SECTION A. Project Title: eVinci Micro-Reactor R&D (Westinghouse TRISO) R3

SECTION B. Project Description and Purpose:

Revision 3

Westinghouse and BEA will cooperate in the irradiation testing of Westinghouse Tri-Structural Isotropic (TRISO) particle fuel compacts. The intention of the Westinghouse test program is to build on the Advanced Gas Reactor (AGR) program's generic TRISO fuel qualification, with the end result being confirmation of the Westinghouse designed large-kernel TRISO fuel's suitability for operation in the Westinghouse eVinci™ microreactor. Westinghouse TRISO fuel is to be fabricated at the TRISO-X pilot facility at Oak Ridge National Laboratory (ORNL) under a separate agreement between Westinghouse and ORNL. The TRISO-X Pilot Facility has been in operation at ORNL since 2016 and produces kilogram quantities of HALEU fuel.

The purpose of this experiment is to perform Tristructural Isotropic (TRISO) fuel capsule testing at Idaho National Laboratory (INL) in support of the eVinciTM microreactor. Fuel capsule testing consists of:

- Beginning of Life (BOL) transient testing in the Transient Reactor Test Facility (TREAT).
- Post-Irradiation Examination (PIE) will occur following transient testing.

Tasks and Division of Responsibilities

Task No.	Task Title	Duration	Responsible Parties
01	TREAT Final Design	Month 1-6/ or 6 months after transient receipt.	BEA
02	TREAT Capsule Fabrication	Month 4-9	BEA
03	TREAT Capsule Assembly 1	Month 10-12 / 3 months after fuel receipt.	BEA
04	TREAT Irradiation 1	Month 13-15	BEA
05	TREAT PIE 1	Month 16-21	BEA/WEC
06	Expert Consulting	Month 1-12	BEA
07	Capsule Fabrication	Month 1-12	BEA
08	Final Report	Month 21	BEA/WEC

Task Descriptions

Task 1: Experimental Design

Scope. The purpose of final design and analysis is to finalize the design output documents drafted during preliminary design for the selected design option. This step will ensure both the programmatic and safety objectives of the experiments are achieved.

Deliverable/s. BEA to deliver final drawings, CAD models, Engineering Calculations and Analysis Reports (ECAR), and the Verification Matrix.

Task 2: Experiment Fabrication

Scope. The fabrication phase of the experiment utilizes design output documents to guide fabrication and assembly of the experiment and related hardware. This fabrication task will provide parts for this experiment as well as subsequent TREAT Mid-Life and end of life (EOL) experiments.

Deliverable/s. BEA to have all parts needed for the experiment on hand.

Task 3: Experiment Assembly

Scope. In this activity, the specimens and experiment hardware are assembled to form the experiment assembly/test train. This is the final activity before an experiment is transferred/shipped to a reactor for irradiation. The final inspections and verifications are performed on the fully assembled experiment and are documented in the as-built drawings.

Deliverable/s. BEA to provide assembly inspection reports and as-built drawings.

Task 4: TREAT Irradiation

Scope. For TREAT irradiations, the experiment undergoes short duration transient testing as outlined in the Experiment Test Plan.

Deliverable/s. As Run analysis report detailing as-run transient conditions and comparing test data and resulting calculated quantities (e.g., temperature profiles) to pre-test analysis predictions. BEA will also provide raw test data files.

Task 5: TREAT PIE 1 (BOL)

Scope. In this task, the specimens from the first TREAT irradiation will be transferred to the Materials and Fuels Complex where they will undergo various procedures to provide the data specified in the Experiment Test plan. Samples will remain in storage until Nuclear Regulatory Commission (NRC) approval of eVinci.

Deliverable/s. Final CRADA PIE report.

Task 6: Expert Consulting

This task is reserved for unanticipated requests for expert consulting.

Task 7: Capsule Fabrication

Scope: This task is to complete fabrication of moderator experiment hardware for irradiation testing, perform final assembly of the test train, and associated quality and administrative activities. Six FeCrAl capsules of yttrium hydride samples will be irradiated for two cycles at approximately 800, 900, and 1000°C. The scope includes fabricating a small tungsten disk for one of the capsules and inserting the sample cans in the clam shell halves and inserting them into the pressure boundary, then seal weld the end caps on.

This scope includes inserting the test train into ATR's B-7 position for cycles 173C-1 and 175A-1. [EO1]

Deliverable/s: Completed assembly inserted into ATR and transfer of irradiated experiment from core to canal for cooling.

Task 8: Final Report

Scope: BEA and WEC to develop a final report upon completion or termination of this PTS to include a list of Subject Inventions.

Deliverable/s: Approved final test report submitted to DOE.

In addition, Westinghouse and BEA will cooperate on the PIE of yttrium specimens that will be irradiated at ATR to provide critical data on the solid moderator for eVinci. BEA will perform activities to provide PIE information for the development and licensing of moderator options for eVinci reactor as supervised by WEC. Results will also be used to envelope the limiting condition of hydride moderator systems for the eVinci reactor.

Phase 1, Task 1: Capsule Fabrication - Complete fabrication of experiment hardware and perform final assembly of the test train. This scope includes inserting the test train into core irradiation position in the ATR located at Idaho National Laboratory (INL).

Phase 2, Task 1: Irradiation vehicle shipment, retrieval, and basic examinations. Task 1 covers actions by BEA to ensure the ATR irradiation vehicle transfer from the ATR to Hot Fuel Examination Facility (HFEF) and to perform basic visual examinations of the irradiation vehicle, including neutron radiography of the irradiation vehicle.

Task 2: The non-destructive and destructive examinations of capsules and individual specimens including all the PIE activities that are described in the PIE plan document (see PLN-6647) at INL's PIE facilities. The minimum PIE requirements are also listed the PIE plan document.

Revision 2:

This revision captures additional scope associated with the Westinghouse eVinci™ Micro Reactor program. The proposed action supports the need for additional data to inform the design activities and to support model validation by obtaining irradiation data for the eVinci™ Micro Reactor materials.

Idaho National Laboratory (INL)will work with Westinghouse to provide tristructural isotopic (TRISO) fuel to aid in the development of Westinghouse's eVinci™ microreactor. Under this scope of work, INL will aid Westinghouse with fuel specification development and work with fuel manufacturers to provide TRISO fuel to Westinghouse. The TRISO fuel will be used for irradiation testing to support research and development (R&D).

The proposed action includes, but is not limited to:

1. Developing fuel specification for the 45kg of High-Assay Low-Enriched (HALEU) TRISO fuel compacts and development of a request for proposal (RFP) for manufacture.
2. Working with fuel manufacturers to manufacture 45kg of HALEU equivalent of TRISO fuel.
3. Preparing 40 kg HALEU equivalent of this fuel for shipment to National Criticality Experiments Research Center (NCERC) at Los Alamos National Laboratory (LANL).
4. Shipping 5 kg of this fuel to INL for future irradiation testing. The fuel will be stored at Chemical Processing Plant (CPP)-651.
5. Providing observations and oversight as well as nuclear safety and INL engineering support required for fuel fabrication efforts.
6. Providing miscellaneous support and consultation.

BWXT will manufacture and ship the TRISO fuel to LANL and INL. Y-12 will provide the material to fabricate the fuel. INL will complete the following work: beginning of life (BOL) irradiation in the Advanced Test Reactor (ATR) and end of life (EOL) follow-up testing at the Transient Reactor Test (TREAT) Facility. Post-irradiation examination (PIE) will be completed at the Hot Fuel Examination Facility (HFEF). The following discussion gives additional information regarding the proposed action:

Task Descriptions:

Task 1: Formalize fuel specification and Request for Proposal (RFP) for fuel

Westinghouse and INL will finalize the fuel specification to meet Westinghouse and manufacturer needs. INL will acquire the fuel manufacturing effort.

Task 2: Fuel fabrication

INL will work with BWXT to ensure that the schedule and specification for the fuel are being met.

