REQUEST FOR PRE-APPLICATIONS (RPA) NO. NEUP-001-10-Rev 1

For R&D Proposals

By Battelle Energy Alliance (BEA) on behalf of the Department of Energy Nuclear Energy Office

ISSUE DATE: **October 9, 2009**

PRE-APPLICATION DUE DATE: **November 10, 2009**

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FY 2010 Request for Pre-Applications Revision

Changes made to the FY 2010 Nuclear Energy University Programs Research and Development Request for Pre-Applications are provided below.

Section 4 Eligibility Information

Added the following text:

> Note that funding is for U.S. researchers only. Collaborations with foreign organizations are allowed if their role is focused on fundamental research and they are not a denied party or a party that requires an export license. Foreign organization participants are not eligible for U.S. funding.

1 INTRODUCTION

This solicitation is a Request for Pre-Applications (RPA) for research and development (R&D) for the United States Department of Energy's Office of Nuclear Energy (DOE-NE) Nuclear Energy University Programs (NEUP). It was prepared by the Battelle Energy Alliance, LLC (BEA), a Management and Operating (M&O) contractor at the Idaho National Laboratory (INL).

The mission of the DOE-NE is to lead the DOE investment in the development and exploration of advanced nuclear science and technology. DOE-NE promotes nuclear energy as a resource capable of meeting the Nation's energy, environmental, and national security needs by resolving scientific, technical, and regulatory challenges through research, development, and demonstration.

NEUP's goal is to support outstanding, cutting-edge, and innovative research at U.S. universities through the following:

- Administering NEUP R&D awards to support NE's goal of integrating R&D at universities, national laboratories, and industry to revitalize nuclear education and support NE's programs
- Attracting the brightest students to the nuclear professions and supporting the Nation's intellectual capital in nuclear engineering and relevant nuclear science, such as Health Physics, Nuclear Materials Science, Radiochemistry, and Applied Nuclear Physics
- Improving university and college infrastructures for conducting R&D and educating students
- Supporting NE's goal of facilitating the transfer of knowledge from an aging nuclear workforce to next generation of workers

This RPA will include a set of mandatory requirements and evaluation criteria that will be used to select a set of applications. Applicants whose application is selected will be asked to submit a response to a subsequent Request for Proposals (RFP).

The primary point of contact for questions regarding this solicitation is Dr. Marsha Lambregts from the Nuclear Energy University Programs Integration Office at the INL Center for Advanced Energy Studies (CAES). However, all technical scope questions need to be submitted through the question and answer feature on the RPA website accessible via the NEUP home page located at www.ne-up.org.

In preparation for this R&D RPA, a NEUP workshop was held on August 13-14, 2009, in Salt Lake City, Utah. Outcomes of this workshop were captured as proceedings and are available at the www.ne-up.org website.

This workshop product is an important source of background information on the R&D areas that will be included in this solicitation. Applicants are encouraged to read and familiarize themselves with these documents before responding to the solicitation or entering the proposal submittal system (online).

A stand-alone pre-application is required for each scope of work of interest. Applicants may submit more than one pre-application. Availability of funding will determine the final number of proposals selected for each technical area.

NOTE: *All information and instructions required to respond to this solicitation are accessible at www.ne-up.org. Applicants may request login credentials at www.ne-up.org beginning at 8 a.m. October 9, 2009 MST. Applicants MUST submit their responses electronically. NO hard copy responses will be accepted.*

2 SCOPE AND OBJECTIVES

NEUP will fund R&D that facilitates achievement of NE's programmatic objectives. NE's strategic goals for nuclear energy are as follows:

1. Extend life, improve performance, and sustain health and safety of the current fleet of nuclear power plants
2. Enable new plant builds and improve the affordability of nuclear energy
3. Enable the transition away from fossil fuels in the transportation and industrial sectors
4. Enable sustainable fuel cycles
5. Assure that proliferation risk is not an impediment to nuclear power deployment

The research needs and priorities have been identified and defined for the Fuel Cycle Research and Development (FCR&D), Generation IV (Gen IV) programs, and Light Water Reactor Sustainability (LWRS) program.

The mission of the FCR&D program is to develop options to current commercial fuel cycle management strategy to enable safe, secure, economic, and sustainable expansion of nuclear energy while reducing proliferation risks by conducting R&D focused on nuclear fuel recycling and waste management to meet U.S. needs.

The Gen IV program aims at long-term technology advances through scientific R&D to further improve the safety performance and lower production costs of advanced reactor concepts for potential commercial deployment in the 2030 timeframe. The Gen IV R&D program will also focus on solving the underlying science and technology challenges (materials, neutronics, and thermal-fluids modeling) of innovative reactor concepts including, but not limited to, those identified in the "Technology Roadmap for Generation IV Nuclear Energy Systems" prepared by the Generation IV International Forum (GIF).

The LWRS program mission is to provide the technical basis for licensing and managing the long-term safe, economical operation of nuclear power plants beyond their current 60-year license. Research elements are focused on the understanding of fundamental aging and degradation behavior in reactor materials, creating improved inspection and monitoring technologies, fostering development of advanced fuels, and incorporating risk-informed, performance-based techniques in safety margin characterization and life-extension decision making.

Additionally, creative, innovative, and "blue sky" mission-relevant investigator-initiated research (IIR) activities that could produce breakthroughs in nuclear reactor technology are also invited to this solicitation and constitute up to 15 percent of the total program R&D awards. This includes research in the fields or disciplines of nuclear science and engineering that are relevant to NE's mission though may not fully align with the specific initiatives and programs identified in this solicitation. This includes, but is not limited to, Nuclear Engineering, Nuclear Physics, Health Physics, Radiochemistry, Nuclear Materials Science, or Nuclear Chemistry. Examples of topics of interest are new reactor designs and technologies, advanced nuclear fuels, instrumentation and control/human factors, radiochemistry, fundamental nuclear science, and quantification of proliferation risk.

Detailed program information and programmatic needs for FCR&D, Gen IV, and LWRS can be found at the RPA website: www.ne-up.org. Table 1 in Appendix A identifies the program-specific research needs for this solicitation, and is organized by technical focus areas and cross-cut areas. This table also includes a work scope titled, "Mission-Relevant Investigator-Initiated Research." Each specified work scope provides the basis for a stand-alone R&D pre-application submittal and has been assigned a Work Scope Identification Number.

Follow-on R&D work from previous projects may be submitted as new proposals for consideration under this RPA. All proposals submitted under this RPA will be considered equally.

3 ESTIMATED FUNDING

Fiscal year 2010 is estimated to have a $38.5 million R&D budget for new R&D awards under this solicitation announcement. Through this solicitation, DOE may issue awards in multiple phases throughout the fiscal year pending availability of funds. Up to 15 percent of the total funding is targeted for investigator-initiated research.

The actual level of funding in each research area depends on the fiscal year 2010 appropriation for the DOE-NE R&D programs. In the event that additional funds become available later in fiscal year 2010, DOE will request full proposals from highly ranked pre-applications and make awards in accordance with the proposal review and evaluation process outlined in this solicitation.

4 ELIGIBILITY INFORMATION

The lead applicant must be a U.S. university or college. Collaborations between universities and industry or national laboratories are permitted. A maximum of 20 percent of an award can go to industry and national laboratories. **Note that funding is for U.S. researchers only. Collaborations with foreign organizations are allowed if their role is focused on fundamental research and they are not a denied party or a party that requires an export license. Foreign organization participants <u>are not</u> eligible for U.S. funding.** Universities that partner with minority-serving institutions will receive additional points during the full proposal review. The following link provides the list of minority-serving institutions: http://www.ed.gov/about/offices/list/ocr/edlite-minorityinst.html. Furthermore, including early career researchers on application teams is encouraged. ("Early Career" would include principal investigators (PIs) within the first 10 years of their academic career as self-identified on the application.)

5 CONTENT OF R&D PRE-APPLICATION AND BASIS FOR AWARD

Each applicant's R&D pre-application shall include the following:

- Commitment to Mandatory Requirements
- Commitment of Partners
- Vita for PI
- Pre-Application Narrative

You may input these pre-application elements on the NEUP R&D pre-application form provided at the RPA website. Access instructions are available at www.ne-up.org.

