DOE-ID NEPA CX DETERMINATION
Idaho National Laboratory

CX Posting No.: DOE-ID-INL-20-068 R1

SECTION A. Project Title: Accelerated Burn-up Accumulation Test of Clean Core Thorium Energy Designated ANEEL-Fuel

SECTION B. Project Description and Purpose:

Revision 1:

This revision provides a better sequence of tasks in the research now that the conceptual design and analysis has been completed.

The ANEEL irradiation test will be performed in the ATR. The first phase of work completed under CRADA-20CRA22 was conceptual design and analysis. Under this new agreement, INL outlines the subsequent execution phases which INL will complete. The high-level phase descriptions include: the preliminary and final design of the irradiation test, fabrication of required testing and handling hardware, assembly of the experiment test specimens and associated hardware, irradiation of the fuel at ATR, and subsequent post irradiation examination (PIE) at MFC (or other suitable facilities at INL). Each subphase of this scope of work will have specific deliverables and requirements to be able to continue to subsequent tasks detailed below.

There are three fuel compositions planned for irradiation with varying uranium oxide to thorium oxide ratios. Some of the specimens are also planned to contain small amount (less than a few weight percent) of burnable absorber. A fourth set of specimens is planned to use only uranium oxide as a control group. The uranium constituent of all specimens will be low enriched uranium as provided by Idaho National Laboratory. The fuel pellets will be arranged into 12 rodlets, each having ~ 4 inch fuel stacks, and clad in zirconium alloy. Each rodlet will be encapsulated in stainless steel during irradiation.

Fabrication and assembly will occur at North Holmes Laboratory (NHL), the Advanced Fuels Facility (AFF), the Experimental Fuels Facility (EFF), and Fuels and Applied Science Building (FASB). Irradiation will occur at the Advanced Test Reactor (ATR). Post irradiation examination (PIE) will occur at the Hot Fuel Examination Facility (HFEF) and the Irradiiated Material Characterization Laboratory (IMCL).

Tasks

Task 1: Complete INL Irradiation Test Preliminary Design.

Complete all activities and requirements to meet preliminary design per the INL Nuclear Materials Experiments Execution Process

Task 2: Complete Final Design and Analysis. Begin Long Lead Fabrication

Complete all activities and requirements to meet final design per the INL Nuclear Materials Experiments Execution Process.

Task 3: Fabricate Experiment Hardware and Fuel Acceptance

Procure and fabricate all materials, hardware, etc. to perform the irradiation test. This includes weld development and qualification. Fuel will be provided by CCTE from TAMU to the specifications developed under phase 1. INL will develop a fuel inspection plan to include review of fabrication and inspection documentation, non-destructive inspection, and destructive analysis of a representative sample of fuel pellets. Additionally, a dissolution process will be developed to facilitate chemical and isotopic analyses. Fuel pellets will be loaded/welded into metallic tubes to create clad rodlets inside of capsules. Capsule will be loaded into open-top irradiation baskets to support their irradiation in ATR.

Task 4: Irradiate Fuel

Perform irradiation of the fuel test train per the irradiation test plan. It is anticipated the irradiation will last 4-5 standard ATR cycles. The irradiated samples will be shipped to HFEF for PIE.

Task 5: Post Irradiation Examination

Perform initial post irradiation examination. Anticipated scope is as follows:

Non-Destructive Exam (on all rods)

- Visual inspection – general condition of rod (especially damage or distortion of cladding)
- Neutron radiography (2 shots at 90º angles) – general condition of fuel (including the central void)
- Axial gamma scan – distribution of radionuclides (used as a measure of local burnup and radionuclide transport within the rodlet)
- Profilometry – dimensional change in the cladding (measure of the pellet growth and interaction with the cladding)

Destructive Exams (start with all high burnup rods and examine lower burnup rods as necessary – assume 1/3 of rodlets examined)

- Rod puncture w/ plenum volume, gas pressure, and gas composition analysis – measure fission gas release

• Optical microscopy including image analysis – evaluate microstructural performance of the fuel (cracking, fission gas bubble evolution, fuel swelling, fuel-cladding interaction, etc.)