Task 3: Fuel shipment

BWXT will prepare a minimum of 7,000 TRISO compacts from 40kg of HALEU oxide for shipment NCERC using shipping containers supplied by Westinghouse. BWXT will also ship to INL a minimum of 600 TRISO compacts from 5kg of HALEU oxide , which will be stored at INL for future irradiation testing.

The project proposes to use the TRISO high-assay low enriched uranium (HALEU) fuel fabrication capability at the BWX Technologies, Inc. (BWXT) facility in Lynchburg, VA. The BWXT plant produces fuel containing both high and low-enriched uranium. BWXT also blends down HEU to lower Enrichments. With their Category I fuel facility license, BWXT can produce TRISO HALEU fuel. The NRC completed the Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) for License Renewal for BWX Technologies, INC., Lynchburg, VA in 2006 for renewing Materials License SNM-42 (NRC Agency-wide Documents Access Management System (ADAMS) ML053410253). Materials License SNM-42 authorizes BWXT to possess nuclear materials, manufacture nuclear fuel components, fabricate research and university reactor components, fabricate compact reactor fuel elements, perform research on spent fuel performance, and handle the resultant waste streams, including recovery of scrap uranium. The term of the license is 20 years.

In 1996, the Department of Energy (DOE) issued the Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) for the Disposition of Highly Enriched Uranium (DOE/EIS-0240). The FEIS, ROD, and supplement analysis evaluated the impacts of blending highly enriched uranium (HEU) to low enriched uranium (LEU) to eliminate the risk of diversion for nuclear proliferation, and, where practical, to reuse the resulting LEU in peaceful, beneficial ways that recover its commercial value. The EIS, ROD, and supplement analysis evaluated and authorized blending of surplus HEU in DOE's inventory at the Y-12 Plant at the Oak Ridge Reservation. It also analyzes the transportation of necessary materials from their likely places of origin to the potential blending sites, and from blending sites to the likely or representative destinations for nuclear fuel fabrication, including BWXT.

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/EIS0203, 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...".

The initial 600 TRISO compacts may not be used completely by the planned irradiation testing plan. These excess compacts would then be managed as follows:

1. The compacts would be used in future unplanned irradiation testing,
2. Used in the Westinghouse Nuclear Test Reactor (NTR) that is planned to be in the INL Demonstration Of Microreactor Experiments (DOME), or
3. the compacts would not be irradiated and be reclaimed or disposed of.

If the excess compacts are used for unplanned irradiation testing, they would be managed similar to other MFC irradiated PIE material as discussed above. The excess fuel compacts that could be used in the Westinghouse NTR for DOME would eventually 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/EIS0203, 1995) and supplemental analyses (DOE/EIS-0203-SA-01 and DOE/EIS-0203-SA-02) and the Amended Record of Decision (February 1996). Any unirradiated material would be reclaimed for future fuel testing research or would be disposed of.

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.

The environmental impacts of transferring LLW from the INL Site to the Nevada National Security Site were analyzed in the 2014 Final Site-Wide Environmental Impact Statement for the Continued Operation of the Department of Energy/National Nuclear Security Administration Nevada National Security Site and Off-Site Locations in the State of Nevada (DOE/EIS-0426) 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.

Revision 1:

This revision addresses two separate proposals that were sent to the DOE Advanced Research Projects Agency – Energy (ARPA-E), as well as a iFOA award. The first ARPA-E is from the MEITNER program (DE-FOA-001798) which is entitled “Self-Regulating, Solid Core Block (SCB) for an Inherently Safe Heat Pipe Reactor” and the second is from the OPEN program (DE-FOA-0001858), entitled “Advanced manufacturing of Embedded Heat Pipe Nuclear Hybrid Reactor”. DOE awarded funding to Westinghouse, BEA, and Triad (LANL) for both the MEITNER and OPEN programs. A subsequent proposal titled eVinci™ Micro Reactor Nuclear Demonstration readiness Project (DOE-FOA-1817) is also included.

The information gathered from the MEITNER, OPEN, and iFOA programs in this revision will support the eVinci Micro Reactor in the MEITNER program. When the activities identified in this revision are complete, this EC will be revised to include a more accurate scope of the eVinci Micro Reactor.

MEITNER

Task 1 Technical Planning

Subtask 1.1 Initial Plans Established: Westinghouse and INL will conduct a Phenomena Identification and Ranking Table (PIRT) analysis applicable to the current eVinci™ Micro Reactor design. The PIRT topical areas will encompass all aspects of the design considering normal and accident operating conditions. Westinghouse will coordinate and document results of the PIRT in the PIRT Report.

A modeling and simulation (M&S) plan will be developed by Westinghouse and INL. Westinghouse will document the plan. At a minimum, provisions will be made to perform M&S in the following areas to support the primary claims that make the eVinci™ Micro Reactor competitive:

- Evaluate the monolith limitations due to thermal stresses and creep induced by (a) thermal gradients with simultaneous random failure of heat pipes including failure of adjacent heat pipes; and (b) stresses induced by load-following transients;
- Model and simulate the complete monolith thermal and neutronic interdependence by estimating accurately doppler, thermal expansion components, and time constants of feedback.

INL will develop models of the eVinci™ Micro Reactor using DireWolf codes including: Rattlesnake, Sockeye, MAMMOTH, BISON and RELAP-7. Rattlesnake will be used together with other MOOSE-based codes, in particular MAMMOTH, to capture reactor physics and perform code-coupled simulations. Sockeye will be used to conduct heat pipe performance analysis (fluid flow, axial temperature distributions, operating limits and margins, power lift, and heat pipe failure consequences). MAMMOTH will be used for steady state and time-dependent coupled neutronics. BISON will be used to model the fuel and thermo-mechanical performance of the core block components. RELAP-7 will be used to model the power conversion system performance (thermodynamic cycle efficiency, heat exchanger performance, and system temperatures and pressures). INL will run computer simulations to evaluate the eVinci™ Micro Reactor’s operational performance and expected transient behaviors during accident conditions, Design Basis Events (DBEs) and Beyond Design Basis Events (BDBEs).

The following reports will be generated by Westinghouse to support this task:

- PIRT Report
- Test Plan (Draft)

- M&S Plan
- Safety Case Report (Draft)

Completion and documentation of the INL analyses is conducted in Subtask 2.4, 2.5, and 2.6.

Subtask 1.2 Updated R&D Plan: Westinghouse will update the Test Plan, based on the R&D performed and any design pivots driven by the Techno-Economic Analysis (TEA), to reflect activities and priorities for the remainder of the program. Westinghouse will document and archive the Test Plan report.

Subtask 1.3 Updated Safety Case: Westinghouse will define and document the safety basis claims to self-regulate its core during Anticipated Operational Occurrences (AOOs), Design Basis Events (DBEs) and Beyond Design Basis Event (BDBEs). Westinghouse will update the Safety Case Report.

Task 2 Materials and Manufacturability Development

Subtask 2.1 Fabrication of Core block: Materials testing and monolith manufacturability will be carried out by Westinghouse and LANL. Westinghouse will investigate design viability and manufacturability of monolith materials for the core and perform material evaluations within available budget and schedule. Westinghouse will prepare a manufacturability report summarizing the findings of this task, including the results of materials testing that may be conducted to support this task.

Subtask 2.2 Materials Development: LANL will investigate canning, cladding, and/or coating of hydride moderator materials within available budget and schedule. LANL will document findings in a report.

Subtask 2.3 Neutron Irradiation of Core Block (Planning): The PIRT performed (Task 1) is likely to identify needs for additional data to inform the design activities and to support model validation. This will likely include the need for irradiation data for the eVinci™ Micro Reactor materials and systems of materials. In this subtask, INL will develop and document an irradiation plan to obtain this data and initiate design and evaluation of irradiation experiments.

Depending upon the irradiation experiment needs, and within available budget and schedule, experimental components will be fabricated. Note that the actual irradiation and associated post-irradiation examination are not included in this scope of work.