5.1 MANDATORY REQUIREMENTS

A mandatory set of requirements (go/no-go) is provided below as Attachment 1. The lead university or college is required to obtain its institutional commitment, as well as the commitment of each collaborating organization, to each of the specified mandatory requirements. Only pre-applications that accept these mandatory requirements shall be eligible for continued evaluation.

5.2 COLLABORATION COMMITMENT

Each institution identified in the RPA as a team member shall be identified in the pre-application, with their commitment made to collaborate in the RFP process, and agree to the mandatory requirements. Minor contributors—anyone not expected to materially participate in the proposal, such as consultants or national laboratory personnel who are not to be paid more than $50,000 to participate in the project—should not be listed.

5.3 VITA

A two-page vita shall be provided for the PI from the lead college or university. It should include his/her relevant credentials, experience, and five most recent publications or commensurate accomplishments.

5.4 PRE-APPLICATION NARRATIVE

Applicant shall provide a narrative that addresses the specific information below:

- Title of Project
- Technical Work Scope Identifier No. (enter the number that appears in the Technical Work Scope Table)
- Name of Project Director/PI(s) and associated organization(s)

- A summary of the proposed project, including a description of the project and a clear explanation of its importance and relevance to the objectives covered by this work scope area
- Explanation of the contribution that will be made by the collaborating organizations
- Explanation of the importance and relevance of the proposed work to the objectives covered by this work scope area
- Logical path to work accomplishment
- Deliverables and outcomes the R&D will produce
- Timeframe for execution of proposed scope (specify if the R&D is for a one-, two-, three-, or four-year period)
- Estimated cost of proposal (order of magnitude); proposals shall not propose costs of more than $500,000/year and $1,500,000/contract.

5.5 EVALUATION CRITERIA

Selection of universities and colleges to respond to the RFP shall be based on how well, in NEUP's judgment, the pre-application meets or exceeds the evaluation criteria. The evaluation criteria and weights for the R&D portion of this solicitation are provided below as Attachment 2. In accordance with the evaluation criteria and available funding, NE will make the final selection of pre-applications that will be invited to respond to the RFP.

6 APPLICATION AND SUBMITTAL INFORMATION

NEUP reserves the right to amend the solicitation schedule as needed.

6.1 SOLICITATION SCHEDULE

Issue Request for Pre-Application	October 9th
Pre-Applications Due	November 10th
Pre-Application Review Completed	December 10th
RFP Released	December 16th
Full Proposals Due	January 26, 2010
Selection Review Completed	March 16th
Selection Announced	April 14th
Awards Completed	July 30th

6.2 PRE-APPLICATION DUE DATE

In accordance with the schedule above, pre-applications are due by 5:00 p.m. MST on November 10, 2009. Submittals to the R&D solicitation MUST be made electronically by using the "Submit pre-application for review" option on the pre-application form. Please read the instructions on the form carefully. Pre-applications not submitted via this option will be treated as incomplete and will not be evaluated. If you run into technical difficulties during the upload process after business hours on November 10, 2009, you can email a copy of your pre-application and other required information to neup@inl.gov before the midnight deadline and the pre-application will be considered responsive.

6.3 LATE PRE-APPLICATIONS

Pre-applications received after the designated date and time, i.e., late, will be treated as nonresponsive and returned without opening. Extension of the R&D pre-application due dates shall be determined at the sole discretion of the NEUP Integration Office on behalf of the DOE-NE.

6.4 SUBMITTAL CONTENT AND FORMAT

The information required for each pre-application submittal is captured on the pre-application form. The key information captured on the form is described in the table below.

Item	Description
Pre-Application Narrative	Size 11 font minimum; Three single-spaced pages maximum; One-inch margins all around minimum.
Mandatory Requirements	Electronic submittal of the pre-application form.
Commitment of Partner(s)	Electronic submittal of the pre-application form.
Vita	Size 11 font minimum; Two single-spaced pages maximum; One-inch margins all around minimum.

7 PRE-APPLICATION INSTRUCTIONS

Submit, in writing (electronically), any administrative questions or requests for additional information on this solicitation to neup@inl.gov. Technical scope questions should be made using the question and answer feature on the NEUP home page located at www.ne-up.org. NEUP will provide a response to substantive inquiries by restating the question and furnishing a response to all potential applicants by posting the question and response on the RPA website.

Pre-applications that fail to provide ALL items and quantities specified in this RPA may be deemed non-responsive in their entirety and will not be invited to submit a response to the RFP.

7.1 QUALITY ASSURANCE REQUIREMENTS

Institutions will be expected to follow quality assurance (QA) principles and requirements in conducting R&D activities. The integrity of R&D products and their usability by NE is predicated on meeting QA requirements as they apply to a specific scope of work and associated deliverables. In most cases, an institution's process for peer review in support of publishing research results will serve as a basis for QA requirements; however, there will be some instances where additional QA requirements will be needed.

Before the RFP is released, the QA requirements for each specific work scope will be defined and added to the Technical Work Scope Table that describes each specific scope of work associated with this solicitation. Institutions will be able to adequately factor these requirements into their R&D final proposal strategy and to include compliance costs as part of their response to the RFP.

While QA requirements are not new to universities and colleges, it is recognized that familiarity with NE programmatic-specific QA requirements will vary; therefore, during the RFP process, the NEUP Integration Office will provide assistance, as needed, in interpreting QA requirements for a specific work scope and in developing options to meet those QA requirements.

8 WORK SCOPE DESCRIPTIONS

Table 1 in Appendix A gives a detailed description of research needs in support of each programmatic element. It should be noted that the submission of novel and creative solutions to the research challenges is strongly encouraged beyond the detailed needs described in Table 1.

9 PROGRAM CONTACTS

Table 2, found in Appendix B, provides a list of technical contacts for each program that can be contacted for further information on their respective areas of work as well as the programs' websites that also provide relevant technical information.

Attachment 1

DOE NE University Programs Pre-Application Mandatory Requirements

Requirement	Description	Evaluation
Commitment to comply with Standard Research Subcontract	The college or university is required to acknowledge that it will comply with the terms and conditions of a Standard Research Subcontract (available on the RPA website) without exceptions.	Pass/fail
Commitment to reporting and budget requirements	Commitment to submit quarterly billing. Commitment to submit quarterly reports to National Campaign Director. Reports approved by Campaign Director, such as an Annual Report.	Pass/fail
Commitment to comply with QA Requirements	The college or university is required to acknowledge that it will comply with QA requirements. Additional explanation is provided below.	Pass/fail

Note 1: If the lead institution has a current R&D contract in place with BEA and is awarded a R&D contract in response to the RFP, then the NEUP R&D award will be added to the existing contract.

Note 2: If an applicant proposes work scope to be conducted at a DOE facility, the work performed at DOE facilities shall be conducted in accordance with 10 CFR 851, Worker Safety and Health Program requirements.

Note 3: Applicants that progress to the full proposal stage will be required to agree to the terms and conditions of the Standard Research Subcontract.

Attachment 2

DOE NE University Programs Pre-Application Evaluation Criteria

Criterion	Description	Weight (Percent)
Scientific/Technical Merit[1]	**All work scopes except IIR**: Advances the state of the knowledge in the relevant program element(s); practicality of scope with respect to the program element; practicality of scope with respect to requested funding and period of performance; logical path to work accomplishment; ability of team to perform work. **IIR**: Advances the state of knowledge in an area directly relevant to the DOE-NE's mission; practicality of scope with respect to DOE-NE's mission; practicality of scope with respect to requested funding and period of performance; logical path to work accomplishment; ability of team to perform work.	50
Mission-relevant	**All work scopes except IIR**: Mission-relevance; aligned with technical objectives; advances the state of the knowledge within the program element **IIR**: Aligned with and directly relevant to DOE-NE's mission; advances the state of the knowledge with respect to DOE-NE's mission.	50
1. Scientific Technical Merit: The technical section of the application will clearly define the research being proposed and its relationship to the relevant program element(s). This criterion will consider the technical merit of the application, including proposed technical objectives and deliverables as well as the likelihood of achieving them.		