Original ECP:

Purpose and Background:

Clean Core Thorium Energy (CCTE), LLC (Clean Core), located in Oak Brook, Illinois, is committed to the development of alternative nuclear fuels. CCTE is focused on development of Thorium-based fuels for Pressurized Heavy-Water Reactors (PHWR) / Canada Deuterium Uranium (CANDU) reactors. Thorium based nuclear fuels are a promising alternative to Uranium based fuels. Thorium is approximately three times more abundant in nature compared to Uranium and occurs mainly as the 'fertile' ^{232}Th isotope. There is an immense potential as a result of the 'breeding' of the fissionable isotope ^{233}U from ^{232}Th, and several experiment and prototype reactors were successfully operated during the mid-1950s through the mid-1970s using Thorium-based fuels. Presently, Thorium based fuels have not been introduced commercially for various reasons, but primarily, estimated Uranium resources have turned out to be sufficient. There is a renewed interest in Thorium based fuels because of its intrinsic proliferation resistance due to the presence of ^{232}U and its strong gamma emitting daughter products, its better thermo-physical properties and chemical stability relative to UO_2 which ensures better in-pile performance and a more stable waste form, and its irradiated fuel contains far less long lived minor actinides than do fuels in the traditional Uranium fuel cycle. The experiment design and irradiation campaign summarized below is fulfilling a critical step in the development and potentially licensing of alternative nuclear fuels that offer much relative to the traditional Uranium fuel cycle.

Idaho National Laboratory (INL) is the nation's lead laboratory for nuclear energy research, development, demonstration, and deployment. INL's Advanced Test Reactor (ATR) and Materials and Fuels Complex (MFC) facilities are required to accomplish the tasks for this project and are discussed below.

The overall project objective of the Parties is to investigate the performance of high burnup "Advanced Nuclear Energy for Enriched Life (ANEEL)" fuel designed by CCTE. The CCTE designed ANEEL fuel is based on $(Th,U)O_2$ in ratios optimized for extended operation in PHWRs/CANDUs.

CCTE has requested INL's support to conduct irradiation testing on mixed thorium-uranium oxide ($(Th,U)O_2$) fuel samples to assess fuel performance. These tests would be conducted as a first step towards development and qualification of the fuel system for intended high burn-up at linear heat generation rates typical of PHWRs and CANDU reactors. INL will perform the design and analysis work to develop an irradiation test rig and its associated safety basis for irradiation in the Advanced Test Reactor (ATR). Fuel pellets will be fabricated at Texas A&M University (TAMU) under a separate agreement between CCTE and TAMU. The fuel specifications for the prototype fuel will be provided by CCTE. INL will provide guidance to TAMU acting on behalf of CCTE regarding fuel qualification and fuel characterization plan. Final rodlet fabrication will be performed by the INL. After the fuel burnup objectives are met in ATR, samples will be transported to MFC and Post-Irradiation Examinations (PIE) will be performed at the Hot Fuel Examination Facility (HFEF).

Irradiation and Conceptual Experiment Design:

The accelerated burnup aspect of this experiment campaign should be interpreted as accelerated with respect to burnup accumulation prototypic of CANDU reactor fuels. The radial dimensions of fuel in this experiment will be approximately 50-60% of those in commercial CANDU reactors to provide the accelerated rate of burnup accumulation. If fuel power is characterized in terms of Linear Heat Generation Rate (LHGR), and if the radial dimensions are scaled uniformly, scaling down by a factor of two while maintaining the same LHGR results in the same temperature distribution with a factor of 4 increase in fuel power density. Simply put, reducing the fuel dimensions by half results in the fuel's rate of burnup accumulation to increase by a factor of 4 if the LHGR can be matched.

At the current point in time, the CCTE experiment design for irradiation in ATR is pre-conceptual. Initial cost estimates allow for 6-10 fueled capsule experiments that are nearly identical to the capsules designed in the Accident Tolerant Fuels drop-in (ATF-1) experiment campaign. Waste streams generated in this activity will be nearly identical to those generated in the Accident Tolerant Fuels campaign (see INL-20-044), yet with far less volume. There are two fuel types requested for irradiation. The first consists of 78 weight percent (wt %) ThO_2 and 22 wt % UO_2. The second fuel type will include the addition of 0.3 wt % B_2O_3. All fuel types will target an initial ^{235}U enrichment ≤ 16 wt %. The fuel pellets will be arranged in ~ 4 inch stacks, and clad by Zircaloy-4. The clad fuel specimen is known as a rodlet, and each rodlet will be encapsulated in Grade 316 Stainless Steel.

