Nuclear Energy Research and Development Cooperative Action Plan

Between

The Department of Energy of the United States of America

And

The Department for Business, Energy, and Industrial Strategy of the United Kingdom of Great Britain and Northern Ireland

The Department of Energy of the United States of America (DOE) and the Department for Business, Energy, and Industrial Strategy of the United Kingdom of Great Britain and Northern Ireland (BEIS), hereinafter the "Participants";

RECOGNISING the important role civilian nuclear energy serves now, and the role it will serve in the future, to meet the ever-increasing global demands for low carbon energy;

DESIRING to facilitate cooperation in the field of research and development for the peaceful uses of civil nuclear energy;

NOTING the Statement of Intent between the Participants on Collaboration in Civilian Nuclear Energy of May 13, 2014, which envisioned cooperation in the area of civil nuclear energy research and development (R&D) on a wide range of technologies, including fuel cycle technologies, advanced reactor and radioisotope technologies, modeling and simulation tools, preservation of technical information and research resources, and other studies of interest;

ACKNOWLEDGING the Agreement between the Government of the United States of America and the Government of the United Kingdom of Great Britain and Northern Ireland on Scientific and Technological Cooperation of September 20, 2017 (the "S&T Agreement");

RECOGNISING the Participants' joint efforts toward development of an implementing agreement for R&D in energy and science related fields, under the S&T Agreement,

Have reached the following understanding:

1. Purpose

1. To ensure nuclear energy's contribution to both countries' strategic energy resources, low-carbon emission and non-proliferation goals, and nuclear safety objectives, a variety of approaches and technical pathways are needed to achieve optimal development of civil nuclear technologies over the long-term. Recognizing the value of bilateral cooperation, this Action Plan seeks to facilitate planned cooperation in R&D of advanced civilian nuclear energy technologies between the Participants.

2. This Action Plan is intended to complement, but not to replace, consultations and collaboration under existing agreements or the implementation of other international cooperation and programmatic civil nuclear activities of either Participant.

3. Execution of planned cooperation under this Action Plan is expected to result in substantive near-term engagement with positive impacts for the nuclear energy visions of each country, while at the same time laying the groundwork for long-term and more comprehensive cooperation.

2. Areas of Cooperation

1. The areas of planned cooperation under this Action Plan may include:
    - A. Radioisotopes for use in space technologies,
    - B. Nuclear reactor technologies,
    - C. Advanced fuels,
    - D. Fuel cycle technologies,
    - E. Advanced modeling and simulation, and
    - F. Enabling technologies.

2. Further detail on these areas and planned forms of cooperation is specified in Annex 1 to this Action Plan.

3. Organization and Implementation

1. The Participants intend to execute this Action Plan with guidance from a Steering Committee consisting of one co-chair from each Participant. DOE may be represented by the Assistant Secretary for Nuclear Energy, or his/her designee, and BEIS may be represented by the Director of Science and Innovation for Climate and Energy, or his/her designee.

2. The Steering Committee is expected to oversee six technical working groups, as described in Annex 1 to this Action Plan ("Working Groups"), focused on each of the areas listed in paragraph 1 of Section 2. Each Working Group is expected to be co-chaired by a representative from DOE and BEIS, or their respective designees.

3. An organizational chart for the conduct of activities under this Action Plan is presented in Annex 2 to this Action Plan. It is recognized that the personnel and organizations listed in the organizational chart may change, and the organizational chart may be updated as appropriate.

4. The Working Groups are expected to meet individually as required, and jointly at least once a year, alternating between the United States and the United Kingdom, to present the results of their activities and their plans and priorities for future work. The Steering Committee is expected to meet annually, or as deemed necessary, to review the activities, progress, and plans of each Working Group and establish priorities for the Working Groups' technical activities.

4. Legal Framework

1. Each Participant intends to carry out the activities under this Action Plan in accordance with applicable laws, regulations and policies to which it is subject, and international agreements to which its government is party.

2. The Participants also note the importance of carrying out activities under this Action Plan in accordance with international legal frameworks relating to non-proliferation, safeguards, security, safety, and liability.

3. Each Participant is responsible for its costs of participating in the cooperative activities under this Action Plan, unless otherwise specified in writing by the Participants.

4. The conduct of cooperative activities under this Action Plan is subject to the availability of appropriated funds, technical resources, and personnel.

