DOE-ID NEPA CX DETERMINATION
Idaho National Laboratory

CX Posting No.: DOE-ID-INL-16-137 R1

SECTION A. Project Title: Post-Irradiation Examination Joint Projects with SCK•CEN

SECTION B. Project Description and Purpose:

Revision 1:

This revision addresses the addition of 3 additional tasks. Due to the change in scope the original tiered ECP is now a new ECP.

Disc Irradiation for Separate Effects Testing with Control of Temperature (DISECT) will consist of parametric testing to evaluate the influence that specific parameters have on a more complex system. The behavior of nuclear fuel under irradiation is impacted by many such phenomena including component redistribution, fission gas behavior, grain refinement, phase transitions, superlattice formation, etc. Each of these behaviors is a function of fission rate, fission density, temperature, and material composition. This project is centered around metallic fuels, specifically U-Zr and U-Mo. Fabrication of the samples, fabrication of the final devices, pre-irradiation characterization, and some post-irradiation studies are to be done at INL with an in-kind contribution from SCK-CEN for irradiation and post-irradiation examination.

The goal of this project is to understand the evolution and manifestation of microstructural features in metallic alloy nuclear fuels. This needs to be done to develop the predictive capability required to implement and qualify new nuclear fuel technologies. While the key phenomena that govern overall fuel performance can be investigated and measured through irradiation under known conditions, it is extremely difficult to isolate features and their causes due to significant interaction between system components and constantly varying conditions.

DISECT is a joint project with the Belgian SCK-CEN laboratory to irradiate U-Zr and U-Mo nuclear fuel specimens in the the BR2 reactor. Fuel specimens are loaded into welded and sealed pucks before insertion into the respective test train capsules. The capsules (one for U-Zr specimens, one for U-Mo specimens) are then welded and sealed. Entire capsule assemblies will be shipped to SCK/BR2 facility where the irradiation is performed. Following irradiation, the capsules will be disassembled and PIE conducted at the Belgium Reactor-2 (BR2) facility. Select fuel specimens will be returned to INL for further PIE work.

Task 2: Disc Irradiation for Separate Effects Testing with Control of Temperature (DISECT)

It is well known that the microstructure of metallic alloys used for various nuclear fuel applications (including research and fast reactor designs) evolves significantly during irradiation. While these changes can have a profound impact on the engineering performance of a fuel system, the complexity of the operating environment and phenomena have historically hindered fuel engineers from providing quantitative mechanistic explanations and computational models desired to guide fuel design decisions. The recent deployment of nuclearized material science instruments and modeling platforms have opened a path to more detailed exploration of this field. As such, two metallic fuels experiments have been chosen to act as a trial run of the international collaboration. These experiments will be conducted to isolate the phenomena of interest and enable these mechanistic descriptions.

Separate effect (or parametric) testing is often used to evaluate the influence a specific parameter has on a more complex system. The behavior of nuclear fuel under irradiation is impacted by many such phenomena including component redistribution, fission gas behavior, and grain refinement, superlattice formation, etc. It is hypothesized that these behaviors may be a function of fission rate, fission density, temperature, material composition, and as- fabricated microstructure.

An irradiation in the SCK-CEN Belgium Reactor–2 (BR2) reactor and subsequent examination in the associated Laboratory for High and Medium Activity (LHMA) and HFEF/Irradiated Materials Characterization Laboratory (IMCL) (at SCK-CEN and INL respectively) will be conducted to explore these relationships. An irradiation test rig design used historically at BR2 will be modified for this experiment. INL will perform the mechanical design of the device as well as operational analysis required to design the experiment and support safety basis development. SCK-CEN will develop the detailed safety package. INL will fabricate the device (to specifications approved by SCK-CEN) as well as the test articles. The test articles will consist of U-Zr and U-Mo fuel that will be fabricated by arc melt casting, hot-rolling, cold-rolling, annealing, and trimming or punching to shape. Pre-irradiation characterization will be performed at INL and potentially other NSUF partner facilities and LHMA (an NSUF affiliate facility). The assembled devices will be delivered to SCK-CEN for irradiation in the BR2. These assembled devices are the experiment capsule assemblies that contain the test articles (UZr and UMo foils contained in sealed pucks inside the sealed capsules) that are inserted into the BR2 reactor irradiation testing positions. Following irradiation, the test articles will receive preliminary examination at the LHMA. Samples will then be extracted for detailed analysis at LHMA and/or transported back to the INL Hot Fuel Examination Facility (HFEF)/IMCL) or other partner facilities. Excess test articles or components, both irradiated and un-irradiated will be added to the NSUF Nuclear Fuels and Materials Library.