Attachment 3

Nuclear Energy University Programs
Research Needs

This section provides a brief overview of the three programs that NEUP supports and describes their organization and overall research needs.

1. Fuel Cycle Research and Development Program

1.1. FCR&D Program Mission and Research Challenges

The mission of the FCR&D program is to research and demonstrate technologies that will enable the safe and cost-effective management of the used fuel produced by the current and future nuclear enterprise in a manner that reduces proliferation risk.

The research conducted in the program is focused on developing novel technology options that will improve used fuel storage, recycle, and disposal options, with performances in cost and environmental consequences significantly improved from current technology performance. The current program technical strategy relies on a succession of interim storage, used fuel separation, transmutation of transuranic elements in appropriate reactors, and long term disposal of other elements and process wastes. University research needs are focused on improving reference technologies; nevertheless, proposals for novel approaches are strongly encouraged.

1.2. Program Structure and Key University Research Needs

The program is organized along six focused research areas and four cross-cutting activities:

- The **separations and waste forms** campaign develops the next generation of fuel cycle and waste management technologies that enable a sustainable fuel cycle, with minimal processing, waste generation, and potential for material diversion. The key university research needs for that activity are to 1) develop a fundamental understanding of chemical properties relevant to separations processes, 2) develop novel separations methods for conventional and advanced fuels, 3) develop fundamental understanding of waste form stability, and 4) develop novel waste forms with enhanced performance.
- The **advanced fuels** research area develops fuels and associated fabrication technologies that enable the transmutation of transuranic elements with extended in-core performance and reduced fabrication challenges. The key university research needs for this activity are 1) development of advanced fuels and target designs for transmutation in advanced reactors and 2) development of novel instrumentation techniques for in-pile and out-of-pile fuels characterization.
- The **transmutations technologies** campaign develops advanced technologies to significantly improve economic and safety performance of advanced transmutation technology recycle systems. The key university research needs for this activity consist of developing advanced fast spectrum transmuter concepts for

enhancing the economics of these systems. *Develop a short course on fast reactors and liquid metal technologies. This need is mentioned here, but proposals in this area will be requested in the infrastructure solicitation that will be issued later this year. (Do **NOT** propose any short courses during this solicitation.)*

- The **materials protection, accountability, and control for transmutation** (MPACT) campaign develops technologies and analysis tools to support next generation nuclear materials management for future U.S. fuel cycles. The key university research needs for this activity are 1) development of new sensor materials and measurement techniques; 2) development of novel methods for data integration and real time analysis; 3) development of advanced concepts for achieving real-time, online, and continuous nuclear material accountancy; and 4) development and demonstration of novel methods for assessing the proliferation risk associated with fuel cycles.
- The **nuclear energy advanced modeling and simulation** (NEAMS) campaign develops science-based capabilities geared at facilitating the development and design of novel technologies. The key university research needs for this activity are 1) development of advanced tools for fuels, separations, and reactor analyses; and 2) development of novel techniques for validation/verification and uncertainty quantification.
- The **used fuel disposition** campaign develops technologies for storing and disposing used nuclear fuel and the waste forms associated with recycling technologies. The key university research needs for this activity are 1) development of innovative storage concepts, 2) development of waste performance evaluation tools, and 3) development of waste packaging materials.
- The **safety and regulatory cross-cutting** activity provides guidance to the technology efforts in order to support rigorous licensing requirements. No key university research needs have been identified.
- The **nuclear physics cross-cutting** activity is focused on improving nuclear data libraries by using advanced experiments, nuclear theory, and evaluation techniques. Key university research needs for this activity are 1) development of models to perform inclusive multi-channel nuclear data evaluations, 2) development of novel measurement techniques for fission multiplicity and fission spectra, and 3) development of novel transmutation concepts.
- The **materials cross-cutting** activity develops transformational materials to enable revolutionary improvements in fuel cycle system design. The key university research needs for this activity include 1) development of advanced alloys and composites that can sustain very high fluences and 2) development of measurement techniques and modeling for advanced reactor structural materials.
- The **systems analysis** activity provides the integrating analyses of nuclear energy and fuel cycle systems to inform FCR&D, programmatic decisions, strategy formulation, and policy development. Systems analysis is used as a predictive/strategic tool, enabling a more proactive approach to understanding the behavior of various fuel cycles and their impact on the associated policy choices. The results of the analyses are used to guide R&D and technology development, and to develop requirements for the various parts of the system as well as

requirements for the system as a whole. Additionally, the results can be used to inform policy decisions and changes to the regulatory structure that governs the nuclear fuel cycle. The key university research need for this activity is the development of science-based metrics.

2. Generation IV Reactor Research and Development Program

2.1. Generation IV Program Mission and Research Challenges

The mission of the Generation IV program is to research and develop reactor technologies with higher safety, economic, and sustainability performance. These reactors are slated for deployment in 2030 and beyond and are capable of delivering either electricity or process heat for industrial applications, including the generation of hydrogen.

The research conducted in the program is focused on developing advanced reactor concepts including, but not limited to, those identified in the "Technology Roadmap for Generation IV Nuclear Energy Systems." The program also executes research on cross-cutting technologies that will enable these concepts, including fuels, materials, and reactor modeling. Current systems being considered by the program include both thermal and fast systems: the very high-temperature reactor (VHTR), the advanced high temperature reactor, the sodium-cooled fast reactor (SFR), the lead-cooled fast reactor (LFR), and the gas-cooled fast reactor (GFR). The program also investigates small and medium-sized reactor concepts. The research program is focused on the key technology challenges for these concepts and supports cross-cutting activities, including Modeling and Simulation, Structural Materials, Energy Conversion, Nuclear Instrumentation and Control, and Innovative Manufacturing Approaches.

2.2. Program Structure and Key University Research Needs

The program is organized along four reactor categories and five cross-cutting activities. Among these elements, one reactor concept (the VHTR) has a very high priority and has a detailed substructure. Due to this strong focus, this section is divided into two subsections: the first one addresses the VHTR program structure and associated research needs, and the second one addresses all other concepts, cross-cutting areas, and associated research needs.

2.2.1. VHTR Program Structure and Key University Research Needs

The VHTR is a helium-cooled, graphite moderated reactor with a core outlet temperature between 750 and 850°C with a long-term goal of achieving an outlet temperature of 950°C. The reactor is well suited for the co-generation of process heat and electricity and for the production of hydrogen from water for industrial applications in the chemical and petrochemical sectors. This program component is organized along four categories:

- **Reactor analysis methods** research is focused on providing practical tools to analyze the neutronics, thermal-hydraulics, and safety of VHTRs. Key university research needs for this activity include 1) development of high performance methods and data for core neutronics and thermal-hydraulic performance, 2) coupled system level operational analyses, 3) coupled integral system safety studies, and 4) fuel management assessments.

- **Reactor materials** research is focused on the development of graphite and high temperature structural materials. Key university research needs include 1) development of fundamental understanding of degradation phenomena of these materials in the VHTR environment, 2) development of constitutive models and overall failure models, 3) development of novel non-destructive examination (NDE) techniques, and 4) development of specific industrial techniques (e.g. , joining, brazing) for the use of these materials in a VHTR.
- **VHTR fuel development and qualification** activities are focused on defining fuel designs and fabrication techniques that produce fuels with very low failure rates, as demonstrated by irradiation and accident safety testing programs. Key university research needs include experimental and theoretical approaches that establish credible fission product transport mechanisms to support the development of a mechanistic source term for VHTRs under normal, accident, and off-normal conditions, including both air and/or moisture ingress events.
- **VHTR deep-burn** activities are focused at understanding the role of the VHTR in the nuclear fuel cycle and its potential for transmutation as well as developing technologies to recycle both fuel and graphite. University research needs in this area include 1) innovative deep burn TRISO fuel particle designs (e.g., TRIZO, TRIZO*, dispersed burnable absorbers, or fission product getter materials.); 2) the associated performance of the fuel designs; 3) studies of fission product/ZrC interactions; and 4) characterization of thermomechanical and thermophysical properties of ZrC (both unirradiated and irradiated), a potential candidate material to replace SiC in the coated particle to enable the deep burn (e.g. high burnup) mission for particle fuel.