5. This Action Plan represents a programmatic commitment and does not create any legally binding obligations between the Participants.

6. Each cooperative activity that may involve the sharing of costs or Confidential Information, or that may give rise to the creation of intellectual property or inventions, is expected to be conducted pursuant to a project-specific agreement or other arrangement, as appropriate, which should include detailed provisions for its execution, including such matters as technical scope, management, total costs and payment provisions, schedule, use and handling of Confidential Information, intellectual property and invention rights, and such other matters relevant to the activities to be performed. "Confidential Information" as used in this paragraph refers to information that: 1) is not generally known or publicly available from other sources; 2) has not previously lawfully been made available to others without obligation concerning its confidentiality; and 3) is not already in the possession of the recipient without obligation concerning its confidentiality.

5. Cooperative Research and Development Activities

1. The Participants intend to carry out collaborative R&D activities to explore advanced civilian nuclear energy technologies in a manner that is safe and secure, and that supports non-proliferation. Joint activities under this Action Plan may take several forms, including:

A. Joint studies, experiments and analyses of radioisotope technologies, advanced nuclear reactor and fuel cycle concepts and technologies;
B. Use of each other's nuclear and non-nuclear facilities for experimental purposes;
C. Exchanges of information and research results; and
D. Collaborative personnel training, including exchanges of staff.

6. Commencement, Modification and Discontinuation

1. Cooperative activities under this Action Plan may commence upon signature by both Participants.

2. Cooperation under this Action Plan may continue for an initial period of five years and indefinitely thereafter, unless discontinued in accordance with paragraph 3 of this Section.

3. The Participants may discontinue their participation in this Action Plan by mutual written approval/decision at any time. Alternatively, a Participant that wishes to discontinue its participation in the Action Plan should endeavor to provide written notice to the other Participant at least six months in advance of the expiration of the initial five-year period, or thereafter, at least six months in advance of the date of discontinuation.

4. This Action Plan may be modified at any time upon mutual written approval/decision of the Participants. Either Participant may propose a modification to the Action Plan, or its Annexes, by means of written notice to the other Participant.

5. Unless otherwise mutually decided in writing, the Participants intend that joint activities under this Action Plan which are not completed at the time of discontinuation of this Action Plan may continue until their completion under the provisions of this Action Plan.

Signed in duplicate.

FOR THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA:

Principal Deputy Assistant Secretary for Nuclear Energy, DOE

Date: September 13, 2018

Place: British Embassy

FOR THE DEPARTMENT FOR BUSINESS, ENERGY AND INDUSTRIAL STRATEGY OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND:

Director of Science and Innovation for Climate and Energy, BEIS

Date: September 13, 2018

Place: British Embassy

ANNEX 1 – AREAS OF COOPERATION AND WORKING GROUP SCOPE

Working Group 1 – Radioisotopes for Use in Space Technologies

The United States has over five decades of experience in the production and safe launch of radioisotope power systems (RPS) for use in space using plutonium-238 based fuel and is currently reestablishing a domestic capability to produce Pu-238 for use in its RPS. The United Kingdom has proposed to provide to the European Space Agency (ESA) Americium-241 (Am-241) recovered from the radioactive decay of Pu-241 in the United Kingdom legacy stockpile as the heat source material to fuel a line of RPS. The Participants intend to carry out collaborative R&D activities in the broad area of space radioisotope power systems. This field has many new aspects to it where information is either not yet available or is incomplete. The decades of experience that the United States program has in this area using Pu-238 heat sources is planned to be used to provide a general direction for the types of information that are useful to the United Kingdom program. Collaboration in this Working Group is subdivided into six focus areas, described below.

1. Launch Safety Methodology and Data Bases

A successful launch approval process requires an analysis of hazards involved for credible nuclear incidents based on materials and components test data and computational analyses. The supporting information is used in operational planning by the mission, launching agency, power system designer, and for the use of other interested agencies. The key activities include: devise a strategy to determine launch safety methodology for key launch locations and testing; develop a work plan to implement a launch safety management structure; develop a launch safety testing needs database.