Irradiation planning will consider use of the INL Advanced Test Reactor (ATR) or other reactor within the Nuclear Science User Facilities (NSUF), as appropriate to acquire the needed data. Definition of the ideal component size, fluence rate, and desired total fluence will be developed via design and analysis tasks as an initial part of this activity; this input will be used to determine which irradiation facility will be most appropriate to complete the irradiation work. The activities for this work scope include design and analysis of the experiment, safety analysis, draft and final Experiment Safety Assurance Package (ESAP), fabrication of the experiment hardware (assumes specimens for irradiation provided by Westinghouse and/or LANL) and project management activities at INL that will support the irradiation test. Note that the initial estimate for specimen irradiation is based on an unfueled, structural irradiation experiment (e.g., Yttrium hydride [YH]) and use of an existing, already-approved drop-in capsule design for use in ATR. The structural experiment will be performed at a later date and through a separate funding source.

Key tasks, to be completed by INL, within available budget and schedule and significant input from Westinghouse, include the following:

- Develop eVinci™ Micro Reactor irradiation plan based on PIRT results
- Identify initial irradiation experiment to be performed and reactor to be used for experiment by coordinating with NSUF.
- Design experiment hardware (or select from existing test vehicles) and perform engineering analysis needed to support insertion of experiment. Complete documentation required to insert experiment into reactor.
- Fabricate the irradiation specimens if material is provided (e.g. Westinghouse or LANL is expected to provide specimens, but INL may support this fabrication as necessary and within available budget).

Subtask 2.4 Preliminary M&S of SCB during Normal Operation: The INL project team will utilize the M&S tools identified in Task 1 to create models of the eVinci™ Micro Reactor design and run multiple normal operation transient scenarios. INL will document these results in a report.

Subtask 2.5 Final M&S of SCB during Normal Operation: INL will update the results of Subtask 2.4 to develop the final SCB models for normal operation scenarios. INL will document these results in a report.

Subtask 2.6 Final M&S of SCB during Normal Operation: The INL project team will utilize M&S tools identified in Task 1 to model the eVinci™ Micro Reactor design and run multiple accident scenarios. INL will document these results in a report.

Task 3 Heat Pipe Development

LANL will model a variable conductance heat pipe. The team will design, and Westinghouse will fabricate prototypical heat pipes for maximum heat load that will be integrated partly in the core and partly to the heat exchangers. LANL will fill and perform characterization tests for the Westinghouse provided heat pipes. LANL will document findings from the testing and modeling efforts. Westinghouse will document a Design and Manufacturing Report.

Task 4 Open Air Brayton Power Cycle Transient Model, Design and Optimization

Westinghouse will explore the design of an open-air Brayton power conversion system for integration with the eVinci™ Micro Reactor. As part of the design, a transient power cycle model will be developed by Westinghouse that will be available for integration with the MOOSE framework for overall system modeling. Upon completion of the work, the total plant performance will be determined, and controls will be demonstrated to show autonomous load following operation of the reactor and power cycle.

Westinghouse will develop design point analysis report of the power cycle and quasi-steady state modeling and a transient analysis report of the power cycle coupled to the heat pipe reactor.

Task 5 Instrumentation and Control Architecture and Design

The I&C (Instrumentation and Control) task develops a reactor I&C system that meets the eVinci™ Micro Reactor functional requirements. The I&C system interfaces with each major reactor subsystem and provides real time information on reactor operation, power conversion operation, micro grid operation and integration. A phased approach will be applied for this first-of-a-kind I&C system design as it provides discrete sub tasks, opportunities for challenge reviews and design reviews.

General functions and performance requirements of the I&C system will be defined, including its logical processing and interfaces. Factors including instrument types, ranges, resilience to radiation and environmental factors, sizing, positioning, and means of installation within the reactor system, and their role in the control of the reactor will be considered. The requirements are analyzed and the specification for the hardware, logic, software and interface details to realize the I&C system is produced. The design and implementation phase follow definition of design requirements. During this phase, detailed hardware drawings are created, identifying how individual electrical components are assembled to make the I&C system. After completion of the hardware drawings, the hardware is procured and assembled into the target system. Software code for the target hardware is then written in accordance with the design specification. During the integration and test phase, software code is installed onto the target hardware and tested to ensure all functional and performance requirements are satisfied.

In conjunction with I&C architecture, the reactor performance will be analyzed in the frequency domain. The models developed in Tasks 1 and 2 for the reactor neutronics and thermal (physics) behavior will be used as the basis for creating dynamic models in the frequency domain. The outcome of this analysis will determine the stability of the design and its response performance to process and grid requirements. The physics-based models developed from this task will be used to validate the performance of target hardware controllers.

The I&C architecture concept will be refined, and a prototype produced. This prototype will demonstrate the functional logic of I&C system and viability of the platform. The working prototype also demonstrates the feasibility of integration with signals from the advanced fiber optic sensors, power conversion system, microgrid management system and remote monitoring and control station. Completion of the prototype reduces technological risk of the I&C system by proving key design aspects before a larger system is designed and built.

Westinghouse will document the following items as part of this task:

- Working I&C prototype;
- System requirements and specification documents for I&C;
- Definition of hardware design drawing package and completed software code;
- Completed test reports

Task 6 Fiber Optic Sensor Development

Distributed and Fiber Bragg Grating (FBG) point sensor arrays will be integrated into the micro reactor design. Radiation-resistant, single point FBG sensors and single section of distributed fiber sensors will be improved. A laser fabrication process to produce at least 50-point sensors in one fiber and to use the ultrafast laser processing to produce distributed fiber sensors along one fiber to achieve 2-cm spatial resolution temperature and strain measurements will be developed.

After fabrication of the fiber sensors, they will be metalized for integration into the heat-pipe assembly prototype. Westinghouse will perform integration of the fiber into the heat-pipe assembly prototype and will also conduct the heat- pipe assembly prototype. In this phase of the project, Westinghouse will either embed the fiber sensors at the reactor face, or with facets at both ends of heat pipe as determined by Westinghouse.

Suitable means of interrogation for advanced, high temperature, radiation resistant fiber optic sensors will be developed. The scope includes design and fabrication of laser or LED based demodulation and processing electronics that stimulate the fiber optic sensor and interpret the feedback signal into engineering units. The demodulation and processing electronics are integrated into the overall instrumentation and control system. A report documenting integration, the design and build of the interrogator system, and 3D rendering map of temperature and strain across the SCB, will be provided by Westinghouse.

Task 7 Moderator Characterization

LANL will analyze hydrogen absorption/desorption kinetics of Yttrium hydride (YH2). Further testing will be done to study vibrational frequencies of hydrogen to help develop techniques that will provide information on diffusion coefficient characteristics. A report documenting findings and describing the process for hydriding yttrium will be provided by LANL.

Task 8 Factory Modeling and Design

Westinghouse will identify fabrication steps for the eVinci™ Micro Reactor design. This will utilize the part breakdown structure from Westinghouse proprietary CAD models of the reactor system. Mapping of the fabrication steps will serve as the template to build a factory process design that will track material flow, utilization of fixed costs (machine, salaried labor, etc.) and operating costs (hourly labor, tooling), with respect to time. This mapping will be integrated into a production model and a market demand model. The models will analyze life cycle costs of each reactor and evaluate risks in factory fabrication process. The model will then be utilized to: (i) maximize throughput, (ii) minimize inventory and (iii) minimize operational cost. A factory operation strategy will be evaluated in terms of capacity ramp-up profile, cost/unit profile with annual production volume, time to fabricate each reactor, throughput constraints and scalability ranges. The model will provide input to the techno-economic analysis model to validate overall business case.

Westinghouse will document the Part Breakdown Structure, Fabrication Process Flow Diagram, Integrated Process Based Cost / Demand model and Factory Operation in a Factory Modeling and Design Report.

Task 9 Final Report

As part of this task Westinghouse will prepare a mid-point TEA report. The final TEA will be included as input to the final program summary report.

The final report shall address topics investigated in all tasks and will include input from LANL and INL. The final report will be prepared and documented by Westinghouse.

