DOE-ID NEPA CX DETERMINATION
Idaho National Laboratory

CX Posting No.: DOE-ID-INL-19-046

SECTION A. Project Title: Micro-reactor Testbed, Instrumentation and Sensors (for sodium filled heat pipes)

SECTION B. Project Description and Purpose:

Micro-reactors (i.e., very small transportable or mobile nuclear reactors with a capacity less than 20 MWt) are being developed to supply heat and power for various applications in remote areas, military installations, emergency operations, humanitarian missions, and disaster relief zones. A wide variety of reactor types are under consideration, including sodium-cooled fast reactors, molten salt reactors, light water reactors, very high-temperature gas reactors, and heat pipe reactors. These miniaturized transportable reactor designs remain largely untested and unproven. System and component testing are needed to demonstrate design safety and system robustness, reliability and efficiency.

The Department of Energy (DOE) Office of Nuclear Energy's (NE) Micro-Reactor Research, Development, and Deployment (RD&D) Program manages national laboratory-led early-stage generic research and technology development for micro-reactor systems and provides cost-shared support for micro-reactor vendor development and licensing activities through the DOE-NE Industry Funding Opportunity Announcement. The program also coordinates efforts between the Department of Defense (DoD), industry, and Nuclear Regulatory Commission (NRC) to support the demonstration of micro-reactor technology on a DOE national laboratory site. National laboratories supporting the Micro-Reactor Program include Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), Argonne National Laboratory (ANL), and Sandia National Laboratory (SNL).

As DOE's lead laboratory for nuclear energy, INL has taken the role of the lead laboratory for the micro-reactor program. To support these efforts, INL proposes designing a non-nuclear micro-reactor test bed (NMTB) to assist developing, demonstrating, and validating micro-reactor components and systems. The test bed supports technology maturation to reduce uncertainty and risk relating to operating and deploying micro-reactor systems. Systems and components can be safely tested to failure at the NMTB, giving valuable information regarding failure modes and thresholds. Potential users of the NMTB include micro-reactor developers, energy users, and regulators. Regulators can be engaged early in the design and testing to expedite regulatory approval and licensing.

The test bed includes an enclosure for housing test articles, electrical heaters, cooling system, instruments and sensors, and data acquisition hardware and is configured in a plug-and-play arrangement. Modeling and simulation (M&S) will be employed to design experiments, and the collected data will be used to validate models. This information guides the placement of sensors and helps predict operating performance under a range of normal, off-normal or accident conditions. M&S is also valuable for scaling prototypical hardware for each test. Computational control and model feedback will be pursued to emulate thermal response times and magnitudes of an operating reactor. The overall objective is to test components and systems to verify the safe, reliable and efficient operation of micro-reactor designs.

The test bed will be located at the INL Energy Systems Laboratory (ESL), Bay D100. Preliminary experiments with single heat pipes will be performed at BCTC Bay. Initial heat pipes will be procured from Advanced Cooling Technologies. The heat pipes will be heated using electrical cartridge heaters located in a mono Hex block and be instrumented with thermocouples, distributed temperature sensors, and pressure sensors. The purpose of this activity is to familiarize INL staff with the operation of heat pipes as well as to aid in the development of computer models (Sockeye) for predicting heat pipe performance. The working temperature is not expected to exceed 750°C and the maximum internal pressure will be below atmospheric pressure. An initial "simulated heat pipe" experiment will be performed at Bonneville County Technology Center using a water-cooled tube to provide an isothermal boundary condition.

The NNMTB is being designed with the following goals:

1. Provide displacement and temperature field data to verify potential design performance and validate analytical models
2. Show core block structural integrity (i.e., evaluate thermal stress, strain, aging/fatigue, creep, deformation)
3. Evaluate interface between reactor components and heat exchanger for geometric compatibility, heat pipe functionality, and heat transfer capabilities
4. Test interface of the heat exchanger to power conversion systems for energy production or for process heat applications
5. Demonstrate advanced manufacturing (AM) techniques, such as additive manufacturing, such as diffusion bonding and hipped-powder metallurgy, for nuclear reactor applications
6. Identify and develop advanced sensors and power conversion equipment, including instruments for autonomous operation
7. Study the effects of cyclic loading on materials and components for load-following applications
8. Enhance readiness of the public, stakeholders, DOE laboratories, and the US NRC to design, operate and test high-temperature reactor components.

The test bed requires the ability to simulate the operational envelope of the micro-reactor. The micro-reactor system includes the reactor core, surrounding reflectors, coolant, containment vessel, and heat exchangers. Auxiliary systems to produce electricity or commodities, such as the power conversion unit, desalination equipment, chemical conversion, and district heating, can be attached to the test bed to demonstrate the utility of these systems. However, such systems must be configured as self-contained plug-ins.

Testing Approach

The program adopts a phased development approach. Heat pipe reactors offer the simplest starting point for integrated testing. The initial set of tests consist of:

1. A single core monolith block with holes for fuel rods and heat pipes to understand heater interface and block response
2. A single heat pipe experiment to obtain flow and temperature data

3. A larger scale article where the monolith and heat pipes (~37) interface with heat exchangers understand the power mechanism driving all heat pipe micro-reactor designs.

The first testing phase examines heat pipe technology, starting with general heat pipe and heat exchanger tests. Additional geometries and specialized heat pipe reactor designs may also be tested. Geometrical prototypes will be designed to accurately represent fabrication details of the core and the heat exchangers (including but not limited to types of welds and bonds). The initial design includes direct air-cooled heat-exchangers at lower pressures although supercritical-CO_2 microchannel heat exchangers at higher pressures may be evaluated in the future. Nitrogen recirculation in the heat exchanger is being considered to decrease oxidation risk for test articles. Initial core tests will be monolithic although future tests may include a shell-and-tube type heat exchanger. Initial tests compare measured temperatures to validate finite element analysis (FEA) predictions.