2. Fundamental Chemistry and Material Science of Am-241/$^{241}Am_xO_y$

The amount of fundamental chemical and material science knowledge available for Am-241 is much less than that for Pu-238. In order to manufacture, model and predict the properties of Am-241 heat sources, the gaps in the chemical, materials, and processing science data base must be filled. Additionally, the stability of various americium-oxygen phases has been noted to be subject to transformation within a few years of self-irradiation, and its oxidation/reduction compatibility property characteristics must be understood. The key activities include: identify most important chemical and physical properties for americium compounds of most interest as heat source; produce a work plan that defines the approach (technical, personnel and institutions) to determining the key chemical and physical properties of americium compounds; determine analytically the heat flow from the selected fuel form.

3. Environment and Personnel Interactions with Am-241

The quantity of knowledge regarding the effects of interaction of Am-241 with personnel and the environment is much less than there currently exists for Pu-238 in both instances. This to a certain extent is an iterative knowledge pursuit as the exact chemical form and material properties could undergo some changes as the results of the first working group's results are obtained and used to fine tune the approach of heat source production. Key activities include: investigate the health effects of Am-241 on humans; radiological and toxicological environmental impacts of Am-241; identify gaps in the knowledge base of Am-241 effects on human health.

4. Storage, Transportation, and Logistics of Am-241

The United States has had several decades of experience in the handling, storage and transportation of actinides such as Pu-238 and Am-241. It is likely that some of this knowledge would be of use to the United Kingdom program and ESA. Certain subjects such as the self-sintering of ceramic material (actinide oxide) during storage and the use of actively cooled casks for transportation, and handling of radioisotope power systems may be of direct applicability. Key activities include: investigate the shipping methods and challenges for Am-241; investigate the storage methods and challenges for Am-241 and operational logistics.

5. High Specific Activity Gloveboxes for Handling Am-241

The vast amount of experience with gloveboxes used for high specific activity alpha emitters garnered at United States and United Kingdom national laboratories and other places should be shared so that the safety and reliability of the facilities that are being established are based on best practice. Work involving Pu-238, Am isotopes, and Cm isotopes at various United States facilities can serve as a model to ensure that the engineered features and consumables associated with the Sellafield United Kingdom facilities benefit from the United States experience. Key activities include: sharing of best practices and lessons learned in high activity alpha emitter in glove boxes.

6. Solvent Extraction Actinide Chemistry

Ongoing discussions between United States and United Kingdom national laboratories have identified research areas on neptunium chemistry that would provide benefit to both BEIS and DOE. Currently the separation process involves the extraction of Np(VI) and Pu(IV) into a TBP/OK solvent phase. This is followed by the use of sodium nitrite to reduce the extractable Np(VI) to the inextractable Np(V), whilst leaving the Pu(IV) in the solvent phase. There are some aspects of the process that could be improved, one of which is to use a salt free (no sodium) reductant to reduce Np(VI) to Np(V).

Effort is expected to be carried out to develop new flowsheets for the separation operations; these are expected to be based on basic R&D and modeling of the Np oxidation/reduction reactions. This information can then be tested during the course of scaling up the production of Pu-238 in the United States The initial experiments are expected to be batch tests conducted at the relevant Np and Pu solvent loaded concentrations and contact with hydroxylamine nitrate (HAN) in nitric acid solutions (HNO_3) for varying times and measure the Pu and Np content of the separated aqueous and solvent phases.

Key activities include:

1. Identify chemical reactions of neptunium and HAN of greatest interest,
2. Devise strategy to determine test chemical reactions as a function of nitric acid and HAN concentration and document in a work plan to obtain the desired information including personnel and institutions,
3. Devise and execute plan for determination of feasibility of using the modified separations strategy, and
4. Document study by publishing a joint paper describing the collaboration.

Working Group 2 – Nuclear Reactor Technologies

Collaboration in this Working Group is subdivided into two focus areas:

- Small modular reactors (SMRs) employing light-water reactor (LWR) technologies with a particular emphasis on integral pressurized-water reactors (iPWRs); and
- Advanced Reactors. There are also additional focus areas in which potential collaborations could be appropriate and are planned to be considered as the programs evolve, such as LWR materials ageing and degradation, and molten salt reactor developments.

1. Small Modular Reactors

SMRs and the potential market and sale opportunities are currently being evaluated by the United States and the United Kingdom for domestic and/or international deployment. There are initially four main activities of collaboration. However, other areas, such as finance and licensing, could be discussed as activities develop in both countries.

