FY2023 Research and Development Grant Executive Summaries

Institution Name	Award Amount	Title of Grant Award
North Carolina State University	$ 500,000.00	Advanced radiation-resistant and high-temperature-tolerant solid-state Ga_2O_3 hydrogen sensors for enhanced safety of nuclear facilities
University of Wisconsin - Madison	$ 500,000.00	New Methodology for Small Boiling Water Reactor Stability Analysis
The Ohio State University	$ 500,000.00	Rad-hard FPGAs to Improve Digital Resilience in Modernizing Digital Instrumentation and Controls Regulatory Infrastructure
Purdue University	$ 500,000.00	Toward a Regulatory Basis for PM-HIP: Role of Artifacts on Impact Toughness
University of Michigan	$ 500,000.00	Model-agnostic Explainability Methods for Trustworthy AI in Nuclear Reactor Applications
Louisiana State University	$ 500,000.00	Electrochemical and Biological Remediation of Radioactively Contaminated Water
Colorado State University	$ 500,000.00	Evaluation of the technical gaps and uncertainties in veterinary uses of byproduct materials
Rensselaer Polytechnic Institute	$ 500,000.00	Experimental and Modeling Study of Fuel Dispersal During the Loss-of-Coolant Accident
University of Puerto Rico Mayaguez	$ 499,963.00	Development and assessment of spectrally matched records for linear and nonlinear analyses of structures, systems, and components in nuclear facilities.
University of California - Berkeley	$ 500,000.00	Safety assessment of in-core and ex-core fuel management for pebble bed reactors by combining hyper-fidelity depletion and machine learning
Texas A&M University - College Station	$ 497,321.00	A Combined High-Throughput Experiments and Simulations Approach for qualifying additively manufactured 316H stainless steel alloys for molten salts reactors.
Kansas State University	$ 499,906.00	Enhancement of Miniature In-Core Fission Chamber Technology for Advanced Reactor Applications
Purdue University	$ 482,592.00	Development of a novel nuclear safety and security probabilistic risk assessment (PRA) model for advanced reactors
University of Alabama - Birmingham	$ 493,560.00	Decontamination & Decommissioning Regulation Optimization by Policy Surveillance: A First Step in Regulation Harmonization that Leads to Many Solutions
University of Pittsburgh	$ 500,000.00	Leveraging acoustic emissions for real-time monitoring of corrosion damage-to-crack transitions in molten salt reactors
University of Maryland	$ 500,000.00	Use of Hybrid Tools to Model Risks of Advanced Nuclear Power Reactor Technologies under a Changing Climate
University of Nevada - Reno	$ 500,000.00	Manufacturing of Spent Fuel Storage Canisters with Superior Stress Corrosion Cracking Resistance using Advanced Hybrid Laser-Arc Welding and High-Pressure Cold Spray Additive Post-Processing

Texas A&M University - Kingsville	$ 250,000.00	Optimization Method for SMR Core Design
University of New Mexico	$ 500,000.00	Using Depletion Sensitivity Analysis to Better Characterize Reactor Fuel Cycles
University of California - Los Angeles	$ 500,000.00	Confidence in Uncertainty: Research to Address Exiting and Emerging Technical Challenges in Characterization and Assessment of Uncertainty of PRA Results for Risk-Informed Decision Making
University of Illinois at Urbana - Champaign	$ 499,997.00	Context-Based Analysis of a Risk-informed, Performance-based Regulatory Approach for Advanced Nuclear Reactors
North Carolina State University	$ 500,000.00	Developments of Guidelines and Benchmarks for Regulatory Assessment of Autonomous Visual Data Collection and Monitoring of Operations and Maintenance

North Carolina State University

Advanced radiation-resistant and high-temperature-tolerant solid-state Ga2O3 hydrogen sensors for enhanced safety of nuclear facilities

Executive Summary:
The objective of this project is to develop breakthrough solid-state hydrogen sensors based on Ga2O3, a revolutionary material that can resist high radiation and temperature levels in nuclear facilities. These sensors will offer unprecedented capabilities for real-time monitoring of hydrogen concentration, avoiding potential dangers such as embrittlement, fire hazard and explosion, and facilitating safe production and storage of deuterium and tritium. Our approach will integrate state-of-the-art techniques for advanced sensor material deposition and device fabrication, exploiting the exceptional properties of Ga2O3 as an ultrawide bandgap semiconductor sensor material for harsh environments. The project aligns perfectly with several technical areas of interest in the NRC's FY2023 Research and Development Grant FOA, namely: (1) Digital engineering/analytics, advanced sensors, and digital instrumentation/controls at nuclear facilities; (2) Characterization of fire hazards in new reactor designs (e.g., sodium) and post-fire safe shutdown capability; and (3) Application of innovative and advanced technologies for decommissioning and remediation of radiologically contaminated sites. The successful outcome of this project will generate crucial insights and essential technical basis for the advancement and implementation of cutting-edge solid-state hydrogen sensors based on Ga2O3, thus boosting the technical capability of NRC and the nuclear community.