The first cycle of irradiation will begin in the Spring of 2022 following ATR's Core Internals Changeout (CIC). The number of cycles of irradiation will be determined in future neutronics/physics analyses.

Post Irradiation Examination:

PIE is an essential component of this fuel development effort because it provides nearly all measurements necessary to understand the fuels irradiation performance. The various PIE techniques performed at the Hot Fuels Examination Facility (HFEF) are either destructive or non-destructive to the irradiated materials. The various destructive and non-destructive PIE techniques are summarized below, seriatim.

<u>Blister Anneal Testing (Destructive Technique):</u>

This test requires that the fuel component be heated to the point where the first failure threshold has been reached as indicated by raised areas (blisters) on the surface of the component. This is required for fuel qualification since blistering is conservatively presented as a precursor to a breach of the fuel cladding, the primary containment of the fuel and fission products. Blister anneal testing can be performed in simple furnaces provided the temperatures can reach a maximum of 550°C. This is a destructive examination.

<u>Fission Product Release (Destructive Technique):</u>

Data obtained from fission gas release may be used in the fuel qualification report. The purpose is to identify the failure thresholds and measure fission product release to define the allowable safety margins for monolithic and dispersion fuel utilization. Specifically source term data is determined based on the type and movement of various fission product inventories. These examinations can be performed in a furnace that can accommodate the sample size and that is capable of reaching at least 2000°C. This is a destructive examination.

Metallography (Destructive Technique):

Metallography is both a qualitative and quantitative measure. This is a destructive examination of irradiated materials requiring sectioning and mounting small pieces of the irradiated fuel for examination in the microscope.

Microhardness Testing (Destructive Technique):

Microhardness testing is done on the system installed in the HFEF met box. This is a destructive examination of irradiated materials requiring sectioning and mounting small pieces of the irradiated fuel.

Scanning Electron Microscope (SEM) / Transmission Electron Microscope (TEM) sample preparation at the Irradiated Materials Characterization Laboratory (Destructive Technique):

Some samples may be sectioned and sent to the Irradiated Materials Characterization Laboratory (IMCL) for preparation for and SEM/TEM investigation. A Plasma Focused Ion Beam (PFIB) may be used to mill micrometer sized samples out of larger specimens. This is a destructive examination and requires the IMCL stack monitor operable for potential air emissions.

Disassembly (Non-Destructive Technique):

Disassembly of the capsules is done only to remove the fuel rodlets from the external capsules. Every effort is made to do so without damaging the internal fuel rodlets. A lathe would be used to cut the endcaps off the capsules. The rodlets are then pushed out of the capsule tube using an appropriately sized drill rod. This is non-destructive (to the rodlet) process.

Eddy Current (Oxide, Non-Destructive Technique):

Eddy current measurements are taken to estimate the oxide thickness that has grown on the fuel components. This is a non-destructive examination.

Gamma Scanning (Non-Destructive Technique):

All irradiated experimental components are scanned using the precision gamma scanner (PGS). Gamma scan results are used to determine the relative 2-D fission density gradient over a surface. This is a non-destructive examination.

Immersion Density (Non-Destructive Technique):

Immersion density data provides fuel swelling values for the material. This information is used in the fuel qualification report as a fundamental fuel behavior property. This is a non-destructive examination.

NRAD (Non-Destructive Technique):

Neutron radiography is performed to identify any cracking in the fuel foil prior to sectioning. This is a non-destructive examination.

Profilometry (Non-Destructive Technique):

Profilometry data is used to determine local fuel swelling and is vital to the fuel qualification report. This is a non-destructive examination.

Visual Examination (Non-Destructive Technique):

The visual examinations of materials at HFEF would be performed to identify any anomalies, changes or defects that may have occurred during irradiation or shipping. The examination is performed using a telephoto lens and camera, taking photos through the HFEF hot cell window. Photographs are taken of the front, back, and end of all capsules. This is a non-destructive examination.

Storage and Used Fuel Specification:

After PIE, irradiated test pin segments and PIE remnants will be stored with other similar DOE-owned irradiated materials and experiments at MFC, most likely in the HFEF or the Radioactive Scrap and Waste Facility (RSWF) in accordance with DOE's Programmatic SNF Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement (FEIS) and ROD (DOE/EIS-0203, 1995) and supplemental analyses (DOE/EIS-0203-SA-01 and DOE/EIS-0203-SA-02) and the Amended Record of Decision (February 1996). Ultimate disposal of the irradiated test pin segments and PIE remnants will be along with similar DOE-owned irradiated materials and experiments currently at MFC. Categorizing this material as waste is supported under Department of Energy Order (DOE O) 435.1, Att. 1, Item 44, which states "...Test specimens of fissionable material irradiated for research and development purposes only...may be classified as waste and managed in accordance with this Order...".