2.2.2. Other Reactors, Cross-Cutting Activities, and Key University Research Needs

This portion of the program is organized along three reactor categories and five cross-cutting areas:

- **Advanced high-temperature reactors** combine the coated particle fuel and graphite moderator of the VHTR with a liquid fluoride salt as a coolant. R&D activities are focused on establishing the concept's viability and selecting promising technologies. The key university research needs for this activity include 1) development of fuels requirements, 2) specific instrumentation and technologies, 3) technologies for forming and joining specific structural materials, 4) computational capabilities for salts, and 5) transmutation analyses for thorium fueled concepts.
- **Fast spectrum reactor** research is focused on improving the economics of these systems and resolving key technological issues. The key university research needs include 1) development of innovative technologies for cost reduction, 2) development of novel reactor concepts with increased performance, and 3) development of in-service-inspection technologies.

- **Small- and medium-sized reactors** research needs to support the early deployment of emerging designs and the development of innovative designs. A key issue for these reactors will be economic competitiveness. The key university research needs for this area include the design of innovative concepts and the development of advanced technologies to significantly improve the performance of these reactors.
- The **modeling and simulation cross-cutting** area develops multi-application computational tools with increased fidelity. Key university research needs include 1) development of tools, frameworks, coupling techniques, and validation/verification and 2) uncertainty quantification method.
- The **structural materials cross-cutting** area develops materials for use in high radiation, high-temperature environments for various coolants. Key university research needs include the development of joining techniques for reactor materials and the modeling of materials behavior under extreme reactor conditions.
- The **energy conversion cross-cutting** activity conducts research in Brayton cycles and heat transport technologies. Key university research needs include the modeling of Brayton cycles, materials corrosion studies, technology development for specific components, and design of heat transport systems.
- The **nuclear instrumentation and control and the innovative manufacturing cross-cutting** activities have no identified university research needs, but proposals submitted under MR-IIR would be considered.

3. LWR Sustainability (LWRS) Program

3.1. LWRS Program Mission and Research Challenges

The LWRS program is performed in close collaboration with industry and the Nuclear Regulatory Commission (NRC). Its mission is to provide the technical basis for licensing and managing the long-term safe, economical operation of nuclear power plants beyond their current 60-year license. While in the past their original licenses had been extended from 40 to 60 years using standard engineering analyses and materials sampling, the challenges of a lifetime extension beyond 60 years demand not only a sold scientific underpinning, but also favorable economics.

Research elements are focused on the understanding of fundamental aging and degradation behavior in reactor materials, creating improved inspection and monitoring technologies, fostering development of advanced fuels, and incorporating risk-informed, performance-based techniques in safety margin characterization and life-extension decision making.

3.2. Program Structure and Key University Research Needs

The program is organized along four focused research areas:

- **Nuclear materials aging and degradation** research develops the scientific basis for understanding and predicting long-term environmental degradation behavior of performance. Key university research needs in this area include 1) evaluation of flux effects and high fluence degradation of reactor pressure vessels, 2) development of capabilities to evaluate concrete performance, and 3) development of a mechanistic understanding of embrittlement via microstructural instability in high fluence austenitic steels.

- **Advanced LWR nuclear fuel development** research is focused on understanding the fundamentals of fuel and cladding behavior and applies this knowledge to the development of high-performance fuels. Key university research needs in this area include 1) design of advanced fuels and claddings, 2) monitoring of their behavior, and 3) improvements of LWR fuels modeling capabilities.
- **Advanced instrumentation, control, and information systems technologies** research is focused on developing capabilities to assess the aging of structures, systems, and components of nuclear power plants. Key university research needs are identified as the development of digital instrumentation and control technologies for improved monitoring and reliability.
- **Risk-informed safety margin characterization** research is focused on developing risk-informed, performance-based methodologies for assessing safety margins. Key university research needs involve the identification and resolution of gaps in the risk informed safety margin characterization methodology.

Appendix A

Work Scope Descriptions

Index for Work Scope Descriptions

Technical Focus Areas	
Section 1	**Fuels**: Performs research and development on fuel systems and fabrication processes to achieve multifold improvements in fuel and fabrication process performance. (This focus area addresses needs in FCR&D, GEN IV, and LWRS.)
Section 2	**Reactors:** Performs research and development on reactor concepts focused on developing advanced reactor, energy conversion and transmutation technologies. (This focus area addresses needs in FCR&D and GEN IV and incorporates Transmutation and Energy Conversion topics.)
Section 3	**Separations and Wastes:** Performs research and development on the next generation of fuel cycle separation and waste management technologies that enable a sustainable fuel cycle with minimal processing, waste generation and potential for material diversion. (This focus area addresses needs primarily in FCR&D.)
Cross-Cut Areas	
Section 4	**Materials:** Provide transformational materials to enable revolutionary improvements in fuels, structural materials and understand the degradation of these and current materials under a variety of fluence conditions.
Section 5	**Modeling and Simulation:** Provide science-based, verified and validated modeling and simulation capabilities essential for the design, implementation and operation of nuclear energy systems with the goal of improving U.S. energy security.
Section 6	**Nuclear Instrumentation and Control:** Provide sensors and processing systems that are capable of measuring temperatures, flux levels, pressures and flows in reactors including high temperature and other extreme environmental conditions. Provide instrumentation to support the detection of diversion. Provide measurement techniques and detectors that improve or complement existing measurement capabilities for the neutron spectrum or fission multiplicity.
Section 7	**Proliferation Resistance and Safeguards:** Provide materials protection, accountability and control for the development of technologies and analysis tools to enable next generation nuclear materials management to prevent diversion or misuse within future U.S. nuclear fuel cycles thereby reducing proliferation risks and enhancing confidence and acceptance of nuclear energy.
Section 8	**Licensing and Safety:** Provide support for rigorous licensing requirements and enable the safe and successful operation of reactors and all fuel cycle related facilities.
Section 9	**Systems Analysis:** Provide high-level systematic assessment of nuclear technology and deployment options to guide and confirm program decisions. Key factors contributing to overall programmatic schedule, cost, and risk will be identified and quantified.
Other	
Section 10	**Mission Relevant Investigator Initiated Research**: Nuclear energy mission relevant, creative, innovative, and "blue sky" research.

Table 1. Work Scope Descriptions

Section 1. Fuels Focus Area			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Fuels	FCF-1	*Advanced Fuel Design* - This element is primarily focused on design of innovative fuels and target forms for advanced reactors. The objective is to come up with fuel designs that can achieve higher performance requirements and multi-fold increases in burn-up than yet achieved, including the associated fabrication processes. The processes needed to fabricate the proposed fuel types are also within the scope of this program element. The university shall provide an advanced fuel design study (including fabrication process design) at the completion of this project.
GEN IV	Gen IV Fuels	G4F-1	TRISO-coated particle fuel is a robust fuel form with high fission product retentiveness. Experimental and theoretical approaches that establish credible fission product transport mechanisms to support the development of a mechanistic source term for VHTRs under normal, accident and off-normal conditions, including both air and/or moisture ingress events, are required. Specifically, (a) first principles computer models (kmc, atomistic) for fission product transport (Ag Cs, I, Te, Eu, Sr) through the TRISO particle SiC layer and graphitic material (fuel pyrolytic carbon, fuel matrix and core graphite) and (b) studies of fission product/ZrC interactions for key fission products of interest (Ag Cs, I, Te, Eu, Sr).
GEN IV	Gen IV Fuels	G4F-2	Key safety functions for VHTRs designed for process heat applications are control for external oxidants (air and moisture). Mechanistic computer models are needed to improve the current empirical understanding of the influence of air and moisture ingress on fission product transport in TRISO particle pyrolytic graphite and graphite block or pebble outer graphite layer.
GEN IV	Gen IV Fuels	G4F-3	A deep-burn VHTR has as its goal the development of a high burnup TRISO-like fuel particle to support transmutation missions. Proposals are sought in the following areas: (a) innovative deep-burn TRISO fuel particle designs (e.g., TRIZO, TRIZO*, dispersed burnable absorbers or fission product getter materials); (b) studies of the associated performance of the innovative fuel designs; (c) studies of fission product/ZrC interactions; and (d) characterization of thermomechanical and thermophysical properties of ZrC (both unirradiated and irradiated), a potential candidate material to replace SiC in the coated particle.