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University of Wisconsin – Madison

New Methodology for Small Boiling Water Reactor Stability Analysis

Executive Summary:
This proposal aims to address the existing challenges associated with density wave oscillations (DWOs) in small modular boiling water reactors (SBWRs) operated under natural circulation for core cooling. DWOs driven by the kinetic wave propagation of vapor in boiling channels, can lead to instabilities and potential damage to the reactor fuel. The research team will leverage their expertise in BWR analysis and utilize TRACE/PARCS codes to simulate a BWRX-300-type reactor and define more precise instability boundaries that account for neutronic feedback mechanisms. The proposed work aims to enhance and innovate the criteria for defining safety stability regions in SBWRs and improve the understanding of DWOs (particularly during startup procedure), their underlying mechanisms, and potential mitigation strategies. The project's specific objectives include analyzing the impact of DWOs on SBWR stability and reactor performance, developing a predictive model for identifying critical parameters that initiate and sustain DWOs, and providing recommendations for design verification and operational guidelines to enhance stability and safety. The proposed research will contribute to the knowledge base, inform licensing and design of future SBWRs, and facilitate the development of advanced control strategies and guidelines for addressing DWO-related challenges. The project team consists of experienced and diverse principal investigators.

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The Ohio State University

Rad-hard FPGAs to Improve Digital Resilience in Modernizing Digital Instrumentation and Controls Regulatory Infrastructure

Executive Summary:
The overall objective of this proposal is to develop a baseline understanding towards the device level performance of Field-Programmable Gate Array (FPGA) devices operated in a nuclear power plant (NPP) radiation environment. The specific objectives are to evaluate the rate of soft errors introduced by Single Event Effects (SEEs) in FPGAs and quantify their radiation upset sensitivity, and to evaluate the sensitivity of FPGA devices to total ionizing dose effects and the resulting degradation in device performance. The proposal also seeks to evaluate the efficacy of radiation upset mitigation techniques implemented in FPGAs in the context of their operation in NPP radiation environment.

A comprehensive understanding of the radiation upset sensitivity in FPGA devices due both to transient and cumulative doses is essential to predict their performance in an NPP environment and assess the efficacy of existing radiation hardening and upset mitigation techniques. A successful outcome of the proposed research will contribute to the development of suitable radiation hardening measures, and thereby, the enhancement of fault tolerance and digital resilience of FPGA-based I&C systems deployed in NPPs.

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Purdue University

Toward a Regulatory Basis for PM-HIP: Role of Artifacts on Impact Toughness

Executive Summary:
The objective of this project is to lay the foundation of the regulatory basis for powder metallurgy with hot isostatic pressing (PM-HIP) manufacturing by understanding how degassing artifacts affect impact toughness and acceptability of PM-HIP nuclear reactor components. PM-HIP is an advanced manufacturing technology that offers notable advantages over conventional alloy casting or forging, including greater structural uniformity and chemical homogeneity, superior mechanical properties, and near-net shape production. However, PM-HIP materials can contain porosity and oxide precipitates as residual artifacts from degassing the metal powders before HIP. These artifacts do not readily form in high-alloy steels and have minimal influence on low strain rate tensile properties, enabling PM-HIP 316L stainless steel to recently gain qualification for nuclear applications. However, there is a need to code-qualify additional PM-HIP alloys, especially low-alloy SA508 reactor pressure vessel (RPV) steel, and the Nuclear Regulatory Commission (NRC) needs to in turn establish the regulatory bases for PM-HIP SA508. However, low-alloy steels are particularly susceptible to degassing artifacts and their impact toughness is highly sensitive to these artifacts due to the high strain rate and localized plasticity. Furthermore, variations in pore morphologies and oxide crystallinity arising from cooling rate differences across large components (e.g., RPVs), may generate spatial variations in impact toughness. To responsibly establish regulatory guidelines for PM-HIP SA508, there is a critical need established by the NRC to understand the interrelationship of degassing artifacts, witness specimens, and impact toughness.   The scientific outcome is a fundamental, mechanistic understanding of how residual degassing artifacts and strain rate affect the impact toughness of PM-HIP SA508 RPV steel. The engineering outcome is a map to guide acceptable impact toughness values based on artifact morphologies, providing a regulatory basis for risk assessment of PM-HIP SA508. Pore and oxide morphologies will be correlated to fracture mechanisms and impact toughness; systematic artifact (i.e., pore, oxide) variations will be obtained from several locations on a PM-HIP SA508 vessel head witness specimen. Advanced and conventional characterization techniques, as well as advanced data processing and computer vision techniques, will enable the determination of ductile-to-brittle transition temperature curves, impact toughness, fracture mechanisms, and strain rate effects. We are uniquely positioned to conduct this work due to our exclusive access to high-value archival and neutron irradiated witness specimens through our ongoing Department of Energy (DOE)- supported neutron irradiation campaign of PM-HIP nuclear structural alloys. We will also leverage these one-of-a-kind results of neutron irradiation effects on pores and oxides, to herein extrapolate impact toughness evolution under irradiation. This project builds upon a longstanding collaboration on microstructural and mechanical characterization of PM-HIP alloys between Purdue and Pasadena City College, a two-year institution designated as a Hispanic Serving Institution and an Asian American and Native American Pacific Islander Serving Institution. Hence, this collaboration uniquely enables this project to train multiple students at the technician through scientist levels, addressing NRC’s goals to train a multi-faceted nuclear workforce.