OPEN

Task 1 Reactor Design & Optimization

Subtask 1.1 Test & Data Acquisition Plans: At the beginning of the project, Westinghouse will formulate an initial Project Plan to outline the activities in the project, which will include schedule, resources, deliverables, milestones and specifying which organizations are responsible, accountable and supporting. This plan will be submitted to ARPA-E to obtain approval on milestones, go/no-go points and respective due dates.

Subtask 1.2 Moderated Core Design Considerations: LANL will utilize available measurement techniques as investigated in MEITNER Task 7 to measure hydrogen redistribution in the hydride block, within available budget and schedule. LANL will document results in a test report.

INL will model/evaluate impact of hydrogen redistribution in the hydride blocks on the core reactivity as a function of temperature, within available budget and schedule. INL will document results in a M&S report.

Westinghouse will summarize/make conclusions on hydride performance as a function of temperature and its impact on the reactor design, safety, and licensing aspects, within available budget and schedule. Westinghouse will document the results in a hydride performance report.

Task 2 Materials Testing

This activity will focus on developing and evaluating various options as a carbon diffusion barrier to protect the TZM heat pipes from carburization due to contact with the core block material. Within available budgets and schedules, LANL and WEC will assess various coating options for materials between the core block and heat pipe materials as defined in the following subtasks. The results of 2.1, 2.2, and 2.3 will be documented in test report(s) by LANL and the results of 2.4 will be documented in a report by Westinghouse.

Sub Task 2.1 Coupon-Scale Coating: Coupon-scale tests will demonstrate, through optical microscopy, that coatings of even thicknesses can be applied on flat substrates of Graphite and/or TZM. The primary purpose of the coating is to provide a diffusion barrier for carbon to avoid carburization of the TZM cladding. As a first step physical vapor deposition (PVD) will be used to deposit the coatings but other coatings techniques can also be evaluated if PVD coatings are unsuccessful.

Sub Task 2.2 Annealing Studies: Annealing studies will be performed on diffusion couples of coated Gr in contact with TZM or coated TZM in contact with Gr at selected temperatures. The structures of Gr/coating/TZM will be assessed for C diffusing through the coating and/or for any reactions occurring at the interfaces.

Sub Task 2.3 Thermal Cycling: If budget and schedule is available, the coated substrates (graphite and/or TZM) will be tested under thermal cycling conditions. Testing may include thermally cycled coated substrates examinations to assess cracking initiation, through optical testing, and/or degradation of mechanical properties, through nano- indentation.

Sub Task 2.4 Initial Material Down-Selection: Based on the initial literature review, LANL will present data and recommend initial data down selection. LANL will then conduct the tests in the above subtasks. Westinghouse will conduct testing above followed by a down-select material systems process, including bonding material between heat pipes and monolith. The down-selected material systems by Westinghouse shall have a high manufacturing readiness level (MRL) and potential to achieve the $1.5/Watt cost target for a NOAK (i.e. nth-of-a-kind) reactor. Westinghouse will also identify any data gaps of the material sets that may require additional thermomechanical and irradiation testing.

Task 3 Fiber Optic and Embedded Sensor

Subtask 3.1 Value of Sensors Determined: This Westinghouse activity involves determining the value of using advanced, high temperature, radiation resistant sensors for autonomous operation versus using operators to control the reactor. This work scope will first identify requirements, then identify sensors that can be used to measure temperature and neutron flux in the core. The technology readiness level (TRL) and MRL of the sensor and interrogator system technology will be determined, a strategy for technology acquisition developed, and a cost evaluation for FOAK (i.e. first-of-a-kind) and NOAK systems will be performed. Technical risks/gaps will be identified. Suitable sensors will be proposed, including preliminary strategies for integrating sensors in the reactor. A cost comparison will be developed between the cost of sensors and instrumentation systems and the cost for operators/staff to manually monitor and control the reactor. This cost comparison will establish the business case for the Autonomous Control System (ACS). Westinghouse will prepare a technology evaluation report to document the results of this task.

Subtask 3.2 Develop Commercial Sensor Production Approach: This activity involves determining the approach for commercialization of advanced, high temperature, radiation resistant fiber optic sensors. The work scope will build from successful testing of the advanced, high temperature, radiation resistant fiber optic sensors which are produced in a laboratory environment. The work scope addresses all aspects of the fiber optic sensor supply chain and manufacturing including sourcing materials, pre-processing, sensor fabrication, post-processing, quality control of the processes, acceptance testing for each sensor including pass/fail criteria, with a focus on production level quantities of fiber optic sensors.

Westinghouse will develop a report on the commercialization approach for advanced, high temperature, radiation resistant fiber optic sensors based on the results of this task.

Task 4 Material Irradiation Testing

An irradiation test plan will be developed to test the critical fuel block components, as described in MEITNER Task 2.4, and developed based on the results from OPEN Task 2 (Materials Testing), which will include the preferred coating options, along with the heat pipe and graphite core block. As part of the test plan, an irradiation test facility (or facilities) will be identified that will be able to provide prototypic conditions for irradiation testing of the coated block plus heat pipe. Within available schedule and budget, irradiations will be performed to verify the coated block and heat pipe performance. INL will document a materials irradiation test plan as part of this task.

Task 5 Market Analyses & Final Report

Subtask 5.1 Market Analysis Confirmed: Westinghouse will update the TEA with any new knowledge/learning to ensure alignment with cost goals and determine any increase in theoretical market size and capture. This will include results of a M&S sensitivity.

Subtask 5.2 Final Report: Westinghouse will prepare a final report documenting the information found in previous OPEN tasks.

Subtask 5.3 Administrative: LANL, with support from WEC and INL, will complete an updated impact sheet describing the desired impact the project team would like to have by the end of the project.

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3.2 Tasks

It is necessary to have a SOW focused on progressing the design to meet the needs of the overall Project with the flexibility necessary to support the evolutionary design path. The descriptions below identify the overall Project tasks being executed to prepare for the NDU. Because of the experimental nature of the work, it will be performed as funding allows. Each Party acknowledges that subcontractors may be used for the completion of certain tasks identified in the Statement of Work. All Parties will identify the applicable subcontractors and will obtain mutual concurrence from any Party owning any Proprietary Information to be supplied to a subcontractor before supplying Proprietary Information to such subcontractor.

3.2.1 Design

Discussion: The objectives of the design tasks for the eVinci™ Micro Reactor are to develop conceptual and preliminary designs sufficient to prepare for the NDU.

Westinghouse Design Tasks: Westinghouse will lead and integrate the overall Project while performing the lead design roles. During conceptual and preliminary design stages, design tasks will focus on the following plant design areas:

- Reactor design
- Fuel and core design
- Reactivity control and shutdown design
- Heat pipe design
- Heat exchanger design
- Power conversion design
- Electrical systems design
- Instrumentation & Control systems design
- Passive decay heat removal design
- Concept of operations development design

For each system and major component, design documents will be developed including SDS and SDD documents. The design activities include tasks for interface control, component safety classification, system design description, 3-D design modeling, and supporting system calculation notes. Procurement and manufacturing design analyses will also be performed.

LANL Design Tasks: LANL will provide within budget and schedules available support for preparation efforts towards an NDU. Tasks associated with this Project include a wide range of possible capability areas LANL has including: design support; testing preparations (including site preparations); DOE Authorization / NRC Licensing support; specific test article preparations (such as high temperature moderator engineering and fabrication); and preparatory testing (such as separate effects tests). LANL will help the Westinghouse design leads leverage available resources to perform design tasks.

3.2.1.1 Design Documents

Westinghouse will develop conceptual and preliminary design documents including SDSs and SDDs. These documents will be updated throughout the design evolution as the activities progress.

3.2.1.2 Design Analyses

Westinghouse, with support from LANL and INL, will perform design analyses in support of design optimization.