The test articles are thin foils of nuclear fuel material (UZr and UMo), fabricated at the Fuels and Applied Science Building (FASB, MFC-787). The foils are contained within quality welded and sealed pucks to control the temperature environment around the UZr and UMo test articles. All fabrication of the foils (including arc melt casting, hot-rolling, cold rolling, and trimming) occurs at FASB. Discs of UMo were punched out of the foils at the Electron Microscopy Laboratory (EML, MFC-774) and returned to FASB. Final annealing after assembly into the pucks occurs at Experimental Fuel Facility (EFF, MFC-794.. Small amounts of solvent and wipes are used for cleaning prior to welding. Puck welding is performed at Advanced Fuel Facility (AFF, MFC-784, and final assembly and orbital capsule end cap welds occurs at the Test Train Assembly Facility. Brazing of instrumented leads will be performed at the Energy Innovation Laboratory (EIL).

Task 3: Irradiation and Post-Irradiation Examination of Uranium Silicide Fuel under Pressurized Water Reactor Conditions Using a Pressurized Water Capsule Irradiation Device at BR2

NSUF awarded a project in 2010 that partly intended to study the effects of irradiation on the water corrosion resistance of U3Si2, a potential high burnup and accident tolerant fuel candidate. The design of the irradiation test was suggested to include a double encapsulated capsule rig like what had been employed for other ATR irradiations in the past. However, in this test, water would be allowed to directly contact the U3Si2 pellets and irradiated for one cycle.

Issues have been identified with performing this test in ATR as envisioned. There is concern that although the encapsulation, including the welds, can be qualified for the temperatures and pressures desired outside the reactor, it is unclear whether the qualification will be valid when under irradiation as the modeling code used in the safety analysis does not properly incorporate the two-phase water condition (liquid and steam) anticipated. In addition, the purpose of the experiment is to test the interaction of liquid water with the fuel material and concern is raised as to the amount of steam that will exist within the capsule. These concerns lead to the following potential option for INL/NSUF to perform irradiation in BR2 using a pressurized water capsule (PWC). PWC for fuel irradiation is an instrumented capsule that can be used for base irradiation of fuel pins up to 1m long, with on-line power monitoring and control of the cladding temperature by setting the water pressure in the capsule. The setup of the device is such that fuel pin failure can be tolerated. Eventually, a fuel pin with instrumentation may also be loaded in the device. Other options may be explored and proposed.

U-Zr and U-Mo fuel pieces may be returned to INL following irradiation for subsequent PIE. The preparation and mounting will be performed at BR2, so small, SEM and TEM sized specimens will be shipped in Type-A containers with appropriate export and import licenses.

Task 4: Cooperative In-Pile Instrumentation Development

INL is implementing a coordinated in-pile instrumentation technology development effort to enable the measurement of phenomena occurring more effectively and efficiently during the irradiation of developmental nuclear fuels and materials. The goals of this effort will be best achieved by leveraging both domestic and international expertise, equipment, and facilities. For this, the NSUF is optimally situated to play a critical role.

High fidelity in-pile instrumentation is needed to determine fuel, cladding, and coolant temperatures, fission gas release, pressure and composition, fuel compositional changes, thermal and mechanical property changes of the fuel and cladding, chemical interactions of the cladding with both fuel and coolant, microstructural changes including crack formation in both fuel and cladding, and gamma and neutron flux.

INL and NSUF are interested in collaborating on in-pile instrument development with SCK•CEN instrument development personnel for sensor and monitor technologies of mutual interest. Potential technologies for collaborative development could include linear variable differential transformer-based sensors, self-powered detectors, ultrasonic based detectors, fiber optical based sensors, etc. Qualification of the devices for in reactor service will be performed with BR2 and NSUF available reactors. Part of the instrumentation development Task 4 collaboration will be advanced through inclusion of particular instrumentation into collaborative irradiation tests as, for example, the instrumentation included in the DISECT experiment. This is a continuing and ongoing collaboration with no particular independent milestones, deliverables, or completion dates as all associated efforts will be part of collaborative irradiation tests.

Original EC:

SCK•CEN (Participant), a Belgian Nuclear Research Centre, and the Department of Energy, Office of Nuclear Energy (DOE-NE), Nuclear Science User Facilities (NSUF) would like to establish an international collaboration through Battelle Energy Alliance, LLC (BEA, Contractor) the managing and operating contractor of Idaho National Laboratory (INL) to develop and expand irradiation testing and post-irradiation examination (PIE) capabilities in their respective facilities. To begin this collaboration, INL and SCK•CEN will partner to test reactor performance and thermal modeling benchmarking using silicon carbide (SiC) temperature monitors. INL has significant experience with in-pile SiC temperature monitors that are analyzed during post-irradiation examination. SCK•CEN is considering use of this technology at the BR2. Current INL activities would be executed at the INL Research Center (IRC) and Energy Innovation Lab (EIL).