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University of Michigan

Model-agnostic Explainability Methods for Trustworthy AI in Nuclear Reactor Applications

Executive Summary:
Artificial intelligence (AI) and machine learning (ML) applications in the nuclear industry are continuously growing in the areas of component monitoring, predictive maintenance, digital twins, surrogate model development, cybersecurity, and more. While neural networks can offer high accuracy in complex applications and are considered among the most powerful AI/ML models, they lack interpretability, which is crucial in the nuclear industry. To address this issue, explainable AI (XAI) methods are proposed, that allow end-users to understand the reasons behind a model's predictions by answering four primary questions: Why does the model make certain predictions? Should I trust this model? Is the model or data biased? When is this model going to be unreliable? The proposed framework aims to be model-agnostic, application-agnostic, and user-friendly for traditional nuclear engineers without a strong background in AI/ML. The proposed research builds on state-of-the-art XAI methods and will demonstrate them on nuclear reactor applications in diverse scenarios of steady-state and transient cases, with experimental and simulation data, single-physics and multiphysics phenomena, and light water and advanced reactor applications. This proposal will take notional concepts of explainability/interpretability/trustworthiness and codify, in a scientifically rigorous way, the assessment procedures for AI/ML based methods or results that support licensing activities. This ensures that the regulator is aware of the explainability algorithms and their software implementation to aid in the development of an industry-level AI/ML regulatory framework.

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Louisiana State University

Electrochemical and Biological Remediation of Radioactively Contaminated Water

Executive Summary:
Advanced ion separation can play a vital role in the cleanup and treatment of radioactive water, as well as the remediation of radioactive soil and concrete by washing. This project is aimed at applying and combining capacitive deionization (CDI) and microalgae cultivation (MC) to treat radioactive water. CDI is a novel electrosorption process that can capture numerous radioactive ions with porous carbon electrodes while MC is a promising bioremediation technology using microalgae that can take up cesium and strontium ions for growth. Experimental and modeling investigations will be carried out to evaluate the potential of CDI, MC, and CDI-MC systems for the treatment of radioactive solutions. Attempts will be made to decompose tritiated water using carbon oxidation and subsequently to capture tritium ions using electrosorption. Technoeconomic analysis will be performed to assess technical and economic feasibility of CDI and MC as alternatives for the treatment of radioactive water.

This proposed work will offer novel radionuclide separation systems that can operate with minimal environmental impacts and will provide a scientific and systematic modeling approach to simulate electrosorption of radioactive ions by porous carbon material. The developed systems can be used during decommission of nuclear facilities, as well as for remediation of radioactively contaminated water. The work will also advance the current understanding of inverse kinetic isotope effects on electrochemical reactions taking place on carbon surfaces, which can be a foundation to couple carbon chemistry and radiochemistry for the development of advanced radionuclide separation processes (e.g., tritiated water treatment processes).

The proposed work will contribute to the development of diverse nuclear workforce. Highly qualified students matriculated in nuclear and nuclear-related fields of Louisiana State University and Southern University and A&M College at Baton Rouge (SUBR) will be recruited for the proposed work. SUBR is a minority-serving institution with an ethnically diverse student pool.

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Colorado State University

Evaluation of the technical gaps and uncertainties in veterinary uses of byproduct materials

Executive Summary:
The objective of this project is to determine gaps in knowledge and uncertainties associated with using unsealed sources of radioactivity in veterinary treatments. Multiple new isotopes have been developed for diagnosis and treatment of animals, resulting in increased risk of occupational and public radiation dose to humans. Our objective is to determine radiation doses to veterinarians, veterinary technicians, pet owners, and the public from existing and new veterinary uses of radiopharmaceuticals.

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Rensselaer Polytechnic Institute

Experimental and Modeling Study of Fuel Dispersal During the Loss-of-Coolant Accident

Executive Summary:
To investigate the implications of higher burnup fuels on licensing amendment, it is crucial to extend existing modeling and predictive capabilities of multiphase flow for the safety analysis of commercial Light Water Reactors (LWRs) under design-basis loss-of-coolant accident conditions. The primary objective of the proposed research is to advance the current understanding and modeling capabilities of three-phase solid-liquid-gas flows to benefit the nuclear industry and NRC in reactor design, licensing, and regulatory applications. In this project, a new test facility will be constructed to study fuel dispersal behavior and develop a comprehensive three-phase flow experimental database, featuring particle characterization, particle phase kinetics and dynamics, and interfacial momentum and energy transfer between phases. The high-quality data obtained from this project will be used to develop the advanced three-fluid model and validate the closure models for fuel dispersal analysis during a design basis accident. The new model is expected to greatly improve the prediction accuracy of three-phase flows, that could be integrated with system thermal-hydraulic and fuel performance codes, such as TRACE and FAST, for a more comprehensive safety analysis regarding fuel burnup extension.