(i) Advanced Manufacturing Technologies – There is the potential to apply advanced manufacturing techniques that can result in a lower fabrication cost, improved component quality and shortened fabrication schedule. However, the technology options are relatively immature, and need to be demonstrated. The key activities include: identifying key advanced manufacturing technologies and evaluating their potential economic impact on deployment and requirements for regulatory acceptance; developing a joint project plan to demonstrate manufacturing technologies; and conducting initial demonstrations of advanced manufacturing technologies.

(ii) Development of Remote Monitoring Capability for the SMRs - The global deployment of standardized SMR units will introduce the possibility of fleet-wide monitoring and management, similar to what is currently done for the aircraft industry, which is expect to require an increased level of on-line monitoring sensors and instrumentation, as well as data encryption, transmission, and fusion methods. The key activities include: identifying candidate operational and performance parameters for monitoring and analysis that may be suitable from an SMR fleet management perspective; determine data protocols for collecting, transmitting, securing and analyzing monitored parameters; and developing a framework for collaboration that would serve to facilitate standardized systems among reactor vendors, utilities, and research organizations.

(iii) Siting SMRs at Existing Nuclear Plants Versus New Sites at Remote Locations – The first deployment of SMRs in either country is likely to be on existing nuclear sites in order to take advantage of existing infrastructure, human resource, and site licensing structure. Alternative options include remote locations where power requirements are less. Therefore, the key activities include: identifying advantages and impacts of siting SMRs at an existing site; and identifying benefits and challenges of siting SMRs at remote locations.

(iv) Use of SMRs as Part of a Hybrid Energy System (HES) - To meet the clean energy goals for both countries, it may be necessary to use SMRs to provide process heat, either in a dedicated fashion, in co-generation mode, or within a network of multiple energy producers and users (hybrid energy systems). Such an implementation approach presents new considerations such as control strategies, load balancing, impact on the stability of the electric grid, co-location with other energy generation technologies, and economic evaluations. The key activities include: exchange of information on potential options, scenarios and issues for deployment; exchange of modeling and simulation information on HES options; exchange of information on the status of emerging technologies for HES.

2. Advanced Non-Light Water Reactors

Both countries have each had successful historical non-light water reactor development and demonstration programs (e.g., fast reactor demonstration and development experience, including Experimental Breeder Reactor (EBR) I and II and Fast Flux Test Facility (FFTF) in the United States, Dounreay Fast Reactor (DFR) and the Prototype Fast Reactor (PFR) in the United Kingdom, gas-cooled reactor development and demonstration experience with reactors developed in the United Kingdom at the Winfrith site, and reactors developed in the United States at Peach Bottom and Idaho National Laboratory). With both nations expressing renewed interest in advanced non-light water reactor technologies, the objective of this activity is to jointly share information and work collaboratively on advanced non-light water reactor technologies such as reactor fuel performance, reactor safety and component design and development, and reactor analysis code comparison and validation. There are two main areas of collaboration:

(i) Information Exchange on Advanced Non-Light Water Reactor Design and Technology – Key elements are information exchange on past and current advanced non-light water reactor programs and preservation and organization of knowledge and data related to advanced reactor technology development, testing, operations, and maintenance. It is very important to initially engage personnel with past non-light water reactor program experience before their technical expertise is lost. The key activities include: information exchange on advanced non-light water reactor systems and components including their design, performance, operations and maintenance, and information on their operability to inform the design and improvement of future advanced reactor technologies; analysis codes to understand the capabilities and differences between the code suites; developing a list of reactor topic areas for future exchange; identifying limitations on data and information exchanges; exploring methods for preserving the information; engaging personnel with previous programmatic experience; preparing a compilation of advanced non-light water reactor data sources and availability; and developing a path forward for the exchange.

(ii) Improved Safety Performance, Cost Reduction, and Increased System Reliability – In order for advanced non-light water reactors to become a commercial proposition, technology approaches are required to improve safety performance, improve cost reduction, and increase system reliability. The key activities include: explore and review designs, techniques, and operations of innovative advanced non-light water reactor technologies that would have the potential to improve the safety performance, reduce the costs, and increase system reliability of advanced reactors (e.g., fuel handling mechanisms, advanced power conversion system, compact heat exchangers, passive safety systems).