In addition, to complete proposed work activities, it is necessary for the project to use the HFEF hot cell which contains both defense and nondefense related materials and contamination. Project materials will come into contact with defense related materials. It is impractical to clean out defense related contamination, and therefore, waste associated with project activities is eligible for disposal at the Waste Isolation Pilot Plant (WIPP). National Environmental Policy Act (NEPA) coverage for the transportation and disposal of waste to WIPP are found in Final Waste Management Programmatic Environmental Impact Statement [WM PEIS] (DOE/EIS-0200-F, May 1997) and Waste Isolation Plant Disposal Phase Supplemental EIS (SEIS-II) (DOE/EIS-0026-S-2, Sept. 1997), respectively. The 1990 ROD also stated that a more detailed analysis of the impacts of processing and handling transuranic (TRU) waste at the generator-storage facilities would be conducted. The Department has analyzed transuranic (TRU) waste management activities in the Final Waste Management Programmatic Environmental Impact Statement (WM PEIS) (DOE/EIS-200-F, May 1997). The WM PEIS analyzes environmental impacts at the potential locations of treatment and storage sites for TRU waste; SEIS-II addresses impacts associated with alternative treatment methods, the disposal of TRU waste at WIPP and alternatives to that disposal, and the transportation to WIPP.

Irradiated sample debris and PIE waste are expected to generate research and development-related TRU waste and mixed TRU waste. TRU waste generated for the experiments will be less than 129 cubic centimeters (conservative estimate assuming all UO_2 fuel will be converted to TRU).

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

The proposed action has the potential to generate radiological and chemical emissions from irradiation in ATR and the destructive and non-destructive PIE at HFEF. Air emissions are anticipated to be minor, and concentrations would not exceed the current monitored air emissions from these facilities. An Air Permit Applicability Determination (APAD) is required for any work or project causing radiological emissions that are not covered under an existing APAD.

The ATR irradiation activities are not modifications in accordance with Idaho Administrative Procedures Act (IDAPA) 58.01.01.201 and 40 Code of Federal Regulation (CFR) 61 Subpart H. ATR radionuclide emissions are sampled and reported in accordance with Laboratory Wide Procedure (LWP)-8000 and 40 CFR 61 Subpart H. All experiments will be evaluated by Environmental Support and Services staff. All radionuclide release data (isotope specific in curies) directly associated with this proposal will be calculated and provided to the Environmental Support organization.

The irradiated specimens will be delivered to the MFC HFEF for disassembly and then undergo routine PIE. All radionuclide release data associated with the PIE portion of this experiment will be recorded as part of the HFEF continuous stack monitor. The PIE examination in HFEF is not a modification in accordance with Idaho Administrative Procedures Act (IDAPA) 58.01.01.201 and 40 Code of Federal Regulation (CFR) 61 Subpart H. SEM/TEM work will involve sample prep and PFIB at IMCL. This is important as PFIB removes material from the sample in preps for TEM and is required to have the IMCL stack monitor operable for air emissions.

In 2019, the effective dose equivalent to the offsite maximally exposed individual (MEI) from all operations at the INL Site was calculated as 5.59 E-02 mrem/yr, which is 0.56% of the 10-mrem/yr federal standard and was calculated using all sources that emitted radionuclides to the environment from the INL site. The additional increment in emissions from the proposed action would not significantly change the total site-wide MEI dose. Therefore, the emissions are bounded by the analysis in the 1995 EIS, which estimated the annual cumulative doses to the maximally exposed worker, offsite maximally exposed individual (MEI), and the collective population from DOE's decision to implement the preferred alternative (DOE/EIS-0203). The potential air emissions and human health impacts associated with the proposed action would be smaller than and are bounded by the impacts presented in the 1995 EIS.

Discharging to Surface-, Storm-, or Ground Water

N/A

Disturbing Cultural or Biological Resources

The ATR Reactor Building (TRA-670) is over 50 years old. No structural or aesthetic changes will be made to the building.