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University of Puerto Rico Mayaguez

Development and assessment of spectrally matched records for linear and nonlinear analyses of structures, systems, and components in nuclear facilities.

Executive Summary:
This research proposal aims to address critical gaps in current regulatory guidelines related to the development and evaluation of ground motion sets used as input for the dynamic time-history analyses performed during the seismic design and assessment of nuclear facilities. The use of a suitable set of input motions is essential when performing time history analyses to ensure the site's seismic hazard is appropriately represented and thus avoid underestimating seismic demands, which could lead to inadequate and potentially unsafe designs of safety-related structures, systems, and components.

The proposed research is of utmost significance for sustaining the capability for seismic event analysis that support safe operation of existing reactors and new reactor licensing applications. Specifically, the proposed work builds on the technical issues and research recommendations identified on a recent NRC Research Information Letter (RIL 2019-01), while also accounting for additional challenges that would arise in the future as nonlinear analyses become more prevalent in the nuclear industry. The research plan encompasses advanced signal processing/modeling technics and realistic nonlinear modeling of soils, structures, and soil-structure systems. The objective is two-fold: (1) to develop clear, efficient, and robust criteria for the evaluation of input motions that would lead to unbiased estimation of the structural response and (2) to formulate a spectral-matching methodology capable of simultaneously matching a design response spectrum and a target power spectral density function, while preserving the key features of the seed records in the time domain. The developed criteria and spectral matching methodology would be implemented into a computer code with the functionalities to select appropriate seed records, generate spectrally matched records, and thoroughly assess the adequacy of the generated records. This would provide NRC staff with a robust tool for performing confirmatory analyses with optimal efficiency and effectiveness.

Although the research plan is specifically targeted at filling a crucial technical gap in anticipation of NRC regulatory needs, it is also expected to advance fundamental understanding and generate further developments in the core mathematical treatment of multi-components nonlinear nonstationary signals. These fundamental new insights can find widespread use in other applied signal processing areas of great interest to the NRC, such as non-invasive dynamic response-based structural health monitoring of containment and other safety-related structures.

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University of California - Berkeley

Safety assessment of in-core and ex-core fuel management for pebble bed reactors by combining hyper-fidelity depletion and machine learning

Executive Summary:
The objective of this project is to define a safe operational envelop for managing pebble fuel both in-core and ex-core. Two demonstration pebble bed reactors (PBRs) are expected to achieve criticality within this decade: X-Energy gas-cooled PBR and Kairos Power fluoride-salt-cooled PBR. If the reactor design of pebble bed systems has been widely addressed, many aspects remain to be explored related to fuel management in-core, but also before and after fuel is used in the reactor. Pebbles present many characteristics that are quite different from traditional pin-type fuel and require to redefine the way fresh and used fuel is handled. (1) Pebbles are smaller than fuel pins, are not connected in an assembly. Furthermore, pebbles can potentially move (roll) and collect in a location if dispersed with risk of criticality. For contest a PWR core contains ~200 assemblies, a PBR ~500,000 pebbles. (2) Pebbles use 10% to 20% enriched fuel and can achieve burnup of roughly 10% to 20% FIMA, two to four times that of LWR fuel. These features have impact both on the front end when fresh fuel is stored and transported, and on the back end. (3) Noticeably different from pins, pebbles embed both the fuel and the moderator, meaning that criticality does not require additional materials, and poison cannot be integrated like in an assembly. We propose to leverage recent advancements in pebble bed reactor depletion and the large and detailed amount of data these new methodologies can generate to ensure fuel pebbles are managed within the expected safety envelope. In addition, we will perform a comprehensive assessment of fuel pebbles storage and transportation for both fresh and used fuel in order to determine guidelines and best practices for safe pebble handling.

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Texas A&M University - College Station

A Combined High-Throughput Experiments and Simulations Approach for qualifying additively manufactured 316H stainless steel alloys for molten salts reactors.