Working Group 3 – Advanced Fuels

The activities under this Working Group are subdivided into four focus areas:

- Light Water Reactor (LWR) Accident Tolerant Fuels,
- Advanced reactor fuels,
- Fuel modeling and simulation, and
- Irradiation testing, characterization and post irradiation examination (PIE)

1. Accident-tolerant fuels for LWRs

DOE and BEIS are both interested in the development of fuels that are more tolerant to accident conditions and enhance the safety of present and future generations of LWRs. Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2-zirconium alloy fuel system, currently used by the LWR industry, can tolerate loss of active cooling in the reactor core during design-basis and beyond design-basis events for a considerably longer time period while maintaining or improving the fuel performance during normal operations and operational transients. There is already collaboration in this area between the United States and the United Kingdom through university led projects between the United States and United Kingdom institutions. The following activities were identified as potential topics of common interest for near term-activities:

- Basic material properties of high-density fuels
- Later discussions might be held to define a potential joint irradiation test

2. Advanced Reactor Fuels

DOE and BEIS are both interested in the development and fabrication of advanced high burn up fuel for advanced reactors, capable of supporting a recycle strategy to increase resource utilization, maximize energy generation, minimize waste generation and improve safety. The development of these advanced reactor fuels could dramatically decrease the amount of high-level waste that requires disposal and the long-term effects of the waste on a repository. This task focuses on building on the United States and United Kingdom experience with advanced fuels. The following activities were identified as potential topics of common interest for near term-activities:

- General information exchange on advanced fuels.
- Discussions on future collaborations that could be mutually beneficial

3. Irradiation testing, characterization and PIE

Irradiation and testing of advanced nuclear fuels and materials requires investment in significant facility and infrastructure capabilities. Coordination of irradiation experiments in test reactors provides an opportunity for nuclear fuel and development programs to achieve irradiation goals. This task focuses on the coordination of irradiation experiments performed by the United States and the United Kingdom. Near term efforts are expected to focus on irradiation experiments that are currently underway in the Advanced Test Reactor (ATR), the Halden reactor in Norway and other appropriate irradiation facilities. Longer term activities are expected to be identified, consistent with the national program goals of the United States and the United Kingdom, and could include collaborative experiments in the available test reactor fleet.

Significant post irradiation and characterization capabilities exist in both the United States and the United Kingdom. Significant opportunities have been identified in this area for bilateral coordination. Near term activities are expected to focus on the development of advanced material characterization techniques and application to fresh and irradiated fuels and the development of advanced thermal property measurement techniques. Longer term activities synergistic with the advanced modeling and simulation activities in both nations are expected to be identified such that multi-scale multi-physics data is expected to be generated using advanced measurement and characterization techniques.

4. Fuel Modeling and Simulation

Development of advanced fuel modeling and simulation capabilities and development of multi-scale, multi-physics experimental techniques are current activities in both the United States and United Kingdom. Informal working relationships have already been established between researchers on a laboratory to laboratory or laboratory to university basis, specifically the licensing of the Moose/Bison/Marmot (MBM) framework to United Kingdom universities and laboratories, and the development of MOX material property relationships for the MBM environment. This task focuses on building these relationships into more definitive and extensive national bilateral collaborations. Near term activities are expected to focus on forwarding the existing relationships, and longer-term activities are expected to build on these relationships to establish coordinated activities involving the laboratories and universities funded in this area of research and development and performing experimental activities that are closely coupled with modeling and simulation activities.

Working Group 4 – Fuel Cycle Technologies

Both DOE and BEIS are interested in pursuing research into future advanced fuel cycles, including but not limited to, the evaluation of closed fuel cycles in which irradiated fuel is reprocessed, and the resulting materials separated into appropriate streams for either recycle, or placed into a form suitable for long term disposal. Both countries have significant experience and expertise in the evaluation and development of fuel cycle options and technologies, and this Working Group is intended to identify collaboration opportunities in three focus areas:

- Fuel cycle scenario analysis
- Separation technologies
- Waste forms

In addition, this Working Group is expected to provide an interface between this DOE Office of Nuclear Energy Action Plan, and related collaborative programs between the DOE Office of Environmental Management and the United Kingdom