Section 1. Fuels Focus Area			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
LWRS	LWR Sustainability	LWS-5	*Advanced Designs and Concepts for Fuel and Cladding* - The purpose of this task area is to increase the understanding of advanced fuel design concepts, including the use of new cladding materials; to increase fuel lifetime; and to expand the allowable fuel performance envelope. These improvements will then allow the fuel performance related plant operating limits to be optimized in areas such as operating temperatures, power densities, power ramp rates, and coolant chemistry (CC). Accomplishing these goals leads to improvement of operating safety margins and improved economic benefits. R&D in this area should include the development of specific technologies for advanced nuclear fuels and the benchmarking and test activities for the developed computer models. This task consists of testing advanced fuel designs and features in prototype forms. The goal is to demonstrate design features that can be utilized in advanced nuclear fuels. The benchmarking is intended to provide confidence in the derived computer models and to make accurate applications possible. Universities performing this research will be expected to produce results that integrate multiple mechanistic processes and will have to work closely with the LWRS Program Office.

Section 2. Reactors Focus Area (Including Transmutation and Energy Conversion)			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Nuclear Physics and Theory Development	FCN-3	*Revolutionary Transmutation Concepts* – Investigate innovative methods for fission product transmutation. Nuclear physics may be able to play a role in the reduction of highly radioactive waste by transmutation or other means. Novel methods are being sought to help minimize the heat load from fission products in separated, processed waste. Such methods could include techniques other than neutron irradiation. University teams will need to propose and study methods for nuclear transmutation of fission products in conjunction with the FCR&D nuclear physics team.
GEN IV	Gen IV Advanced Reactor Concepts: Advanced High Temperature Reactor	G4B-1	Advanced high-temperature reactors combine the coated particle fuel and graphite moderator of the VHTR with a liquid fluoride salt as a coolant. R&D activities are focused on establishing the concept's viability and selecting promising technologies. A key difference between salt and helium cooling is considerable increase in the heat transfer rate out of the fuel allowing for a 4-8x increase in power density which translates into higher cycle efficiency and smaller cores for modular fabrication. The higher density also places much greater demands on TRISO fuel performance. Research is needed to compare AHTR and VHTR coated particle fuel design requirements and to develop and test high flux, high power fuel.
GEN IV	Gen IV Advanced Reactor Concepts: Advanced High Temperature Reactor	G4B-2	Advanced high-temperature reactors combine the coated particle fuel and graphite moderator of the VHTR with a liquid fluoride salt as a coolant. R&D activities are focused on establishing the concept's viability and selecting promising technologies. A key viability engineering issue for the system is valves. Liquid salt mechanical valves do not currently exist for AHTR conditions. Candidate valve design, development, and testing are required.

Section 2. Reactors Focus Area (Including Transmutation and Energy Conversion)			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4H-1	Supercritical CO_2 shows promise as a working fluid suitable for fast and thermal reactors because of its compatibility with materials and thermodynamic properties. Basic R&D is needed in turbomachinery performance and loss mechanisms in reactors. Development and testing of computer models for supercritical CO_2 Brayton cycle energy technologies is sought. For new energy conversion technology, system optimization requires a detailed modeling of the system components and their response to steady-state and off-normal conditions. The university participants could contribute detailed CFD modeling of key components, such as the main compressor, for comparison to one-dimensional system level models and experimental data from ongoing small-scale testing. Alternately, contributions could be made to the development of plant dynamics models and control strategies, including the investigation of alternative cycle layouts (e.g., having turbomachinery on multiple shafts). The efficiency of different power conversion cycles is degraded by leaks at component interfaces. R&D is needed to develop models and/or test beds to predict the performance of seals (labyrinth, dry liftoff seal, brush, etc.) and bearings. The economics of different power conversion cycles is a strong function of turbomachinery efficiency and durability. R&D is needed to develop models for turbomachinery bearings (gas foil, magnetic, and hydrodynamic) and S-CO_2 windage loss.
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4H-3	The VHTR is well suited for the co-generation of process heat and electricity and for the production of hydrogen from water for industrial applications in the chemical and petrochemical sectors. A mature infrastructure exists for using and transporting transportation and heating fuels. With the VHTR/HTGR as a source of process heat, optimization of VHTR for heat process applications is required. Development of approaches to coupling of the heat source with the wide variety of process heat applications (co-generation, coal-to-liquids, chemical feedstocks) is sought with an emphasis on novel approaches that can greatly improve the ease of coupling, the operability of the combined system, and the ultimate economics.

Section 2. Reactors Focus Area (Including Transmutation and Energy Conversion)			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV SMR	G4S-1	Development of new concepts that utilize advanced technologies or innovative engineering is sought and should be viable for commercial deployment by as early as 2018, but no later than 2030. The scope of the proposed project should include a thorough viability assessment of the concept, a detailed technology gap analysis, and a comprehensive technology development roadmap.
GEN IV	Gen IV Thermal Transmutation Systems	G4T-1	Studies are requested to explore the potential for transmutation in thermal reactor systems, especially VHTRs, to compliment the VHTR deep burn program element. Proposals are sought to (a) explore the fuel/core designs in these systems that maximize plutonium and minor actinide destruction while retaining passive safety and improving the fuel economy, and proliferation resistance; and (b) examine novel thorium-fueled cycles that minimize the need for isotope separation/recycling yet develop mitigation strategies for the gamma dose from U-233.

Section 3. Separations and Waste Focus Area			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Separations & Waste Forms	FCS-1	Investigate fundamental interfacial electrochemistry of actinides and fission product elements important in the fuel treatment process; for example, determination of thermodynamic properties in process relevant molten salts (e.g., LiCl, LiCl-KCl) or characterization of kinetics and mass transport properties of important species in process relevant molten salts. Collection of fundamental data to support better data and understanding of electrochemical separation methods is needed. Investigate alternate aqueous and dry processes, including those based on volatility and ionic liquids. Apply modeling and simulation to the identification of alternate ligands for solvent extraction applications.
FCR&D	FCR&D Separations & Waste Forms	FCS-2	Develop new and innovative methods for the capture and immobilization of volatile fission products (iodine, tritium, krypton, and carbon-14) from used nuclear fuel off-gas (during shearing and dissolution). New adsorbents or separation technology for isolating and concentrating captured volatile off-gas species. Report describing technical results and efficacy of new technology.
FCR&D	FCR&D Separations & Waste Forms	FCS-3	Develop novel separations methods for gas reactor (SiC or TRISO) fuels; investigate transformational separations technologies; or develop a fundamental understanding of An(III) separation from Ln(III) elements. Investigate advanced methods of exposing the actinide content of TRISO fuel kernels to chemical treatment.
FCR&D	FCR&D Separations & Waste Forms	FCS-4	Develop a fundamental understanding of waste form stability over geologic time scales, including effects of various stresses—elevated temperature, the decay of radionuclides into other elements, high radiation fields, and other varying environmental conditions—leading to the prediction of radionuclide release over millennia. The focus of this work scope is on engineered waste form performance.
FCR&D	FCR&D Separations & Waste Forms	FCS-5	Develop and test next generation of nuclear waste forms capable of radionuclide immobilization, with simple remote fabrication capability and predictable performance. Evaluate the recycle of commercially valuable components of used nuclear fuel.

Section 3. Separations and Waste Focus Area			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Used Nuclear Fuel Disposition	FCD-1	Develop innovative used fuel and nuclear waste interim storage concepts capable of at least 100 years duration. Include multi-year test plans followed by reports describing technical results and efficacy of new technologies.
FCR&D	FCR&D Used Nuclear Fuel Disposition	FCD-2	Development of advanced methods for evaluation of the performance of waste disposal forms—in a variety of geologic media and over geologic time scales—of used nuclear fuel and specific waste forms for fission products, including iodine, krypton, tritium, and carbon-14. The focus of this work scope is on geologic repository performance.