Executive Summary:
U.S. Nuclear Regulatory Commission (NRC) has recently endorsed (Regulatory Guide 1.87 Revision 2, Jan 2023) ASME Section III, Division 5, which governs the construction of structural components for use in high temperature reactor systems [1]. 316 stainless steel (SS) is one of only six alloys approved for nuclear use [1, 2]. 316H alloy is particularly of interest for molten salts reactors (MSR) and currently under investigation by Kairos Power (and others) as part of regulatory reviews of the KP-FHR design (and other MSR designs). However, Division 5 cannot cover environmental effects (of coolant and irradiation) on structural failure modes for all reactor types, and for all different design characteristics for the same reactor type [1, 2]. The recommended approach is for owner/operator to have the responsibility to demonstrate to NRC that these effects on structural failure modes are accounted for in their specific reactor design. Moreover, INL, EPRI, and other industrial partners are utilizing advanced/additive manufacturing (AM) to tailor the mechanical properties of these alloys. INL and EPRI (with industrial partners) are currently working on establishing specific Code Cases for these AM 316 alloys. Furthermore, the newly established DOE-NE program of Advanced Materials and Manufacturing Technologies (AMMT) has published a roadmap for qualifying novel materials and AM processes [3]. This roadmap proposes the deployment of physics-based models, AI/ML algorithms, and ion irradiation for rapid qualifications of AM alloys. **Objectives and Benefits:** Here, we propose to employ high-fidelity multiphysics modeling, small-scale mechanical testing, proton irradiation, and high-throughput testing/characterization to accelerate the modeling and data development and understanding of (1) irradiation effects, (2) deformation behavior, (3) corrosion and (4) the interplay between them on the degradation of irradiated AM 316H SS in molten salts reactor environments. Those topics are critical to reactor risk management. However, with the limited information available in those areas, it is difficult for NRC to develop guidelines. The research contributes to NRC's regulatory activities through the following objectives. First, the project fulfills the data need to identify the safety concerns of AM for nuclear; Second; it will facilitate the development of guidelines that operators can utilize to demonstrate the accounting for environmental effects on materials degradation in MSR, which are out of scope of ASME Section III, Division 5; Third, it will provide a proof-of-concept for utilizing multiphysics models, ion-irradiation, and small-scale mechanical testing for rapid qualification of novel materials and processes, as recommended by the Advanced Materials and Manufacturing Technologies AMMT report [3]. This proposal is appropriate for the FOA because it directly responds to one of the interests listed there, e.g., Evaluation of technical gaps and major uncertainties in assessing risk for operating new and advanced reactors (e.g., modeling of complex dependencies, advanced calculation techniques, etc.

[1] T. Sham, ASME Section III, Division 5, High Temperature Reactors, INL/CON-23-71326-Revision-0, 2023. Also, ASME Boiler and Pressure Vessel Code, 2017 Edition, Section III Division 1, and Section III Division 5.

[2] Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor, 2021.

[3] M. Li et. al., Department of Energy Office of Nuclear Energy Advanced Materials and Manufacturing Technologies (AMMT) 2022 Roadmap.

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Kansas State University

Enhancement of Miniature In-Core Fission Chamber Technology for Advanced Reactor Applications

Executive Summary:
The objective of this research effort is to advance operational performance of neutron flux sensor technology to fill gaps in up-coming advanced reactor applications. This work addresses reported shortcomings including: 1. Online sensor recalibration methods supporting longer cycles of operation. 2. Higher operational temperatures to support gas-cooled, Brayton cycle, molten-salt, and pebble bed reactors. 3. Improved accuracy and spatial resolution in distributed neutron flux monitoring. 4. Prompt sensor time-response for integration into reactor protection systems including wide dynamic range to cover fuel-loading, start-up range monitoring as well as full-power operations.

The benefits of this research are numerous, ranging from advancements in sensor response modeling and testing to workforce development and outreach to diverse youth. A new NIST-traceable source fabrication method will enable fission chamber signals from neutron irradiation to be precisely replicated on the bench-top without the need for neutron irradiation and reactor facilities. Modeling capability will be extended to include 3-dimensional time-dependent device physics (charge carrier generation, diffusion, drift, bulk and interface trapping, recombination, avalanching) coupled with radiation transport. This modeling will be benchmarked with more predictable signal conditions than ever before demonstrated in fission chamber sensors thanks to the novel radioactive source fabrication development. This will expand our scientific understanding of fission chamber sensors and will be applied to extending the sensor performance envelope, including higher temperature operation.

Workforce development and education will engage our diverse youth in partnership and recruiting with Fisk University and outreach to rural Kansas communities and regions exhibiting high Hispanic and Native American population and lacking a representative minority serving organization. The goal will be to maximize awareness and knowledge of nuclear related opportunities in education, training, and employment in smaller communities not able to maintain connections to institutions of higher education.

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Purdue University

Development of a novel nuclear safety and security probabilistic risk assessment (PRA) model for advanced reactors

Executive Summary:
Nuclear safety and security of nuclear reactors share a common objective which is to ensure the protection of the population and the environment from an undue radiological hazard. Historically, many analytical methods have been developed and implemented to support safety- based risk assessment and decision analysis. Adapting and extending risk assessment to physical and cyber nuclear security applications has been limited because of the adaptive nature of adversaries and the lack of historical data of malicious attacks. Additionally, applying this to advanced nuclear reactors, small modular reactors, and microreactors have not been evaluated fully given the immaturity and novelty of these technologies, most of which have not been licensed. It is imperative to assess if these reactors have the means to fully understand and evaluate their risk in a cost-effective manner. In addition, these reactors must meet the regulatory requirement set forth by the NRC. This proposed work has one main goal: Develop an integrated nuclear safety and security PRA model for advanced reactors. This goal has three objectives: Objective 1: Modify the current Potential Facility Risk Index (PFRI) for advanced reactors: Objective 2: Extend the model capability to include safety analysis by incorporating PRA; and Objective 3: Test the combined model on an existing reactor. Hypothetical scenarios will be modeled and performed at the Purdue University Reactor (PUR-1) and then applied to an advanced reactor. The combination of these objectives will provide a new approach for integrating nuclear safety and security using PRA techniques accepted by the US NRC. The proposed project advances knowledge and understanding within this area by creating a novel model that integrates nuclear safety and security risk. This model uses accepted PRA tools adapted for nuclear power plants that includes safety and security. The model incorporates credible safety and security scenarios integrating PRA and pathway analysis. The results will provide total risk probabilities for accident and security scenarios and risk scores (1-10, with 1 being "low" risk and 10 being "high" risk). The results of the research will provide value in determining facility designs and the integration of safety and security.