Generating and Managing Waste

Irradiated sample debris and PIE waste are expected to generate research and development-related TRU waste and mixed TRU waste. TRU waste generated for the experiments will be less than 129 cubic centimeters (conservative estimate assuming all UO2 fuel will be converted to TRU). Categorizing this material as waste is supported under DOE O 435.1, Att. 1, Item 44, which states "…Test specimens of fissionable material irradiated for research and development purposes only…may be classified as waste and managed in accordance with this Order...".

Small amounts of low-level waste would be generated in the form of personal protective equipment (PPE) and towels used for cleaning and polishing.

Project activities would also result in the generation of small amounts of industrial waste.

Project personnel would work with WGS to properly package and transport regulated, hazardous or radioactive material or waste according to laboratory procedures.

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

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.

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"

Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement and Record of Decision (DOE/EIS-0203, 1995) and supplemental analyses (DOE/EIS-0203-SA-01 and DOE/EIS-0203-SA-02) and the Amended Record of Decision (1996)

Final Environmental Impact Statement for the Waste Isolation Pilot Plant (DOE/EIS-0026, October 1980) and Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant (SEIS-I) (DOE/EIS-0026-FS, January 1990)

Final Waste Management Programmatic Environmental Impact Statement [WM PEIS] (DOE/EIS-0200-F, May 1997) and Waste Isolation Plant Disposal Phase Supplemental EIS (SEIS-II) (DOE/EIS-0026-S-2, September 1997)

Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada (DOE/EIS-0243) and supplemental analysis (SA) (DOE/EIS-0243-SA-01).

Final Environmental Assessment and Finding of No Significant Impact for the Replacement Capability for Disposal of Remote-Handled Low-Level Radioactive Waste Generated at the Department of Energy's Idaho Site (DOE/EA-1793, December 2011)

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."

Transportation, receiving, and storing used nuclear fuel, as well as, research and development for used nuclear fuel management is covered by DOE's Programmatic Spent Nuclear Fuel (SNF) Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement and Record of Decision (DOE/EIS-0203, 1995) and supplemental analyses (DOE/EIS-0203-SA-01 and DOE/EIS-0203-SA-02) and the Amended Record of Decision (February 1996). The analysis includes those impacts related to transportation to, storage of,and research and development related to used nuclear fuel at the INL (see Tables 3.1 of the SNF Record of Decision (May 30, 1995) and Table 1.1 of the Amended Record of Decision [February 1996]. The EIS limits the number of shipments to the INL, and the proposed activities would fall within the limits of the EIS.

The potential for transportation accidents has already been analyzed in the SNF EIS (Section 5.1.5 and Appendix I-5 through I-10). NEPA coverage for the transportation and disposal of waste to WIPP are found in Final Waste Management Programmatic Environmental Impact Statement [WM PEIS] (DOE/EIS-0200-F, May 1997) and Waste Isolation Plant Disposal Phase Supplemental EIS (SEIS-II) (DOE/EIS-0026-S-2, Sept. 1997), respectively. The 1990 ROD also stated that a more detailed analysis of the impacts of processing and handling TRU waste at the generator-storage facilities would be conducted. The Department has analyzed TRU waste management activities in the Final Waste Management Programmatic Environmental Impact Statement (WM PEIS) (DOE /EIS-200-F, May 1997). The WM PEIS analyzes environmental impacts at the potential locations of treatment and storage sites for TRU waste; SEIS-II addresses impacts associated with alternative treatment methods, the disposal of TRU waste at WIPP and alternatives to that disposal, and the transportation to WIPP.

The environmental impacts of transferring low level waste from the INL to the Nevada National Security Site were analyzed in the 1996 Nevada Test Site EIS (DOE/EIS-0243) and supplemental analysis (SA) (DOE/EIS-0243-SA-01) and DOE's Waste Management Programmatic EIS (DOE/EIS-200). The fourth Record of Decision (ROD) (65 FR 10061, February 25, 2000) for DOE’s Waste Management Programmatic EIS established the Nevada National Security Site as one of two regional LLW and MLLW disposal sites. The SA considers additional waste streams, beyond those considered in the 1996 NTS EIS, that may be generated at or sent to the Nevada National Security Site for management.

Onsite disposal of RH-LLW was analyzed in the Final Environmental Assessment for the Replacement Capability for Disposal of Remote-Handled Low-Level Radioactive Waste Generated at the Department of Energy’s Idaho Site (DOE/EA-1793, 2011).

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: 03/07/2022