Subject to future negotiation and agreement, other tasks may be performed. Additional tasks require review by the program environmental lead and may require additional NEPA review.

Through NSUF, INL is currently funded to conduct post-processing research, but lacks the ability to immediately irradiate the SiC temperature monitor sample set within a short timeframe. SCK•CEN brings the ability to start this smaller irradiation project (Task 1) upon receipt of the samples and over a duration of approximately 4 months. SCK•CEN is interested in learning INL's current capabilities and the forthcoming post-processing research from this collaboration.

This EC covers the following work: The technical objective of this work is to develop new peak temperature measurement capabilities for the SCK•CEN reactor. INL seeks to improve the postprocessing capabilities of the SiC temperature monitors.

SCK•CEN will contribute experience, capabilities, and the BR2 reactor including: an irradiation capsule design, neutronics and thermohydraulic calculations, neutron activation analysis (NAA) for impurity activation assessment, hot cell experience for opening the capsule and unloading samples, hot cell experience for installation of conductivity measurement equipment, and collaboration with university specialists in conductivity measurements.

INL will contribute experience, capabilities, and facilities to support this effort including: the INL IRC, a high accuracy (9 digit) Agilent Model N6705A DC Power Analyzer with a calibrated N6762A Precision Power Modules, constant temperature chamber, vent hood to a HEPA filter, and an annealing furnace (or similar equipment).

The following subtasks outline the expectations to complete Task 1:

1. INL will purchase, box, ship, and insure 24 SiC temperature monitors (1 .00 mm outside diameter x 12.5 mm long) to SCK•CEN for irradiation in the BR2 reactor (Export #EAR99 NLR). SCK•CEN will look to purchase SiC temperature monitor materials from a different source for simultaneous irradiation in the BR2 reactor.

2. Shortly after reception of the material, INL and SCK•CEN will participate in an initial coordination meeting (either telecom or in-person) to develop work execution strategy and fine-tune the planning based on an assessment of the expected post-irradiation dose level of the specimens (NAA planned at BR1 prior to BR2 irradiation) and the amount of material available.

3. SCK•CEN will irradiate the SiC temperature monitors in pairs at temperatures between 200-400°C in the BR2 reactor up to dpa levels that will be defined in the initial coordination meeting. At least half of the samples will be irradiated to ≥1 dpa. The first irradiation test will be performed as a drop-in type test in BR2 only, so without online instrumentation.

4. After irradiation, SCK•CEN will measure the actual dose level and the isotope composition required to define the shipment. SCK•CEN will prepare a Type A radioactive material shipment of one SiC temperature monitor from each of the sample pairs to INL. The package will need to be defined on the basis of the characteristics of the material after irradiation, notably its dose level.

5. INL will ship and receive one SiC temperature monitor from each sample pair from SCK•CEN to INL after irradiation under the agreed conditions in the BR2 reactor. SCK•CEN will take care of the export processing requirements.

6. INL and SCK•CEN will perform parallel independent electrical resistivity measurements at LHMA and INL to determine peak temperature in each of the SiC temperature monitor pairs.

7. SCK•CEN will prepare and export remaining SiC temperature monitor pairs for shipment as a Type A shipment from SCK•CEN to INL after measurements are obtained for the NSUF library. The package will need to be defined on the basis of the characteristics of the material after irradiation, notably its dose level.

8. INL will ship and receive remaining SiC temperature monitors from SCK•CEN to INL. All 24 SiC units will be retained for possible additional measurements/reference before ultimate use in an application or disposal.

9. INL and SCK•CEN will compare results and prepare a joint report with SCK•CEN documenting outcome of the PIE and measurements.

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

Emissions from the project will be discharged into the facility exhaust, which is run through several series of HEPA filter banks prior to its emission. These emissions are monitored with an ANSI N13.1 2011 compliant monitor. Radionuclide emissions would be encompassed by source term documented in APAD INL-20-002, Table 3-HFEF Source Term from DSA-003-HFEF.

Discharging to Surface-, Storm-, or Ground Water

N/A

Disturbing Cultural or Biological Resources

FASB and HFEF are eligible for listing on the National Register of Historic Places (NRHP), and all project activities associated with the building must undergo cultural resource review (CRR).

Generating and Managing Waste

Fuel fabrication follows a usual blending of fissile and non-fissile material, sintering of pellets, and cutting into thin foils used for insertion into the fuel pucks. There is some waste generated in the fuel fabrication process, as usual for FASB fabrication work. Laser orbital welding of the pucks and capsules, and brazing of the instrumented leads generate small amounts of solder waste. A small amount of LLW is anticipated to be generated in the form of wipes and PPE.

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, 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 continuous 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 L. Anderson, DOE-ID NEPA Compliance Officer on: 08/17/2021