3.2.1.3 Reporting

For design analyses performed during the Project by Westinghouse, LANL, and INL, as appropriate, will produce a summary report. The format, content, and structure of the reports, as well as the schedule for completion, will be defined and agreed upon jointly by WEC, LANL, and INL. This is further detailed in section 3.2.6.3

3.2.2 Testing

Discussion: NDU design will necessarily differ from the production reactor design and requires specialized engineering for testing. Testing design support is needed for all areas (e.g. materials, fuel, in-pile, out-of-pile) to include the overall design of the NDU system. A NDU design specification will consider mechanical, neutronic and heat transfer design activities.

Westinghouse Testing Tasks: Westinghouse will lead testing for the broader Project and program. Deliverables will include testing plans and designs appropriate for the tests.

LANL Testing Tasks: LANL will provide within budget and schedules available design support for preparation efforts towards the NDU. Within budgets and schedules available, LANL will provide support for testing and design activities such as modeling and simulation (M&S), core material design, and engineering support.

INL Testing Tasks: INL will provide appropriate and available design support for the preparation efforts. Within budgets and schedules available, INL will provide support for testing and design activities such as test setup and execution, M&S, and material design assessments and engineering support.

3.2.2.1 Test Plan

Westinghouse will draft the overall Project Test Plan. INL and LANL will provide input to WEC for the testing activities and must concur with Westinghouse's proposed final Project Test Plan. INL will assist in developing status reports. The content, format, structure, and schedule for the reports will be jointly defined as the Test Plan is completed.

3.2.2.2 Test/Experiment Records

For tests or experiments conducted by LANL, INL, and/or Westinghouse, a test or experiment report or presentation may be provided. The content, format, structure, and schedule for the reports or presentations will be jointly defined as the Test Plan is completed.

3.2.3 Modeling, Simulation, and Analysis

Discussion: The modeling, simulation, and analysis tasks support the development and evaluation of the conceptual and preliminary designs to prepare for the NDU.

Westinghouse Modeling, Simulation, and Analysis Tasks: Westinghouse will lead the overall Modeling & Simulation (M&S) tasks. The M&S work scope covers the integrated analysis for the eVinci™ Micro Reactor plant systems in support of design and safety analysis. Individual system analyses and integrated system levels will be performed leveraging the modeling techniques developed by previously funded programs.

LANL Modeling, Simulation, and Analysis Tasks: Within available budgets and schedules, LANL will assist M&S efforts led by WEC and INL to help support preliminary design efforts. LANL has access to high performance computing resources as well as personnel who can assist the other parties with decay heat analyses and scaling of high- performance computing calculations.

3.2.3.1 INL Material and Fuel System Irradiation Testing and Analysis

INL or an INL subcontractor will perform material irradiation testing to support the Project. Irradiations will be done at temperatures typically ranging from 600-1000 °C and at various fluences and burnups to be specified as the design and program evolves. The purpose of these tests is to measure the effect of radiation on the material properties. INL, with potential subcontract support, will design the experiments. Test sample materials will be supplied to INL by Westinghouse. Test equipment and consumable materials will be procured by the Parties and/or a Party's subcontractor(s). Following irradiation, the material properties will be evaluated as a function of fluence and/or burnup. These can include creep, fatigue, uniaxial yield strength, ultimate strength, irradiation growth, elastic properties/Young's modulus, thermal conductivity, thermal expansion and if applicable to specific materials, tritium/He release, and irradiation assisted stress cracking.

3.2.3.2 INL Nuclear Cross-Section and Scattering Testing and Analysis

INL will evaluate and, if necessary, perform measurements of neutron absorption and scattering cross-section for various materials to be used in the eVinci reactor system. These can be differential or integral cross-sections, depending on the need of the program. The testing will be performed at a range of parameters to be specified as the design evolves. The purpose of these tests is to validate cross-section measurements used in the design and in computer code benchmarking. INL will design the test experiments. The test sample materials will be supplied to INL. Test equipment and consumable materials will be procured by INL.

3.2.3.3 INL Criticality Benchmark Testing and Analysis

INL, will perform testing to benchmark criticality at a range of temperatures. The tests will measure power reactivity coefficients and the neutron multiplication factor for use in computer code benchmarking. The experiments will be designed by INL. The test sample materials will be specified by Westinghouse and provided to INL by Westinghouse. Test equipment and consumable materials will be procured by INL.

3.2.3.4 INL Irradiation Testing and Analysis

INL will perform transient testing as necessary, which may include utilization of the INL Transient Reactor Test Facility (TREAT), to simulate design basis and severe accident conditions, events, or phenomena important to the design development. These experiments may be formulated by either INL, LANL and/or Westinghouse, as needed, depending on the specific expertise and experiment. The test sample materials will be specified by Westinghouse and provided to INL. Test equipment and consumable materials will be procured by INL.

3.2.4 NDU Site Preparation

Discussion: Preparing for locating the NDU at a site will require many years of work and will include, safety authorizations, site preparations, and collation of the NDU and separate effects testing.

Westinghouse Site Preparation Tasks: Westinghouse will integrate and lead NDU site preparation activities while performing key roles for success of this overall task, including development of site specification document reflecting the site requirements.

LANL NDU Site Preparation Tasks: LANL will provide within budget and schedules available support for preparation efforts towards the NDU site. LANL could provide tasks such as safety basis support, high temperature moderator engineering and fabrication, heat pipe support, core block materials, and engineering support.

INL NDU Site Preparation Tasks: INL will provide within budget and schedules available support for preparation efforts towards the NDU site. INL will work with Westinghouse and LANL to develop high level draft criteria for site selection and evaluate potential NDU sites.

3.2.5 Safety Design Basis Analyses and DOE Authorization / NRC Licensing

Discussion: Safety analyses activities supporting development of the design, preparation for the NDU, and the deployment design include:

- Internal hazards
- External hazards
- Physical and cyber security
- Shielding and radiation protection
- Materials analysis

DOE Authorization / NRC Licensing activities include:

- Safety Design Strategy (SDS)
- Conceptual safety and design report
- NEPA strategy and compliance
- Regulatory requirements identification

A graded approach, as outlined in NQA-1, will be used as necessary and based on the technology readiness for each of the eVinciTM Micro Reactor systems, subsystems, and components.

3.2.6 Project Administration and Management

3.2.6.1 Project Management Plan (PMP) and Task Management

Development and execution of the PMP guides how the Project will be executed, monitored, and controlled in accordance with internal procedures and requirements, subject to concurrence by all Parties. The PMP will provide higher resolution to the scope, cost, and schedule, tasks and Project change control processes and will be updated as work progresses. A separate PMP will be developed for each Phase of the Project.

Furthermore, the Parties will identify engineering tasks associated with specific Phases of the Project. This will serve as a collaborative means for the Parties to describe engineering tasks to be executed, identify respective lead and support efforts for the Parties, define specific details for the Project deliverables, set forth a schedule for engineering task execution, define progress reporting requirements, and establish the resources required to complete each engineering task. The Parties must concur on the tasks to be executed and the associated costs and schedule prior to the commencement of each task.

3.2.6.2 Project Management Processes

The documents listed below will be developed in support of the PMP.

- Project Requirements Management Plan
- Project Configuration Management Plan
- Project Quality Plan

- NDU Design Plan

3.2.6.3 Project Reporting

The DOE FOA 1817 quarterly reports will provide an overall summary of the status and current activities including, but not limited to:

- Resource management
- Project controls/financial status
- Business development efforts
- Outreach activities

3.2.6.4 Final CRADA Report

In accordance with Article X Reports and Publications (paragraph A.2) of the terms and conditions of this CRADA, the Parties acknowledge that the Contractors have a responsibility to timely provide to the DOE's Office of Scientific and Technical Information (OSTI) a final report, upon completion or termination of this CRADA, to include a list of Subject Inventions.

3.2.6.4.1 Prepare initial draft final report addressing the results of the objectives and deliverables

LANL/INL will prepare initial draft final report and deliver initial draft final report to Westinghouse at least thirty (30) days before the time to complete this CRADA.