Section 4. Materials Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Fuels	FCF-3	*Characterization Equipment* – This element is focused on developing advanced characterization equipment that can be used with fuel samples (fresh and irradiated) where various thermal-mechanical properties of interest can be measured at micron scale (or lower-scale). The proposal may include modification to already existing equipment to enhance radiation tolerance or lower the length-scale of the measurement domain, as well as design of innovative concepts tailored for nuclear fuel applications. The university shall provide a prototype design tested with surrogate materials at the completion of this project.
FCR&D	FCR&D Used Nuclear Fuel Disposition	FCD-3	Develop advanced engineering materials for use in waste packages in a variety of geologic media. Include multi-year test plans followed by reports describing tests and results of technical evaluations. Reports describing how engineered barriers survive various geologic environments.
FCR&D	FCR&D Materials	FCM-1	Develop advanced alloys or composites that can sustain multi-fold higher fluences. These alloys and composites are envisioned for use as reactor structural materials.

Section 4. Materials Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Materials	FCM-2	*Aging and Stability Testing and Lifetime Modeling* – The microstructural stability of advanced structural materials must be validated at elevated temperatures and extended lifetimes. This requires specific testing of the candidate alloys under the anticipated operating characteristics and the development of semi-empirical modeling of fast reactor structural material aging and irradiation degradation mechanisms. Existing facilities should be able to perform this testing protocol. The university team will perform thermal aging and stability tests. These tests will assess the candidate alloys and be closely coordinated with the advanced alloy development. The university team will develop a structural material lifetime model and create a predictive computer code. This model will be extensively validated by comparison to existing reactor operating data and existing materials test. This model will capture fluence and temperature effects, but is not anticipated to be atomic level detail. Proposals may address the testing or modeling portion of this need or they may address both.
GEN IV	GEN IV Advanced Reactor Concepts: Advanced High Temperature Reactor	G4B-3	Advanced high-temperature reactors combine the coated particle fuel and graphite moderator of the VHTR with a liquid fluoride salt as a coolant. R&D activities are focused on establishing the concept's viability and selecting promising technologies. Structural materials (alloys) compatible with liquid fluoride salts need to be qualified. Currently, the most promising structural material approach for AHTRs is to clad alloys qualified under the VHTR program (Alloy 800H or 617) with nickel. Molybdenum alloys are also chemically compatible with fluoride salts above 1,000°C. A significant amount of information on MSR salt chemistry and its impact on metallic corrosion is available from both the MSRE and more recent development activities. Proposals are sought in the areas of (a) development and demonstration of materials technology for cladding shaped and joined structures, (b) multi-component, dynamic fluoride computational chemical analysis to improve the understanding of corrosion in this complex system, and (c) new methods of analyzing fluoride salt chemistry and salt purification systems.

Section 4. Materials Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4A-1	High temperature materials are required to accommodate the high helium outlet temperatures in a VHTR that is needed for process heat and hydrogen production. Aging and environmental effects are required to fully characterize the behavior of these alloys in VHTRs. Experiments are sought that will help elucidate mechanisms of environmental embrittlement of candidate high temperature alloys. Alternatives to chromia forming alloys are also sought for high temperature environments. Methods are needed for accelerated testing/simulation of very long term aging behavior. Materials/approaches also are sought to improve the resistance of protective oxides to thermal cycling/high velocity gas/particulate erosion
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4A-2	For pressure vessel steels to be used in VHTRs, experimental, calculational, and NDE methods are needed to characterize negligible creep in pressure vessel steels. NDE methods are sought to characterize microstructures in heavy section ferritic-martensitic steels. Methods for modifying and controlling pressure vessel emissivity are required. In the longer term, evaluations of more advanced high temperature, high strength metals (steels, alloys) for VHTR reactor pressure vessel applications that are robust, reliable, cost-effective, and amenable for modular multiple manufacturing techniques (including ring forging, field welding/joining, and heat treatment) are sought. The development and characterization of advanced joining techniques for ODS alloys, ferritic-martensitic steels, or advanced austenitics are also welcome.
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4A-3	High temperature materials are required to accommodate the high helium outlet temperatures in a VHTR that is needed for process heat and hydrogen production. Mechanical properties of Ni based alloys are under consideration. Experiments are sought to better understand the mechanisms of dynamic strain aging in high temperature alloys and the mechanisms of strain localization and creep cavitations in high temperature materials. New strategies are required for creep resistant alloys at 1,000°C and above. Proposals that establish microstructure/properties/processing relationships in diffusion bonding and brazing Ni-based alloys are also welcome. Constitutive models need to be developed for creep-fatigue of Ni based alloys

Section 4. Materials Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4A-4	Graphite is the structural material for VHTRs. As such, *in situ* NDE is required to characterize and/or verify its structural adequacy. Proposals are sought that will develop NDE techniques viable for 1) detecting disparate flaws such as voids, large inclusions, and large crack in large graphite components or billets; 2) degradation of thermal properties (i.e. conductivity/resistivity) and stress build-up in graphite; and 3) detecting fiber damage or fiber/matrix damage within composites.
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4A-5	Composites are under consideration for use in high temperature locations in VHTRs. Experiments are sought to measure creep rupture properties of nuclear grade composite and composite joint structures. Long-term effects of the nuclear environment on the thermal barrier integrity of fibrous insulation materials are also of interest. Proposals that focus on the development of irradiation resistant, continuous fiber reinforced composites (SiC/ SiC, ceramic and Carbon-based) are also welcome.
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4A-6	For ceramics to be used in HTGRs, improvements in analytic models to describe performance, degradation, and failure are required. Areas of interest include the following: • Simulation of the maturation of defect structures in graphite crystalline grains and bulk material strain, stress, and creep effects, including neutron cascading, graphite growth, and shrinkage • Benchmark modeling microstructure effects against experimentally verified results of highly penetrating ion irradiation damage • Failure prediction methodologies for composite materials under impure helium environments and irradiation, including SiC/SiC composites, under oxidative attack, irradiation-induced creep, and progressive load shifting with crack propagation • Determination of SiC and carbon fiber composite dimensional stability, anisotropic dimensional changes, and fiber and matrix integrity, in terms of effective composite lifetime, and failure modes

Section 4. Materials Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	GENIV Fast Reactors	G4L-1	The microstructure stability of advanced structural materials must be validated for fast reactors at elevated temperatures and extended lifetimes. Semi-empirical modeling of fast reactor structural material aging and irradiation degradation mechanisms need to be developed to predict high neutron fluence and temperature effects and bulk/macrostructural mechanical properties, including yield strength, creep, fatigue, ductility, etc., as a function of time, temperature, irradiation damage, and pressure history. Validation and verification of the micro-structural stability of advanced structural materials operating at high temperature, high neutron damage conditions for extended operating lifetimes for anticipated fast reactor operating conditions.
GEN IV	GENIV Fast Reactors	G4L-2	A supercritical CO_2 cycle is under consideration as part of the power conversion system in a fast reactor system. Experiments to study corrosion chemistry and establish the performance limits of candidate metallic alloys in CO_2 are needed.
	LWR Sustainability	LWS-1	Evaluation of flux effects and high fluence degradation of reactor pressure vessel (RPV) steels. Evaluating high fluence effects (embrittlement and/or late blooming phases) is essential in ensuring reactor pressure vessel integrity for operation beyond 60 years. Evaluation of high fluence specimens (from past industrial capsules or campaigns) and single variable experiments may be required to evaluate the potential for embrittlement and to provide a better mechanistic understanding of this form of degradation. Testing may include impact and fracture toughness evaluations, hardness, and microstructural analysis. Modeling of microstructural changes and mechanical performance is also an important need. New methods to generate meaningful data out of previously-tested RPV specimens are needed. Alternative methods for surveillance testing should also be evaluated. Methods for modifying activated RPV specimens currently located ex-core to extract smaller samples, keeping remaining coupon pieces in service, are encouraged. Universities engaging in this effort will be expected to produce data or mechanistic modeling to help reduce the uncertainty associated with the long-term aging of reactor pressure vessel steels.