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Decontamination & Decommissioning Regulation Optimization by Policy Surveillance: A First Step in Regulation Harmonization that Leads to Many Solutions

Executive Summary:
There are subtle but significant differences in regulations and recommendations between federal agencies, state agencies, and non-governmental organizations that limit systemic safety standardization. This research aims to apply policy surveillance methods to all relevant decontamination and decommissioning regulations and recommendations with the intent to ease jurisdictional discrepancies and facilitate improved analysis of regulatory effectiveness. Policy surveillance methods have been applied to public health initiatives and can be adapted to the needs of the radiation protection community (ERG 2022, Leclair 2017). The primary deliverable of this research is a web-based database that can be used by regulators, licensees, and policymakers to compare relevant regulations and recommendations quickly and accurately. This database will help resolve conflicting jurisdictional oversight for agencies and provide guidance for the synthesis of appropriate action plans. Most importantly, this database will also facilitate analysis of the effectiveness of regulations in meeting environmental and public health goals. Traditional analysis is a time-intensive process and is at risk of producing results that are quickly rendered obsolete due to changes in law and regulations. Once built, a policy surveillance database, in contrast, can be updated with less effort and time as changes occur, thus providing a resource that is a better representation of the regulatory system. The application of policy surveillance methods to decommissioning and decontamination will also provide a framework for expanding the project to cover other areas of radiation-related regulation. This research will provide a resource that can be used to harmonize regulations between different jurisdictions, increase the proficiency of regulators and policymakers, and optimize regulations to balance the risks and rewards of radiological technologies and lead toward the implementation of semi- automated policy surveillance for use in health physics.

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University of Pittsburgh

Leveraging acoustic emissions for real-time monitoring of corrosion damage-to-crack transitions in molten salt reactors

Executive Summary:
Molten salt reactors (MSRs) are an advanced nuclear reactor design of interest due to their improved efficiency, increased safety, and reduced fuel interaction requirements relative to legacy light water reactors. Because of the high levels of radiation expected in MSRs post-start up, remote operations and maintenance approaches are required, particularly for structural health monitoring given the highly corrosive nature of the molten salt mixtures under consideration for MSRs. However, while the need for remote structural monitoring is clear, the elevated temperatures, high dose rates, and highly corrosive operating environment (if sensors are salt wetted) are a significant challenge for sensor development. A relevant technology that has shown promise for meeting these challenges is acoustic emission sensing via fiber optics, but studies are needed to confirm (1) the molten salt compatibility of such sensors and (2) the efficiency of this approach for detecting corrosion-to-crack transitions in MSR environments. The overarching objective of the proposed effort is to address this engineering need through the development, implementation, and validation of real-time, acoustic sensing technology for structural health monitoring in molten salt reactor components.

To accomplish this objective, a collaborative research program is proposed that will (1) identify an optical fiber acoustic emission sensing configuration that is compatible with MSR environments and (2) demonstrate the efficacy of acoustic emissions-based monitoring to detect the onset of stress corrosion cracking propagation in a molten salt environment. The proposed program will provide clear engineering benefits via the development of an effective, scalable, and remote structural health monitoring approach for MSR applications, while also disseminating appreciable stress corrosion cracking susceptibility data for MSR environments into the open literature. Additionally, the development and validation of high temperature-capable, radiation-tolerant sensing technology for structural health monitoring will positively impact other nuclear applications. For example, products and knowledge gained from the proposed effort could be leveraged in other advanced reactor designs, such as liquid Pb-based systems, where high temperatures also challenge existing sensor technologies. Lastly, this proposal will sponsor more than six summer undergraduate research project for students from backgrounds that are traditionally underrepresented in STEM to work on cutting-edge research on nuclear-relevant topics through a dedicated partnership with West Virginia State University (a minority serving institution).

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University of Maryland

Use of Hybrid Tools to Model Risks of Advanced Nuclear Power Reactor Technologies under a Changing Climate

Executive Summary:

Context: Advanced nuclear technologies represent a key resource for mitigating the effects of a changing climate. Advanced reactor technologies are expected to reduce construction timelines, increase efficiencies, reduce operating costs, and employ multiple safety-enhancing technologies. These facilities are also exposed to meteorological/hydrological hazards that may increase in frequency and severity due to a changing climate. Realizing the benefits of nuclear power while ensuring public health and safety requires robust probabilistic risk assessments (PRAs). However, foundational PRA software and tools are associated with limitations that have led to assumptions and "workarounds" that reduce model transparency and limit the degree to which complexities can be captured. These limitations can be particularly acute when seeking to model spatially/temporally dynamic hazard events under complex dependencies and in light of new technologies with limited data. There is a need for research to identify, assess, and develop strategies/tools that can address the unique suite of PRA challenges encountered when modeling risks posed to and by advanced nuclear power reactor technologies under a changing climate.