3.2.6.4.2 Revise initial draft and prepare final report addressing the results of the objectives and deliverables

The Parties agree to secure pre-publication review from each other wherein the non-publishing Party shall provide within thirty (30) days any written objections to be considered by the publishing Party.

3.2.6.4.3 Deliver Final Report

It is the Contractors' obligation to ensure that the final report is properly reported to DOE's OSTI.

Summary of Anticipated Tests

- Solid moderator irradiation testing of yttrium hydride and zirconium hydrid
  - Fluences up to 5-8 dpa, at temperatures ranging from 200 C to 1200 C
  - Facilities being considered for the irradiations – ATR, MIT reactor, HFIR
- Coupled heat pipe and core block irradiation tests
  - Fluences up to 5-8 dpa, at temperatures ranging from 200 C to 1200 C
  - Facilities being considered for the irradiations – ATR, MIT reactor, HIFR
- Irradiation testing of an eVinci micro reactor unit cell
  - The unit cell includes graphite core block, heat pipes, solid moderator material, and TRISO fuel compacts
  - Facility being considered to perform irradiations – TREAT and ATR

· Irradiations will include steady-state physics and nuclear heated thermal-hydraulic tests (including criticality and reactivity coefficients) of the unit cell in TREAT; burnup tests in ATR of a unit cell followed by transient tests in TREAT

Original EC:

This environmental checklist (EC) replaces EC INL-19-036 and clarifies that the proposed action does not irradiate nuclear material specimens in a test reactor. Because potential materials and systems for the eVinci™ Micro Reactor have not been identified, designed, tested, or developed, reactor irradiation testing of materials is beyond the scope of this EC. If the proposed efforts identify such materials and a need for irradiation testing, additional analysis in compliance with the National Environmental Policy Act (NEPA) will be performed to evaluate and disclose the environmental impacts associated with irradiation activities.

Westinghouse Electric Company (Westinghouse), Idaho National Laboratory (INL), Los Alamos National Laboratory (LANL), and the National Nuclear Security Administration (NNSA) perform research for the "Self-Regulating, Solid Core Block (SCB) for an Inherently Safe Heat Pipe Reactor." Under the proposed action, Westinghouse, INL, Echogen Power Systems, Limited Liability Corporation (LLC), and the University of Pittsburgh (the University) employ modeling and simulation tools to evaluate the eVinci™ Micro Reactor Solid Core Block (SCB) self-regulating behavior that may contribute to the regulatory licensing basis. The proposed action tests key hardware to demonstrate SCB manufacturability and to validate modeling tools. The proposed action involves the following tasks:

Establish a Management Plan

Under the proposed action, Westinghouse, LANL, and INL establish a management plan guiding the following elements:

- Governance
- Communications
- Work authorization
- Issue resolution.

Phenomena Identification and Ranking Table (PIRT) Analysis

For this task, Westinghouse and INL complete a PIRT analysis for the eVinci™ Micro Reactor and design variants that might evolve throughout the project. Modeling and analysis at INL use standard neutronic and thermomechanical tools (Monte Carlo N-Particle [MCNP] transport code and ABAQUS modeling) to study reactor design sensitivity and optimization and to identify and avoid potential modeling issues before completing Multiphysics Object Oriented Simulation Environment (MOOSE) modeling and simulation (M&S). The PIRT analysis employs the following M&S efforts:

- Evaluating three-dimensional SCB thermo-mechanical performance (stress, strain, temperature, creep, irradiation dose, etc.) using MOOSE-BISON-MCNP
- Developing MOOSE-BISON-SOCKEYE-MCNP models to analyze eVinci™ heat pipe performance (fluid flow, axial temperature distributions, viscous-sonic-capillary-entrainment-burnout limits, operating margins, power lift, and heat pipe failure consequences)
- Using MOOSE-Reactor Excursion and Leak Analysis Program (RELAP7)-Analysis System (ANSYS) to assess power conversion performance (thermodynamic cycle efficiency, system temperatures and pressures, and heat exchanger design).

These M&S activities evaluate the following eVinci™ Micro Reactor design features:

- Monolith (fuel, heat pipes, axial reflectors and shields, moderator, primary heat exchangers, decay heat exchangers and embedded sensors) and monolith materials
- Normal and accident conditions
- Instrumentation and control (I&C) system (including a fiber optic sensor system)
- Power Conversion.

M&S evaluates eVinci™ Micro Reactor competitiveness using methods listed below:

- Use multi-point kinetics equation to delineate key challenges and impacts on reactor safety and operations

- Evaluate monolith limitations from thermal stress and creep induced by (a) thermal gradients with simultaneous random heat pipe failure; (b) load-following transients and (c) potential pellet monolith interaction from swelling
- Model and simulate the complete monolith thermal and neutronic interdependence by estimating accurately doppler, thermal expansion components, and time constants of feedback.

Project scope includes constructing, designing, testing, and verifying eVinciTM Micro Reactor simulation models using MOOSE and ANSYS multi-physics platforms coupled with various other codes to evaluate operational performance and expected transient behaviors during accident conditions (e.g., anticipated operational occurrences (AOOs), Design Basis Events (DBEs), and Beyond Design Basis Events (BDBEs)).

Demonstrate Monolith Manufacturability

Westinghouse and LANL develop monolith prototypes to demonstrate the monolith manufacturing capability and evaluate material performance. Westinghouse fabricates monolithic blocks using vacuum diffusion bonding (VDB) followed by block diffusion-brazing, and LANL utilizes Powder Bed Fusion and Directed Energy variants of laser advanced manufacturing. The current baseline material is SS316L. Other candidate materials include P91, and,

potentially, TZM. Future research needs involving temperature, irradiation, and prototype fabrication only consider candidate materials having reasonable ultimate tensile strength and elongation.

The task includes destructive and tensile testing on prototype block materials. The Westinghouse Churchill Facility and LANL characterize the materials. LANL ion irradiates qualified material samples to characterize material behavior before and after irradiation. Ion irradiation uses a particle accelerator and not a nuclear reactor.

Thermo-mechanical evaluations assess thermal expansion, thermal conduction, creep behavior, and irradiation behavior. Initial experiments complete these evaluations using samples that undergo tensile testing at 25ºC, 300ºC and 600ºC. The project also evaluates stress relaxation properties using strain rate jump tests during tensile testing at 600ºC. Characterizing sample microstructures uses several methods such as Transmission Electron Microscope/Scanning Transmission Electron Microscopy (TEM/STEM). The project completes testing in a priority order, and removes materials not showing promise during temperature testing from further evaluation.

The proposed testing ultimately identifies a single block material to study block thermal expansion. Data from sensors embedded in the prototype block verifies and validates the M&S codes and identifies material deviation pre and post ion irradiation and block deformation correlation factors.

The PIRT analysis may identify additional data needs for design activities and model validation such as reactor irradiation data for the eVinciTM Micro Reactor materials and systems. If the analysis identifies reactor irradiation data needs, the project will develop an irradiation plan, design irradiation experiments, and fabricate and irradiate sample specimens. Irradiating samples using a test reactor, such as the Advanced Test Reactor (ATR) at INL, characterizes fuel system performance through the end of life irradiation. In addition to M&S, INL would plan and irradiate experiments for the eVinci™ Micro Reactor SCB materials, including experiments on monolith, fuel, heat pipe (wick, sodium), and metal hydride moderator materials. As previously noted, it is presently unknown if such testing is needed, and if the proposed analysis identifies a need for irradiation testing, additional analysis in compliance with the National Environmental Policy Act (NEPA) will be performed to evaluate and disclose the environmental impacts.

If the analysis identifies a need for unfueled irradiation experiments using only structural materials, then an approved drop-in capsule design may be used in ATR.

Key tasks for this phase are listed below:

- Review PIRT results and identify irradiation data needs and develop an irradiation plan (if needed)
- Coordinate with National Scientific User Facilities to identify a reactor and initial irradiation experiments
- Design experiment hardware (or select from approved test vehicles) and perform engineering analysis supporting experiment insertion
- Fabricate the irradiation specimens (Westinghouse or LANL provide specimens, and INL supports fabrication).