Section 4. Materials Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
	LWR Sustainability	LWS-2	Analysis of concrete performance in LWR applications – universities engaging in this effort will be expected to produce data or mechanistic modeling to help reduce the uncertainty associated with the long-term aging and performance of concrete. The long-term stability and performance of concrete structures within a nuclear power plant is a concern because there is little operational data or experience to inform relicensing decisions. The collection of samples from aging (or decommissioned) plants or other nuclear facilities will provide valuable information on the long-term performance of aging nuclear power plant structures. The interface between concrete structures and metal components is also of high technical interest. This work will support the LWRS program strategic goals by providing key data and mechanistic understanding on concrete degradation phenomena that may occur based on current knowledge. A more complete mechanistic understanding of this degradation mode will be critical to reducing uncertainty and providing reliable long-term predictions for this irreplaceable reactor component.
	LWR Sustainability	LWS-3	Mechanistic understanding of embrittlement via microstructural instability (phase transformations) in high fluence austenitic stainless steel components – a predictive model will provide insight into embrittlement caused by microstructural changes. The relationship among microstructure, hardening, and embrittlement must also be explored. This work will support the LWRS program strategic goals by providing key data and mechanistic understanding of irradiation-induced effects, which are expected to become more severe with extended service beyond 60 years of lifetime. This work also provides data and a mechanistic understanding to enhance the current state of knowledge of irradiation-induced embrittlement and inform life extension decision processes. Universities engaging in this effort will be expected to produce data or mechanistic modeling to help reduce the uncertainty associated with the long-term irradiation of nuclear reactor core-internals.

Section 5. Modeling and Simulation/Methods and Data Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Modeling and Simulation	FCMS-1	Development of multi-scale, multi-physics models for characterization of complex microstructural and thermomechanical phenomena pertinent to advanced fuels, waste forms, and geological environments.
FCR&D	FCR&D Modeling and Simulation	FCMS-2	Improvement of tools and framework to promote high-fidelity reactor modeling, including neutronics, structural dynamics, and thermo-hydraulics.
FCR&D	FCR&D Modeling and Simulation	FCMS-3	Creation of methods and tools that will allow first principal simulation results, done at lower length scales (e.g. atomistic), to be coupled to higher level continuum-performance simulations at larger length and time scales. These methods and tools must be usable on advanced computational platforms.
FCR&D	FCR&D Modeling and Simulation	FCMS-4	Development of novel techniques for robust validation/verification and uncertainty quantification of advanced simulation tools leading to better defined confidence margins.
FCR&D	FCR&D Nuclear Physics and Theory Development	FCN-1	*Nuclear Theory and Modeling* – university teams will perform a systematic evaluation of how advanced measurement techniques can be used to help guide improved nuclear theory and theory, resulting in a strategic plan at the end of the first year. The following years will focus on nuclear model development with periodic reporting on validation and cross-section evaluation studies. The investments made in nuclear experiments can only be fully realized when evaluated in a more comprehensive theoretical treatment. This research topic will develop the capability to perform inclusive multi-channel nuclear physics evaluations, capable of delivering inter-reaction covariance data as a function of incident neutron energy. Improved nuclear models will be developed and validated in collaboration with the FCR&D nuclear physics team. In addition, these models will be employed to evaluate and construct new data sets for key fuel cycle nuclides.
GEN IV	Gen IV Heat Transport, Energy Conversion, Nuclear Heat Applications	G4H-2	AHTRs and liquid metal systems rely on direct reactor auxiliary cooling as part of the ultimate heat sink in their design. Given the importance of this system to the overall safety of these concepts, proposals are sought that would design, simulate, and demonstrate the performance of these systems under prototypic conditions

Section 5. Modeling and Simulation/Methods and Data Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV Methods (NGNP): Design and Analysis Methods for High Temperature Reactors and Coupled Process Heat Plant Dynamics	G4M-1	The VHTR is well suited for the co-generation of process heat and electricity and for the production of hydrogen from water for industrial applications in the chemical and petrochemical sectors. The understanding of the implications of coupling the VHTR to the industrial process is lacking. Analysis of the dynamic (coupled) simulation of reactor-driven process heat plants, including load matching and rejection, process upsets, and use of multiple modules is requested
GEN IV	Gen IV Methods (NGNP): Design and Analysis Methods for High Temperature Reactors and Coupled Process Heat Plant Dynamics	G4M-2	The neutronic behavior of current annular VHTR cores is different from LWRs and fast reactors. Methods for efficient coupling of assembly and core simulator codes is needed for optically thin cores. Methods that account for burnable poisons and control rods is needed in nodal kinetics codes for prismatic VHTRs. Fuel management techniques (i.e., block/fuel placement and core loading/refueling strategies) and fuel cycle optimization (i.e. fissile fertile, burnable poison loading, uranium utilization, transuranic fuel consumption) approaches for prismatic VHTR cores need to be developed. New approaches are also sought to neutron slowing-down, resonance region interactions, and neutron upscatter in reactors. Cross-section measurement and validation in isotopes prominent in high burnup fuels are also needed.
GEN IV	Gen IV Methods (NGNP): Design and Analysis Methods for High Temperature Reactors and Coupled Process Heat Plant Dynamics	G4M-3	There are very few high fidelity system level analyses of VHTRs to understand, at a more detailed level, some of the more complex transients in VHTRs. High resolution, time-dependent multiphysics analysis of pipe breaks in VHTRs that account for helium blowdown, water ingress, and fission product/dust transport are sought to better understand phenomena that occur in these events.

Section 5. Modeling and Simulation/Methods and Data Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV Methods (NGNP): Design and Analysis Methods for High Temperature Reactors and Coupled Process Heat Plant Dynamics	G4M-5	Scaled thermal hydraulic experiments will be performed to provide experimental validation of important accidents in scenarios in a VHTR as required for licensing. As part of these experiments, proposals are sought to support scaling, experimental design, and fundamental phenomena identification for core/vessel behavior in depressurized and pressurized conduction cooldown scenarios, performance of the VHTR reactor cavity cooling system, mixing in the lower plenum, heat transfer in the core and the associated core bypass flows under normal operation, natural circulation in the reactor under pressurized conduction cooldown conditions, and air ingress events.
	LWR Sustainability	LWS-6	*Fuels Modeling Efforts* – central to the advanced LWR nuclear fuel development R&D pathway is the development and use of fuel performance models, which is key to the success of other program elements such as fission gas release and swelling, CC accelerated corrosion and crud deposition, and PCI. This program element should lead to developing high fidelity models and interfaces between neutronics, thermal hydraulics, fluid dynamics, and CC. Development of these models should be adaptable to complicated design geometry such as part-length rods, different rod lengths, and impact of increased power and flow uncertainties. Three-dimensional models should also be developed with equivalent spatial and temporal resolution and expandability of current 2-D models. The high fidelity modeling should include material behavior (constitutive) models and numerics for multiple special geometries (2-D r-z + r-theta with materials modeling and axial splicing/interaction). To ensure modeling efforts benefit all users from industry, academia, national laboratories, and the DOE, data and code should be publicly available, provide code portability using simplified subroutines for higher-length scale codes, and define inputs and outputs of each length-scale modeling tool. Universities engaging in this effort will be expected to produce data or mechanistic modeling to help reduce the uncertainty associated with the long-term aging of reactor pressure vessel steels.

Section 6. Proliferation Resistance & Safeguards Cross Cut			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D MPACT	FCP-1	New sensor materials and measurement techniques for nuclear materials control and accountability (including process monitoring) are needed. This task includes development, design, and testing of devices with increasing sensitivity, resolution, radiation hardness, and lowered cost of manufacture. Areas of interest include 1) sensors based on radiation detection; 2) sensors based on other detection methods (such as optical or thermal, etc.) techniques; 3) new active interrogation methods, including basic nuclear data (neutron and photo fission, nuclear resonance fluorescence); and 4) non-radiation based techniques such as stimulated Raman, laser-induced breakdown spectroscopy, fluorescence, etc.
FCR&D	FCR&D MPACT	FCP-2	Need to develop new methods for data validation and security data integration, and real-time analysis with defense-in-depth and knowledge development for the facility operations under normal and off-normal conditions: 1) information validation and security; 2) quantitative integration of disparate data; and 3) real-time analysis, review, and notification.
FCR&D	FCR&D MPACT	FCP-4	*Proliferation Risk Assessment* – Proliferation "resistance," and associated proliferation risk, is a concept that expresses the relative measure of the confidence that nuclear material or technology cannot be easily misused. An opportunity exists to integrate across traditional boundaries to achieve major advances in capabilities to develop and conduct proliferation risk assessments and subsequently optimize advanced nuclear energy systems from a proliferation risk reduction perspective. The ultimate goal of this effort will be to develop and use new analytical tools that could revolutionize our ability to compare the proliferation risk of nuclear energy systems in a way that is comprehensive and communicable. For such tools to be comprehensive, they should include professional socio-political analyses that open an avenue to study the reasons for public concern, and the effect of public perception on the viability of advanced nuclear fuel cycles. The universities will define, develop, and demonstrate a multi-faceted risk assessment approach for evaluating the proliferation risks and sociological factors associated with the nuclear fuel cycle.

