DOE-ID NEPA CX DETERMINATION
Idaho National Laboratory

CX Posting No.: DOE-ID-INL-21-059

SECTION A. Project Title: Characterizing Inconel X750 Spacer Material Properties

SECTION B. Project Description and Purpose:

Summary

Candu Energy Inc. (CEI), a member of SNC-Lavalin Nuclear (SNC) provides a wide variety of engineering and technical services required for the continued operation of nuclear power reactors. SNC is currently engaged in work relating to maintenance and life extension of Candu nuclear reactors. In this capacity, SNC is performing mechanical tests on ex-service material extracted from reactors, followed by modelling and assessment of component integrity. Due to limitations in the nature and quantity of material that can be obtained from a reactor, testing and evaluation at a microstructural level is required to supplement component scale mechanical test data.

SNC is requesting to collaborate with respect to characterizing and quantifying the microstructure and mechanical properties of highly irradiated Inconel X-750 removed from CANDU reactors. This material has an extremely high concentration of helium and hydrogen, and the mechanical degradation as a function of radiation damage is not yet fully understood. With the recent upgrades to INL's Irradiated Materials Characterization Laboratory (IMCL), INL is among the few places internationally, that can execute this work.

This work scope includes:

- receiving material provided by SNC
- sample preparation
- advanced microscopy
- novel small-scale mechanical testing and reporting

The work includes leveraging open-sourced literature and archive materials within the Department of Energy's (DOE's) Nuclear Fuels and Materials Library to supplement the experimental data collected from the material provided by SNC. Upon the successful completion of this CRADA, the remnant experimental material from this program is available for inclusion into DOE's Nuclear Fuels and Materials Library for future investigation by the larger nuclear community.

The overall objective of this work is to develop a baseline microstructural and micro-mechanical examination of the provided irradiated Inconel X-750 material irradiated at two nominal temperatures (200°C and 330°C) and compare this to available open literature of other examinations of comparable materials from other sources. This material was irradiated in a high thermal flux CANDU reactor, resulting in thermal transmutations and a resulting dose of approximately 60-80 dpa and an approximate helium concentration of 20000-30000 appm helium (3000-5000 appm hydrogen). The baseline experiments will be complemented with additional testing from available archive Inconel X-750 at different doses and helium concentrations that are available in DOE's Nuclear Fuels and Materials Library. The results of this work will be combined with component scale mechanical testing results provided by SNC. Overall, this work will help establish a quantitative relationship for degradation of Inconel X-750 irradiated in a high thermal flux.

In combination with previously published data, the data obtained in this work should allow for a more comprehensive model of material degradation. In particular, the temperature dependence of the mechanical response is anticipated to provide insight into the mechanisms affecting load capacity required to cause failure. Modelling with the goal of characterizing degradation at the component scale would be done collaboratively by SNC and INL participants.

Hold Points

Hold Point 1: A hold point will be placed on work after the Inconel X-750 cross-section samples are unpackaged and inspected before sample preparation is performed. SNC will be notified when the samples have been successfully received and observed and presented images of their condition. Consultation with SNC will occur at this point at which they will authorize sample preparation to proceed.

Hold Point 2: After metallographic sample preparation has been completed, a second hold point will be placed on work. SNC will be sent images of the prepared spacer cross-sections and consulted on which exact locations Transmission Electron Microscope (TEM) lamella and micro-mechanical specimens will be milled from via Focused Ion Beam (FIB). After sample locations are agreed upon, FIB work will proceed.

Hold Point 3: After FIB work has been completed, a final hold point will be placed on work after images of the completed TEM lamellas are sent to SNC. At this point, SNC will confirm that the lamellas are acceptable to proceed with TEM microscopy.

Tasks

Task 1: Microscopy

TEM microscopy data will be collected from lamellas made from each unique irradiation condition (unique dose, dose rate, and/or irradiation temperature history). For each lamella, the microstructural examinations will include:

- Imaging and quantification (size, number density, and spacing) of Loops, Stacking Fault Tetrahedrons (SFTs), and helium bubbles within the matrix (grain interiors).
- Imaging and quantification (size, number density, spacing, and area coverage) of helium bubbles on the grain boundaries (intent on multiple per sample).
- Analytical analysis and diffraction analysis of gamma prime disordering and dissolution.

Task 2: Mechanical Testing

A series of small-scale tensile tests will be performed on each provided material. Micro-tensile specimens will have the approximate dimensions of 3 µm x 3 µm x 8 µm as a function of testing temperature, ranging from room temperature to 350°C. These tests will include:

Electron Backscattered Diffraction (EBSD) prior to preparation to ensure we know the grain orientations within the tensile gages.

- Samples are bi-crystalline and include a boundary approximately located in the mid-gauge.
- High resolution images before and after testing, and video recording.
- Digital image correlation for strain analysis used to generate engineering stress-engineering strain curves for each specimen in order to extract specimen mechanical properties: yield strength, maximum strength, and total elongation to failure.

A limited series of meso-scale tensile tests will be performed on one material provided. The specimen dimensions for these meso-scale tensile tests will fall within the following upper and lower bounds: minimum 7 µm x 7 µm x 18 um and maximum 100 µm x 100 µm x 250 µm. The test temperature for these meso-scale tests will be limited to room temperature and 300°C only.

If sample preparation procedures allow for the geometry and orientation of the materials to be well known, all small-scale tensile specimens will be manufactured along the inner diameter edge of the component. This orientation allows the uniaxial tensile stress to be in the same direction as the component sees in service, which provides the most valuable mechanical data results, allowing for more accurate comparisons between small-scale test data and component test data.

Component testing on the Inconel X-750 CANDU spacers will be performed by SNC using external facilities, and the data will be provided as part of this CRADA, to provide a link between small scale testing and component testing, to develop a more fundamental understanding of the material degradation and link with microscopy data.

Task 3: Modelling

All modelling will be performed by SNC in collaboration with INL. This will include a comprehensive model of material degradation. In particular, the temperature dependence of mechanical response is anticipated to provide insight into the mechanisms affecting load capacity required to cause failure.

Task 4: Publication and Presentation

All small-scale mechanical test data and microscopy data produced by INL will be scientifically analyzed and written up for publication in the appropriate research journals and presented at the appropriate technical meetings/conferences. It is anticipated that the novel, in-situ, Scanning Electron Microscopy (SEM), high temperature testing on component material irradiated to high dose will add both insightful scientific value to the nuclear materials community and increased commercial interest from the nuclear industry. Novel post-irradiation examination techniques that produce representative, quantitative mechanical data with increased statistics coupled with mechanistic insights make for strong publications and deserve to be showcased in order to fill in knowledge gaps, expand the capabilities of IMCL/INL research, and grow new and existing collaborations.

There are no planned equipment purchases. Samples will be retained in the NSUF Library at the completion of the project.

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

N/A

Discharging to Surface-, Storm-, or Ground Water

N/A

Disturbing Cultural or Biological Resources

N/A

Generating and Managing Waste

Minor amounts of low level rad waste will be generated from cutting, grinding, and polishing 0.8 mm x 0.8 mm x 0.8 mm specimens

Releasing Contaminants

When chemicals are used during the project there is the potential for spills that could impact the environment (air, water, soil)

Using, Reusing, and Conserving Natural Resources

All materials would be reused and recycled where economically practicable. All applicable waste would be diverted from disposal in the landfill where conditions allow.

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, items B3.6, "Small-scale research and development, laboratory operations, and pilot projects"

Justification:
The proposed R&D activity is 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 Anderson, DOE-ID NEPA Compliance Officer on: 04/13/2021