The second phase of testing focuses on gas-cooled designs. In a gas-cooled design, reactor internal temperatures across the core can vary by as much as 300 to 400°C, while the core pressure could be as high as 1000 psi. Thermal transients lead to creep and creep-fatigue damage. Prototype reactor geometries will be fabricated and tested.

The system requires connecting to facility electrical power, facility exhaust, and various gas supplies including compressed air. The system will have the ability to interface with the microgrid test bed. The entire unit will be configured to accommodate testing indoors in the ESL high bay.

SYSTEM DESCRIPTION

Electrical heaters will be employed to simulate the heat generated by the nuclear fuel rods.

Instrumentation
Instruments having enough resolution to validate high-fidelity computer codes measure and monitor specified experiment parameters. This data is recorded directly to INL's high performance computing enclave. The specific types of instrumentation to be provided may include:

- Ultrasonic pulsed arrays – Piezoelectric sensors and actuators that excite the structure using a subset of the piezoelectric patches and record the response using other piezoelectric patches.
- Acoustic emission sensors – Cracking or other damage to the monolithic structure emits an acoustic signal that can be detected acoustic sensors
- Laser Doppler vibrometer with steering mirror – The laser Doppler vibrometer acts in a stand-off manner and detects corrosion
- Interferometry coupled with full-field, high resolution video-based structural dynamics – record full-field, high-resolution shapes of vibrating structures using video.
- Accelerometers –Measure the resonant frequencies, mode shapes and damping ratios of the monolith.
- Thermal imagers – Record temperature distribution across the test article.
- Strain gauges and stand-off displacement sensors – These detect monolith damage resulting in structural deformation.
- X-ray CT scans – Track two-phase flow.
- Barkhausen noise sensor – Monitor crystallographic changes in metal.
- High-speed digital image correlation – Obtain in situ strain at surface.
- Wireless embedded sensors – Used where possible.
- Thermocouples – Mounted to test article.
- Distributed fiber optic temperature sensors – Mounted to test article.
- Flux sensors – Characterize electrical noise.
- Mass flow and pressure – Temporal measurements.

Data requirements
The system can be accessed locally or remotely via a 100 GB data network. Test data directly feeds to the INL High Performance Computing (HPC) enclave. ESL supplies data acquisition computers and workstations for test engineers and vendor representatives. Arrangements for handling of proprietary data must be pre-arranged and applicable non-disclosure agreements (NDAs) in place before testing commences. Export control of the design configuration and test data may be necessary. The HPC interface, cyber security, data access and storage will be considered. All data stored in accessible server.

Individual projects and programs using the NNMTB require project or program specific environmental checklists.

Initial equipment purchased will include 2 sodium filled heat pipes, 15 electrical heaters, 2 stainless steel mono blocks, temperature sensors, and data acquisition equipment. The initial full test article will include 37 heat pipes supplied by Los Alamos National Laboratory and 54 cartridge heaters with a length of one meter. The project will start in October 2019 and will be completed in 2025.

SECTION C. Environmental Aspects or Potential Sources of Impact:

Air Emissions

Project activities have the potential to release hazardous and chemical contaminants into the air. Regulatory requirements will be determined prior to commencing modification of facilities using the APAD process.

Generating and Managing Waste

Industrial waste in the form of scrap wood, scrap metal, packaging material, Resource Conservation and Recovery Act (RCRA) empty chemical containers, rags, insulation, wire, carpet scrap, tile scrap, drywall, pipe scrap, etc., will be generated during the project. Hazardous waste generation has the potential to be generated from paint waste, adhesive waste, cleaning solvents, and spill material.

All waste generated during the project will be characterized, stored, and disposed at the direction of Waste Generator Services (WGS).

Releasing Contaminants

Chemicals will be used and will be submitted to chemical inventory lists with associated Safety Data Sheets (SDSs) for approval prior to use. The Facility Chemical Coordinator will enter these chemicals into the INL Chemical Management Database. All chemicals will be managed in accordance with laboratory procedures. When dispositioning surplus chemicals, project personnel must contact the facility Chemical Coordinator for disposition instructions.

Although not anticipated, there is a potential for spills when using chemicals. In the event of a spill, notify facility PEL. If the PEL cannot be contacted, report the release to the INL Spill Notification Team (208-241-6400). Clean up the spill and turn over spill cleanup materials to WGS.

Using, Reusing, and Conserving Natural Resources

All applicable waste would be diverted from disposal in the landfill when possible. Program personnel would use every opportunity to recycle, reuse, and recover materials and divert waste from the landfill when possible. The program would practice sustainable acquisition, as appropriate and practicable, by procuring construction materials that are energy efficient, water efficient, are bio-based in content, environmentally preferable, non- ozone depleting, have recycled content, and are non-toxic or less-toxic alternatives.

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" and B1.31 “Equipment installation.”

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); smallscale 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;" and

B1.31 "Installation or relocation and operation of machinery and equipment (including, but not limited to, laboratory equipment, electronic hardware, manufacturing machinery, maintenance equipment, and health and safety equipment), provided that uses of the installed or relocated items are consistent with the general missions of the receiving structure. Covered actions include modifications to an existing building, within or contiguous to a previously disturbed or developed area, that are necessary for equipment installation and relocation. Such modifications would not appreciably increase the footprint or height of the existing building or have the potential to cause significant changes to the type and magnitude of environmental impacts."

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

Approved by Jason Sturm, DOE-ID NEPA Compliance Officer on: 08/01/2019