Section 7. Instrumentation			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	FCR&D Fuels	FCF-2	*In Situ Instrumentation* – This element is focused on innovative *in situ* instrumentation design that can provide data during in-pile testing of fuels. Different phenomena in the fuel occur at different time-scales and the scope include instrumentation that can provide data on property changes in the earlier phase of irradiation as well as at later stages of burn-up. The university shall provide an advanced instrumentation prototype with complete laboratory testing at the completion of this project.
FCR&D	FCR&D MPACT	FCP-3	Develop online, real-time, continuous accountability instruments and techniques that support the challenge of permitting significant improvements in the ability to inventory fissile materials in domestic fuel cycle systems in order to detect diversion and prevent misuse.
FCR&D	FCR&D Nuclear Physics and Theory Development	FCN-2	*Improved Measurement Techniques* – This research topic will pursue advanced measurement techniques that could complement ongoing measurements. In particular, fission multiplicity and fission neutron spectrum measurements as a function of incident neutron energy have been identified as important data in recent sensitivity analyses. Innovative ideas for detector development and testing are needed to facilitate the high fidelity requirements of the FCR&D effort. University teams will develop new measurement systems to address the data needs noted above. Candidate systems will be reviewed and refined in conjunction with the FCR&D nuclear physics team. The following years will focus on construction and testing of a prototype device.
GEN IV	GEN IV Advanced Reactor Concepts: Advanced High Temperature Reactor	G4B-4	Advanced high-temperature reactors combine the coated particle fuel and graphite moderator of the VHTR with a liquid fluoride salt as a coolant. R&D activities are focused on establishing the concept's viability and selecting promising technologies. Few existing instruments will perform under the high-temperature liquid fluoride salt environment. Research and development of salt-wetted instrumentation for both operations (high accuracy temperature, flow, and neutron flux) and maintenance is required.

Section 7. Instrumentation			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
GEN IV	Gen IV Methods (NGNP): Design and Analysis Methods for High Temperature Reactors and Coupled Process Heat Plant Dynamics	G4M-4	This research area will pursue advanced techniques for measuring VHTR/HTGR core temperature and flux, especially for recirculating pebble bed reactors.
	LWR Sustainability	LWS-4	*Advanced Online Monitoring Survey* – The research will focus on NDE methods that will provide techniques to examine, or monitor in real time, those effects being studied in the advanced nuclear fuels pathway, including fission gas release and transport, pellet-clad interaction, cladding oxidation, crud formation, corrosion, hydrogen embrittlement, and failure. This research will develop inspection capabilities for reactor monitoring. The ability to monitor aspects of ductility loss in used fuel cladding while in storage is an example of this program element. Universities performing this research will be expected to produce results that integrate multiple mechanistic processes.

Section 7. Instrumentation			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
	LWR Sustainability	LWS-8	Digital instrumentation and control technologies for improved monitoring and reliability. Research is needed to improve upon available methods for online monitoring of nuclear plant systems, including physical structures that are critical to safety, as well as control system reliability. Research should investigate the use of advanced prognostic technologies for monitoring and predicting system health and performance, as well as methods needed to analyze the reliability of integrated hardware/software technologies that comprise digital systems. High priority research areas include the following: 1) prognostic methods that can be deployed for monitoring nuclear plant systems, structures, and components, and that can be demonstrated in test bed environments representative of nuclear plant applications; and 2) methods for analyzing the dynamic reliability of digital systems, including hardware and software systems based on formal methods that can be demonstrated on systems that are proposed or representative of systems proposed for nuclear plant control and automation. This research is expected to support the development of methods and technologies to support digital instrumentation and control integration for monitoring and control as well as for noting areas of improved reliability and areas requiring further information and research. Universities performing this research will be expected to produce results that integrate multiple mechanistic processes.

Section 8. Licensing and Safety			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
	LWR Sustainability	LWS-7	R&D should address the Risk-Informed Safety Margin Characterization (RISMC) methodology and capability gaps in probabilistic risk analysis (PRA) and deterministic safety analysis to enable effective implementation of RISMC in practice. Areas of high priority include the following: 1) a comprehensive methodology to characterize nuclear power plant safety margins in the risk-informed framework and determine how these margins could change over the plant extended operation; 2) effective techniques for dynamic PRA and inclusion of reliability of passive systems and components; and 3) advanced modeling and simulation methods to support the development, verification, and validation of next-generation system safety codes that enable the nuclear power industry to perform analysis of a nuclear power plant's transients and accidents with a high degree of confidence. Universities performing this research will be expected to produce results that integrate multiple mechanistic processes.

Section 9. Systems Analysis			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
FCR&D	Systems Analysis	FCSA-1	Development of science-based metrics – The metrics currently used in the program include things such as fuel cycle cost, waste volume, radiotoxicity, and decay heat. These metrics have been used to develop system level requirements, however for the most part, they do not have a scientific basis and do not enable comparison across energy options. In addition to individual metrics, an aggregate fuel cycle "indicator" is desired that combines the individual metrics.

Section 10. Mission-Relevant Investigator-Initiated Research			
Program	**Campaign**	**Work Scope ID. No.**	**Work Scope Description**
All	N/A	MR-IIR	Nuclear energy mission relevant, creative, innovative, and "blue sky" research. This area includes research in the fields or disciplines of nuclear science and engineering such as, but not limited to, Nuclear Engineering, Nuclear Physics, Health Physics, Nuclear Materials Science, Radiochemistry or Nuclear Chemistry that are relevant to NE's mission though may not fully align with the specific initiatives and programs identified in this solicitation. Examples of topics of interest are new reactor designs and technologies; advanced fuel cycles, including advanced nuclear fuels; alternate aqueous and dry processes, including volatility and ionic liquids; instrumentation and control/human factors; radiochemistry; and fundamental nuclear science.

Appendix B

Program Contacts

Table 2. Technical Program Contacts

Program	Contact	Email Address	Telephone Number
Fuel Cycle R&D	Program Website	https://inlportal.inl.gov/portal/server.pt?open=514&objID=1358&parentname=CommunityPage&parentid=3&mode=2&in_hi_userid=2&cached=true	
Separations and Waste Forms	Terry Todd	terry.todd@inl.gov	208 526-3365
Advanced Fuels	Kemal Pasamehmetoglu	kemal.pasamehmetoglu@inl.gov	208 526-5305
Transmutation Technologies	Robert Hill	bobhill@anl.gov	630 252-4865
Materials Protection, Accountability, and Control	Mark Mullen	mmullen@lanl.gov	505 665-0312
Modeling & Simulation	Andrew Siegel	siegela@mcs.anl.gov	630 252-1758
Used Fuel Disposition	Mark Peters	mtpeters@anl.gov	630 252-6511
Safety and Regulatory	John Kelly	jekelly@sandia.gov	505 844-8993
Nuclear Physics Data	Tony Hill	tony.hill@inl.gov	208 526-9366
Materials	Jeremy Busby	busbyjt@ornl.gov	865 241-4622
Gen IV	Program Website	http://www.nextgenerationnuclearplant.com/	
Very High Temperature Reactor	Dave Petti	David.Petti@inl.gov	208 526-7735
Other Advanced Reactors	Dan Ingersoll	ingersolldt@inl.gov	865 574-6102
Light Water Reactor Sustainability	Program Website	https://inlportal.inl.gov/portal/server.pt?open=512&objID=442&mode=2&	
	Ronaldo Szilard	Ronaldo.szilard@inl.gov	208 526-8376