options to measure displacement under irradiation is to instrument a test capsule with a linear variable differential transformer (LVDT). LVDT equipped experiments require wire feedthroughs from the experiment capsule and this design can increase the cost of an experiment up to five times compared to a similar, non-instrumented design. In addition, the wires from each experiment quickly congest the limited space within the reactor and thus limit the through-put of experiments. In the interest of increasing the throughput of characterization and thus accelerating experiment testing, passive instrumentation that can be cheaply deployed and be easily observed allows researchers to rapidly answer critical questions. Anisotropic materials, such as zirconium or titanium, are known to change dimensions under radiation in a preferential direction. This contributes to what is known as radiation growth and creep and is often viewed as a liability in a material. However, this response can be benefited by tailoring the crystallographic texture of the material so that the growth and creep behavior can be controlled in specific directions. If well characterized, the textured material can be used as a radiation-driven actuator to constrain or monitor a specimen. After irradiations, the dimensional change of both actuators and the specimen can be measured at high accuracy which enables the rapid and reliable screening tests for novel alloys. Combined with experiment data and advance modeling, a multi-fidelity machine learning algorithm can predict underlying constitutive relations of irradiation-induced dimensional change as caused by swelling, growth, and creep. Because the source of the strain is independent, the machine learning algorithm, at first, can be developed by performing series of mechanical testing, such as quasi-steady state tension/compression, fatigue, and thermal creep, at room (excluding creep) and elevated temperatures on fresh actuator material and fast reactor materials such as Alloy 709 and iron-chromium-aluminum alloys. The coupled development of these algorithms and measurement method will then enable INL and researchers an accurate, high-throughput method for determining both thermal and radiation contributions to dimensional instabilities within radiation environments.

Research Plan: This project will be broken into three tasks:

Task 1: Design of an irradiation experiment to examine two materials with known radiation growth, and creep properties. These materials need to be well understood as they will be used to calibrate and use as actuator. Tests will include out of pile mechanical testing (Year 1) and in-pile irradiation testing (Year 2).

Task 2: Development of a machine learning algorithm using fresh and irradiated material tests along with the crystal plasticity modeling. This model should be able used for analyzing irradiated specimen data. Irradiated data will be used for training as well.

Task 3: Integrate the materials into a combined experiment that will position the two materials as restraints against each other and evaluate the competing effects of both materials against each other. Additive manufacturing will be used to create a compact vessel that accommodates the needed material for actuators, test material and reference materials. The model from Task 2 will be used to determine deformation behavior compared to neighboring unrestrained samples. The model results will be used to isolate radiation behavior from thermal behavior.

Lab work and fabrication will be performed at the INL Research Center and the Irradiated Materials Characterization Laboratory at the Materials and Fuels Complex. There will be additional work performed by collaborators at North Carolina State University and the Massachusetts Institute of Technology.

Chemicals and materials to be used offiste are those needed for the polishing and mounting of microscopy samples. Samples are neutron irradiated/activated zirconium.

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

The use of chemicals may result in the generation of some emissions. A small amount of fission product gases will be released at IMCL. Those gases would then exit the IMCL ventilation/exhaust stack.

Discharging to Surface-, Storm-, or Ground Water

N/A

Disturbing Cultural or Biological Resources

N/A

Generating and Managing Waste

Waste to be generated on-site includes PPE, and low-level waste.

Waste to be generated off-site includes: Polishing waste: grit paper, slurry waste. Mounting materials: sticky tape, epoxy, plastic/metal sample holders

Releasing Contaminants

When chemicals are used, there is the potential the chemicals could be spilled to air, water, or soil.

Using, Reusing, and Conserving Natural Resources

All materials will be reused and recycled where economically practicable. All applicable waste will be diverted from disposal in the landfill where conditions allow. Project description indicates materials will need to be purchased or used that require sourcing materials from the environment. Being conscientious about the types of materials used could reduce the impact to our natural resources Project activities may release known greenhouse gases (GHGs) to the atmosphere and increase INL's energy use.

SECTION D. Determine Recommended Level of Environmental Review, Identify Reference(s), and State Justification: Identify the applicable categorical exclusion from 10 Code of Federal Regulation (CFR) 1021, Appendix B, give the appropriate justification, and the approval date.

For Categorical Exclusions (CXs), the proposed action must not: (1) threaten a violation of applicable statutory, regulatory, or permit requirements for environmental, safety, and health, or similar requirements of Department of Energy (DOE) or Executive Orders; (2) require siting and construction or major expansion of waste storage, disposal, recovery, or treatment or facilities; (3) disturb hazardous substances, pollutants, contaminants, or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)-excluded petroleum and natural gas products that pre-exist in the environment such that there would be uncontrolled or unpermitted releases; (4) have the potential to cause significant impacts on environmentally sensitive resources (see 10 CFR 1021). In addition, no extraordinary circumstances related to the proposal exist that would affect the significance of the action. In addition, the action is not "connected" to other action actions (40 CFR 1508.25(a)(1) and is not related to other actions with individually insignificant but cumulatively significant impacts (40 CFR 1608.27(b)(7)).

References: 10 CFR 1021 Appendix B to subpart D, Item B3.6, "Small-scale research and development, laboratory operations, and pilot projects"

Justification: The proposed R&D activities are consistent with CX B3.6 "Siting, construction, modification, operation, and decommissioning of facilities for small-scale research and development projects; conventional laboratory operations (such as preparation of chemical standards and sample analysis); small-scale pilot projects (generally less than 2 years) frequently conducted to verify a concept before demonstration actions, provided that construction or modification would be within or contiguous to a previously disturbed area (where active utilities and currently used roads are readily accessible). Not included in this category are demonstration actions, meaning actions that are undertaken at a scale to show whether a technology would be viable on a larger scale and suitable for commercial deployment."

Is the project funded by the American Recovery and Reinvestment Act of 2009 (Recovery Act) ☐ Yes ☒ No

Approved by Jason Sturm, DOE-ID NEPA Compliance Officer on: 02/04/2021