Objectives: This research project leverages a graded approach to develop hybrid modeling approaches that address obstacles that nuclear PRA analysts face when using present-day PRA tools to model risks posed to and by advanced nuclear power plants exposed to prolonged hydrological and meteorological hazards posed by a changing climate. Specifically, the objective of this project is to use hybrid modeling approaches to address a range of practical and technical obstacles faced by PRA analysts, including (1) modeling broad classes of complex dependencies, (2) characterizing PRA inputs in data-sparse environments, (3) modeling latent conditions (e.g., due to the potential for unknown system states and interactions), (4) modeling of passive and semi-passive systems, and (5) capturing non-stationary processes due to climate change.

Benefits: This project addresses multiple NRC-defined research areas of interest, including:

(1) technical gaps and major uncertainties in assessing risk for new and advanced reactors;

(2) characterization of hazards related to flooding, high winds, and climate change; (3) data visualization; and (4) analytical approaches for PRA modeling, reliability, and resilience assessments. In addition to solving emergent technical challenges, the proposed research project will expose student researchers to advanced technologies, PRA challenges, and existing/new PRA methods and software tools. It will also allow students to engage with the nuclear PRA community.

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Manufacturing of Spent Fuel Storage Canisters with Superior Stress Corrosion Cracking Resistance using Advanced Hybrid Laser-Arc Welding and High-Pressure Cold Spray Additive Post-Processing

Executive Summary:
The goal of the proposed research is to develop and demonstrate an innovative process to manufacture dry storage canisters (DSCs) for spent nuclear fuels (SNFs) with superior resistance to chloride-induced stress corrosion cracking (CISCC) using a novel concept of advanced hybrid laser-arc welding (HLAW) followed by high-pressure cold spray (HPCS) post-processing. The project addresses the NRC programmatic mission objectives for evaluating technical gaps and major uncertainties in assessing risk for decommissioning and waste management. The primary expected outcome of this research is increased safety and security against CISCC in DSC's for SNF storage applications. This work involves graduate students from University of Nevada Reno and the Ohio State University and providing opportunities to undergraduate students from minority serving institution, fostering the development of the next generation workforce in nuclear science and engineering.

The objectives for this project are to use HLAW to join ASS plates; subject the welded joint to HPCS; test the welded joint; and apply modelling to DSC welds to demonstrate efficacy against CISCC. This proposed approach will provide a powerful tool to improve the CISCC resistance in DSCs and save millions of dollars in repair and rework costs. Also, it will eliminate potential exposure of radiation from DSCs, thus benefiting society.

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Texas A&M University – Kingsville

Optimization Method for SMR Core Design

Executive Summary:

This project aims to develop a methodology to automate the optimal burnable poison pattern search for small modular reactor (SMR) core design by developing a methodology that couples MATLAB optimization and parallel computing toolboxes with the SCALE6 code package, a light-water reactor design and licensing software suite. The objectives of the optimization algorithm will include minimizing the deviation of the multiplication factor and minimizing the fuel pin peaking factor throughout the fuel cycle to meet the various design requirements arising from innovative pressure water reactor derived SMR development. Texas A&M University-Kingsville, as a Hispanic-Serving Institution, provides the research infrastructure and academic environment. By conducting the proposed research on SMR development, TAMUK contributes to expanding the presence of underrepresented groups in nuclear science. Such endeavors not only broaden perspectives but also foster innovation, ultimately cultivating a more inclusive scientific community.

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FY2023 Research and Development Grant Executive Summaries

University of New Mexico

Using Depletion Sensitivity Analysis to Better Characterize Reactor Fuel Cycles

Executive Summary:
The goal of this work is to improve our ability to characterize the time-dependent evolution of fuel and reactor physics properties in operating and advanced reactors. This goal will be accomplished by improving our understanding of sources of uncertainty that limit our ability to model nuclear fuel cycles. Specific aims of this work include:

1. Understanding how stochastic noise limits our ability to accurately predict the isotopic inventory of spent fuel.
2. Understanding how uncertainty in nuclide fission yields and cross section data affects our ability to predict the isotopic inventory of spent fuel.
3. Understanding how uncertainty in nuclear data and fuel isotopic inventories introduces uncertainty in key reactor physics properties, including the end-of-cycle (EOC) reactor design eigenvalue and local and global delayed neutron fraction ($\beta\beta eeeeee$) estimates.

If successful, this work will improve our ability to predict the composition of spent fuel, to predict heat generation in spent fuel, to control advanced reactors, and to accurately model and optimize advanced reactor fuel cycles.