Irradiating specimens at INL typically includes post-irradiation examination (PIE) at the Materials and Fuels Complex (MFC) including the Hot Fuels Examination Facility (HFEF), the Analytical Laboratory (AL), Electron Microscopy Laboratory (EML), and the Irradiated Materials Characterization Laboratory (IMCL) and includes various non- destructive and destructive examinations. HFEF examinations include neutron radiography, visual inspection, element contact profilometry, dimensional measurements, precision gamma scan, fission gas release analysis, metallography, and retained fission gas testing. The AL examinations include burn-up analysis and immersion density. EML examinations include microstructural analysis (Focused Ion Beam [FIB], SEM, and TEM). IMCL examinations include microstructural analysis (FIB, TEM, and EPMA). These activities are consistent with the current missions of these facilities.

After PIE, INL stores irradiated test segments and PIE remnants 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 occurs along with similar DOE-owned irradiated materials and experiments currently at MFC. Because the need for irradiation testing and PIE is unknown, total amounts of irradiated sample debris and secondary waste are also unknown. However, 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, irradiation and PIE projects at INL use the HFEF hot cell which contains both defense and nondefense related materials and contamination. Project materials come into contact with defense related materials. It is impractical to clean out defense related contamination, and therefore, waste associated with this type of activity 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 is found in the 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. DOE 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.

Packaging, repackaging, transportation, receiving, and storing used nuclear fuel and R&D 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 (EIS) 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 analyses include 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 environmental impacts of transferring low level waste (LLW) from the INL Site 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 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 low level waste (LLW) and mixed low level waste (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.

The potential for transportation accidents was analyzed in the SNF EIS (Section 5.1.5 and Appendix I-5 through I-10) and in the FRR EIS (Sections 4.2.1 and 4.2.2).

In addition to disposal of irradiated fuel specimens, industrial, mixed, and low level waste could be generated if the PIRT analysis identifies additional data needs for design activities and model validation such as reactor irradiation data for the eVinciTM Micro Reactor materials and systems. This could include grinding and polishing consumables, plastics, sleeves, and swipes needed for radiological and contamination control, construction waste for facility modifications and equipment installation, molds, and sample residue from analytical chemistry. This waste would be

classified and disposed in accordance with INL procedures and DOE regulations/requirements and analyzed in additional NEPA analysis if irradiation at INL is deemed necessary.

Heat Pipe Design, Modeling and Prototyping

As part of this task, LANL modifies an available transient heat pipe software simulation model for implementing multi- physics software tools. Westinghouse supplies the model reference design and fabricates project-designed prototype heat pipe wicks for maximum heat pipe heat loads. Wick design considers load and vapor density imbalances and wick surface activation enhancing wetting and effective passivation inhibiting corrosion. This task also studies performance and lifetime issues associated with design and affordable manufacture of advanced, high power density wicks having a large length to diameter ratio. LANL completes a separate effects test and characterizes double ended and variable heat pipe conductance at various reactor heat conditions. Projecting a heat pipe array from both reactor ends doubles the area available for the heat pipe to transfer heat. The length condensate travels through the heat pipe wick from the heated to cooled zones increases reactor power throughput by up to a factor of four. Such enhanced performance is key to scaling heat pipe cooled micro reactors to higher power density.

Supercritical CO2 Power Cycle Transient Model, Design and Optimization

Westinghouse explores a supercritical carbon dioxide (sCO2) power conversion system for integration with the eVinciTM Micro Reactor. Design work includes developing a transient power cycle model integrated with the MOOSE or ANSYS framework. This task determines total plant performance and demonstrates controls to show autonomous load following operation of the reactor and power cycle.

The first step of this task completes a design point analysis to determine cycle architecture and the size of major equipment (heat exchangers and turbomachinery). The task also performs initial power cycle optimization based on boundary conditions and heat source and cooling sink characteristics using a multivariate nonlinear optimization MATLAB code with associated component cost models and cost database.

Following the design point analysis, the proposed action develops preliminary power cycle controls using quasi-steady state modeling. The proposal identifies control states as a function of the power cycle architecture and the eVinciTM Micro Reactor requirements. Control states include a cold system state, minimum idle (running but not producing power), full power, and shutdown state. The task identifies required control elements (valve or turbomachinery speed control) based on system transitions from each control state and develops a preliminary control logic document. This forms the transient model basis and the controls development.

Based on design point analysis results and quasi-steady state modeling, the project develops a transient cycle model (completed in the GT software Suite, with Simulink based controls) for integration with other system models. This task develops major equipment performance specifications and selects pipe sizes and materials. It also develops detailed power cycle process and instrumentation diagrams (PID) and required subsystems (inventory control, seal conditioning, bearing supply) for developing a 3D power cycle model and evaluating cost estimates. In addition, this task establishes control architecture and hardware, instrumentation, preliminary load lists, and an electrical single line diagram. This task concludes with preliminary power cycle design and costs and the sCO2 power cycle timeline projections.

Instrumentation and Control (I&C) Architecture and Design

The I&C architecture and design task develops a functional reactor I&C system meeting the eVinciTM Micro Reactor functional requirements. The I&C system interfaces with reactor subsystems and gives real time information on reactor operation, power conversion operation, micro grid operation, and integration. The I&C system design uses a phased approach as it provides discrete sub tasks and opportunities for challenge and design reviews.

This task defines I&C functions and performance requirements, including logical processing and interfaces. It considers instrument types, ranges, resilience to radiation and environmental factors, sizing, positioning, and installation in the reactor system, and how these factors correlate to reactor control. This work analyzes requirements and specifies hardware, logic, software and interface details to produce the I&C system. During this phase, the project creates detailed hardware drawings and identifies I&C system assembly, then procures hardware and assembles the target system. Software code is written according to design specifications and installs software code onto target hardware.

Testing then verifies the system satisfies functional and performance requirements.

In conjunction with I&C architecture, the project analyzes reactor performance in the frequency domain. Creating dynamic models in the frequency domain is based on models developed for reactor neutronics and thermal behavior in previous tasks. This analysis determines design stability and required response performance. The physics-based models developed from this task validate target hardware controller performance.

This step also refines I&C architecture and produces a prototype to demonstrate the I&C system functional logic and platform viability. The working prototype also integrates advanced fiber optic sensor signals, sCO2 power conversion system, microgrid management system, and remote monitoring and control station. Completing the prototype reduces I&C system risk by proving key design aspects before designing and building a larger system.

Fiber Optic Sensor Development

This task integrates distributed and Fiber Bragg Grating (FBG) point sensor arrays in the micro-reactor prototype to give measurement solutions used to monitor reactor safety and optimize the control scheme. The project constructs the micro-reactor core monolith components using diffusion bonding and brazing, which integrates fiber sensors (FBG sensor arrays and distributed fiber sensors) in selected heat pipe sections.

Sensor fabrication and testing: The University of Pittsburgh builds upon current radiation-resistant, single point FBG sensors and distributed fiber sensor technologies including University fiber optic design and specification Background Intellectual Property. The University also develops a laser fabrication process producing at least 100-point sensors in one fiber and distributing fiber sensors along one fiber to achieve 2-cm spatial resolution temperature and strain measurements.

Sensor integration and testing: Following University fiber sensor fabrication, the University metalizes the fiber sensor for integration into the heat-pipe assembly prototype by Westinghouse and the University. Westinghouse constructs the heat-pipe assembly prototype by diffusion bonding and brazing stainless-steel plates, which embeds fiber sensor embedment along any heat pipe radial section. Westinghouse embeds the fiber sensors at the reactor face or at end facets on both heat pipe ends.

To integrate sensors, the University removes excessive surface materials and polishes the surface for bonding or brazing using a Wire Electrical Discharge Machine (EDM). Westinghouse and the University both perform this task, which includes Westinghouse and University Background Intellectual Property.

Sensor testing and interrogation: After embedding fiber sensors in stainless steel plates and brazing/bonding with the heat pipe, the University and Westinghouse evaluate sensor-fused “smart” heat pipe temperature and radiation resistance by testing sensors at temperature at least 100°C higher than normal operating temperatures (i.e. 750°C) enabling use of an accelerated aging test to evaluate fiber sensor longevity and stability and measure sensor performance. Based on the integrated sensor, the University and Westinghouse evaluate, purchase, and assemble a system to continuously measure temperature across the heat pipe face and monitor strain at selected points to gauge micro-reactor performance during normal and transient operations. Westinghouse and the University jointly perform this task using both Westinghouse and the University Background Intellectual Property.

Moderator Characterization

The proposed action quantifies temperature gradient induced hydrogen diffusion in the Yttrium lattice. For this task, LANL measures hydrogen diffusivity using Doppler imaging and other conventional measurements and examines control migration and reactive feedback of micro-engineered barriers or clads.

eVinciTM Micro Reactor Factory Modeling and Design

In this task, Westinghouse identifies eVinciTM Micro Reactor fabrication based on the prototypes built in previous tasks by utilizing the part breakdown structure, i.e. how the reactor parts and components are assembled using the reactor’s CAD model. Mapping the fabrication steps creates a factory process design template, which tracks material flow and fixed (machine, salaried labor, etc.) and operating costs (hourly labor, tooling), with respect to time. Mapping also leads to integrated process-based cost model (PBCM) software, which integrates a production model and a market demand model. The PBCM model analyzes life cycle costs of each reactor and evaluates factory fabrication risks. This task then runs and optimizes the PBCM model in terms of (i) maximizing throughput, (ii) minimizing inventory and (iii) minimizing operational cost to identify and characterize balanced factory operation. The project evaluates the factory operation strategy using capacity ramp-up profile, cost/unit profile for annual production volume, time to fabricate each reactor, throughput constraints, and scalability ranges. The PBCM serves as a pseudo techno-economic model to validate an overall business case.

Final Report

Westinghouse, LANL and INL prepare a final report that includes the following:

1) Computer-based modeling and simulation tools and their interfaces to model the eVinci™ Micro Reactor

2) An integrated production model and a market demand model

3) Using micro-engineered barriers or clads to control migration and its reactivity feedback;

4) Performance of an interrogation system to continuously measure temperatures across the heat pipe face and along the SCB to create a 3D temperature and strain rendering map

5) I&C architecture, functional logic, and viability

6) Preliminary power cycle controls developed using quasi-steady state modeling

7) Heat pipe wick maximum heat load optimization coupled to the heat exchangers

8) Phenomena Identification and Ranking Table (PIRT) analysis for the eVinci™ Micro-Reactor.

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

Rev 3:
Minor radiological air emissions are expected from the irradiation of TRISO fuel in TREAT and will require an APAD to verify associated requirements.
Original EC and Revision 1 work only:
The proposed MS and software development at INL will not produce air emissions. Radiological and chemical emissions could be generated from ATR or TREAT irradiation and PIE if project tasks identify the need for reactor irradiation data. While currently unknown, air emissions are anticipated to be minor, and concentrations would likely not exceed the current monitored air emissions from INL facilities. An Air Permit Applicability Determination (APAD) may be required.
Irradiation activities in the ATR 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 are evaluated by Environmental Support and Services staff. All radionuclide release data (isotope specific in curies) directly associated with any future irradiation will be calculated and provided to the Environmental Support organization and evaluated in additional NEPA analysis as required.
All radionuclide release data associated with future PIE needed for completion of the proposed tasks will be recorded as part of the HFEF continuous stack monitor. 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.

Discharging to Surface-, Storm-, or Ground Water

NA

Disturbing Cultural or Biological Resources

Cultural: Pursuant to the 2023 Programmatic Agreement, the proposed action does not meet the threshold of a federal undertaking and there is no effect to historic properties.

Generating and Managing Waste

When wastes are generated, how they are disposed can adversely affect the environment. Managing wastes appropriately and responsibly and implementing recycling or reuse practices, where feasible, during project activities can reduce the potential impact on the environment.

Before irradiating samples in ATR or TREAT, a waste management plan (for the irradiated materials) would be developed. Some low-level radioactive waste is expected to be generated. Activities associated with this revision have the potential to generate about 5 kg of TRU waste.

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

NA

Environmental Justice

According to the CEQ Climate and Economic Justice Screening Tool, the INL site as well as the Research and Education Campus in Idaho Falls, ID are located in U.S. Census tracts that are identified as disadvantaged communities. Census tracts identified as disadvantaged meet or exceed socioeconomic, environmental, health, or demographic thresholds identified by CEQ. Given that activities analyzed in this document will happen within the boundaries of existing DOE/INL land and/or facilities where there are no permanent residents, any impacts to Environmental Justice in surrounding communities are anticipated to be negligible.

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:
B3.6 "Small-scale research and development, laboratory operations, and pilot projects" 10 CFR 1021, Appendix B, B3.6, "Small-scale research and development, laboratory operations, and pilot projects" and B3.10 "Particle accelerators"

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, Sept. 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 for the Multipurpose Haul Road Within the Idaho National Laboratory Site (DOE/EA-1772, 2010).

Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) for the Disposition of Highly Enriched Uranium (DOE/EIS-0240).

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;"

CX B3.10, "Siting, construction, modification, operation, and decommissioning of particle accelerators, including electron beam accelerators, with primary beam energy less than approximately 100 million electron volts (MeV) and average beam power less than approximately 250 kilowatts (kW), and associated beamlines, storage rings, colliders, and detectors, for research and medical purposes (such as proton therapy), and isotope production, within or contiguous to a previously disturbed or developed area (where active utilities and currently used roads are readily accessible), or internal modification of any accelerator facility regardless of energy, that does not increase primary beam energy or current. In cases where the beam energy exceeds 100 MeV, the average beam power must be less than 250 kW, so as not to exceed an average current of 2.5 milliamperes (mA)."

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.

The impacts of transporting spent fuel, special nuclear materials, and research fuels between MFC and other INL Site facilities using the Multi-Purpose Haul Road were analyzed Final Environmental Assessment for the Multipurpose Haul Road Within the Idaho National Laboratory Site (DOE/EA-1772).

The project proposes to use the TRISO high-assay low enriched uranium (HALEU) fuel fabrication capability at the BWX Technologies, Inc. (BWXT) facility in Lynchburg, VA. The BWXT plant produces fuel containing both high and low-enriched uranium, for use in the U. S. Naval Reactors program. BWXT also blends down HEU to lower Enrichments. With their Category I fuel facility license, BWXT can produce HALEU. The NRC completed the Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) for License Renewal for BWX Technologies, INC., Lynchburg, VA in 2006 for renewing Materials License SNM-42 (NRC Agency-wide Documents Access Management System (ADAMS) ML053410253). Materials License SNM-42 authorizes BWXT to possess nuclear materials, manufacture nuclear fuel components, fabricate research and university reactor components, fabricate compact reactor fuel elements, perform research on spent fuel performance, and handle the resultant waste streams, including recovery of scrap uranium. The term of the license is 20 years.

In 1996, the Department of Energy (DOE) issued the Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) for the Disposition of Highly Enriched Uranium (DOE/EIS-0240). The FEIS, ROD, and supplement analysis evaluated the impacts of blending highly enriched uranium (HEU) to low enriched uranium (LEU) to eliminate the risk of diversion for nuclear proliferation, and, where practical, to reuse the resulting LEU in peaceful, beneficial ways that recover its commercial value. The EIS, ROD, and supplement analysis evaluated and authorized blending of surplus HEU in DOE's inventory at the Y-12 Plant at the Oak Ridge Reservation. It also analyzes the transportation of necessary materials from their likely places of origin to the potential blending sites, and from blending sites to the likely or representative destinations for nuclear fuel fabrication, including BWXT.

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

Approved by Robert Douglas Herzog, DOE-ID NEPA Compliance Officer on: 11/18/2024