By improving confidence in our ability to control reactors by identifying sources of uncertainty in EOC reactor eigenvalue estimates, $\beta\beta eeeeee$ estimates, and boiling water reactor (BWR) flow control maps, this work will aid in the “evaluation of technical gaps and major uncertainties in assessing risk for operating, new and advanced reactors.” Furthermore, identifying sources of uncertainty in the composition of spent fuel will aid in the “evaluation of technical gaps and major uncertainties in assessing risk for decommissioning and waste management.” By developing these sensitivity analysis methods in high-fidelity, reactor-agnostic, continuous-energy Monte Carlo codes, these methods will be accessible to both operating Light Water Reactors (LWRs) and novel advanced reactor designs.

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Confidence in Uncertainty: Research to Address Exiting and Emerging Technical Challenges in Characterization and Assessment of Uncertainty of PRA Results for Risk-Informed Decision Making

Executive Summary:
The proposed research aims to examine important technical gaps in PRA uncertainty analysis domain and provide technical foundations for resolution. The different types of uncertainty considered are completeness, parameter, and model uncertainty. Among the topics to study is the assessment of uncertainty and trustworthiness of Machine Learning (ML) methods that are of rapidly rising interest and field applications for model building and probabilistic assessment of risk and safety, particularly for advanced reactor concepts, including small modular reactors. ML techniques already play a prominent role in designing and developing means for reliability and integrity monitoring of systems with passive safety features, and new capabilities of digital control rooms. Machine Learning methods are also being explored to replace some of the more conventional data analytics methods used in PRAs in such areas as Human Reliability Analysis, Common Cause Failure Analysis, and External Events Hazard Analysis. The methods and procedures resulting from the research will be formulated at a practical level, and with objective of enhancing the quality and credibility of PRA uncertainty analysis and results. The emphasis will be on improving the realism of the quantified uncertainty distributions, complementing NUREG-1855, guidance with emphasis on techniques for quantification of uncertainties.

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University of Illinois at Urbana – Champaign

Context-Based Analysis of a Risk-informed, Performance-based Regulatory Approach for Advanced Nuclear Reactors

Executive Summary:
The objective of this project is to evaluate the role of technology-inclusive, risk-informed, and performance-based (RIPB) safety regulation for advanced nuclear reactors, focusing on the engineering-informed legal and regulatory context in which such regulation occurs. In doing so, the project will address the NRC's noted interests in research on performance-based technology-inclusive safety assurance, evaluating technical gaps and major uncertainties in assessing risk for advanced reactors, and continuing to refine techniques in probabilistic risk assessment (PRA). This project will be executed in three tasks: (I) Conduct a "context analysis" to develop a thorough understanding of the legal and institutional contexts of regulating advanced nuclear reactors; (II) Conduct a comparative analysis of existing regulatory constructs through a comprehensive review of engineering, legal, and policy literature regarding the existing approaches to regulate technological system risks to identify the potential scholarly gaps in support of designing the RIPB approach to regulating advanced nuclear reactors; and (III) Conduct a case study to demonstrate an application of the regulatory context and design recommendations. A strength of this proposal is that the team includes experts from law and policy as well as nuclear engineering.

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Developments of Guidelines and Benchmarks for Regulatory Assessment of Autonomous Visual Data Collection and Monitoring of Operations and Maintenance

Executive Summary:
Reality capture technologies, such as visual sensing and laser scanning using drones and robotic devices, have been gaining increasing attention during operations and maintenance (O&M) of industrial facilities. These technologies are being pursued by the existing fleet of nuclear plants to increase efficiency, reduce staffing needs, and improve the quality of monitoring the facilities and various systems. Advanced reactor vendors are pursuing these technologies for developing digital twins to manage not only O&M but also construction of new reactors. More specifically, video cameras and laser scanners are being used to develop 3D models of components and systems. The 3D images are then used for a variety of purposes such as virtual inspections by comparison with 3D design models, visualization, monitoring, schedule management, etc. Overall, “as-built” digital twins developed using these technologies are a key step in the development of autonomous monitoring and control systems for nuclear plants. The expectation is that the autonomous systems will be highly efficient and accurate in their capabilities for diagnosis, prognosis, and strategy assessment in managing the entire lifecycle of a nuclear plant.

This proposal aims to help the regulators, inspectors, and plant operators be prepared for the next generation of reality capture and robotics technologies for virtual inspection and monitoring and integrating them into the current practices.

Specifically, this project proposes to (i) characterize technical specifications and the associated parameters that govern the accuracy of virtual inspections and monitoring, including parameters related to autonomous navigation of robots used for visual data collection; (ii) conduct laboratory studies to quantify uncertainties in parameters that govern the accuracy of visual sensing based measurements and autonomous navigation; (iii) characterize uncertainties and recommend possible solutions to reduce uncertainties wherever applicable; (iv) identify items that are conducive to virtual inspection and monitoring and the items that are not; (v) develop benchmark problems that can be used to test and assess the quality of a virtual reality (VR)-based monitoring platform, and (v) develop recommendations for periodic calibration of virtual inspection and monitoring

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