1. Fuel Cycle Scenario Analysis

Although the United States and the United Kingdom currently operate different fuel cycles that support differing reactor technologies, both countries have continued to evaluate similar future fuel cycle options in recent years. The intention of this activity is to bring together some of the leading analysts in the United States and the United Kingdom in order to better understand each nation's drivers, metrics, assumptions, and tools, for strategic assessment of future fuel cycle options. The key activities include: develop a common understanding of the metrics that are being considered in the United States and the United Kingdom; share key assumptions, data, and analysis, and develop an understanding of where and why any differences arise; compare and contrast the tools that have been developed or are being developed for strategic assessment; develop common data, tools and analyses that can be shared, where appropriate; identify ways in which decision and policy makers can be better informed using fuel cycle assessment. Following a workshop between the United States and the United Kingdom in September 2015, specific areas for future collaboration were identified:

- Using U.K. and U.S. fuel cycle and fundamental neutronics analysis techniques to understand the viability of particular reactor technologies and systems being promoted by industry and academic vendors
- Fuel cycle tools and methods development, comparison and verification to enable consistent approaches (e.g. ORION, VISION, DYMOND, CYCLUS etc.)
- Fuel cycle assessment on future nuclear energy systems relating to a variety of energy requirements (e.g., LWR, Advanced Reactors etc. and associated fuel cycles)

2. Separation Technologies

There already exist a number of technical exchanges between U.S. and U.K. national laboratories in this field in aqueous separations and pyro-processing technologies. The activities leverage both modeling and simulation of separation flowsheets, as well as experimental designs, operations and experimental data. The key activities include: investigation into the chemistry of neptunium in separation processes; evaluation of thermodynamics of minor actinides with advanced ligands. Following a workshop between the United States. and the United Kingdom in September 2015, specific areas for future collaboration were identified:

- Understanding the fundamental chemistry to enable reliable Neptunium extraction for advanced recycle processes (including enabling the holding of Np (VI) valency state and redox chemistry of HNO_2
- Maximising the safety requirements and engineering considerations of separations process including radiolytic degradation and the minimising hydrogen generation
- Understanding actinide and lanthanide reaction kinetics, thermodynamics and their impact on radiochemical separations
- Development and use of on-line monitoring techniques for radiochemical separations

3. Waste Forms

Following a workshop between the United States and the United Kingdom in September 2015, several topics were discussed, and one specific area for future collaboration was identified:

- Development of substrates and immobilisation matrices for iodine capture and immobilisation

Other topics for further discussion and development include:

- Glass forms, and corrosion thereof
- Ceramic, and glass-ceramic waste forms for higher loadings and durability
- Electrochemical waste forms
- Metal waste forms (limited opportunity for development?)
- Hot Isostatic Pressing (HIP) – ceramic, glass, polymer
- Titanate ceramic/Synroc waste form

Working Group 5 – Advanced Modeling and Simulation Tools

As computational resources become increasingly more powerful, advanced modeling and simulation is becoming a more active area of capability development. Furthermore, modeling and simulation is being increasingly integrated in to experimental research programs. As such, it is natural for Working Group 5 to interact closely with the other Working Groups. Nevertheless, a wide range of modeling and simulation activities are being pursued, and the Advanced Modeling and Simulation Tools Working Group has been subdivided into four focus areas in order to coherently address a broad spectrum of topics:

- Reactor simulations
- Model development
- Validation and Verification
- Nuclear data

1. Reactor simulations

This focus area broadly consists of engineering scale simulations of reactor performance and safety. Considerable development efforts are underway to modernize and possibly couple traditional reactor simulation tools in such areas as fuel performance, thermal hydraulics, structural mechanics (including structural-fluid interaction), and neutron transport. For example, as mentioned in the description of the Advanced Fuels Working Group, predictive multi-scale fuel performance simulation capabilities are being developed by both DOE and BEIS, which might afford opportunities for collaboration in this area.

2. Model development

The "predictive" and "multi-scale" aspects of advanced modeling and simulation require improved physics-based models for a very broad range of phenomena. The Participants both have a rich history of physics-based development of fuel performance models, such as work done by the Theoretical Physics Division at AERE Harwell, and specific opportunities are expected to be sought for behavioral models of mutual interest, especially where complementary strengths exist (e.g., different areas of emphasis, such as length scales and mathematical approaches, that could be synergized).

3. Validation and Verification

Validation of the underlying mechanistic models (*e.g.* materials science, thermal-hydraulics, neutronics, continuum and structural mechanics) both in separate effects and integrated simulations, is essential for ensuring that the advanced modeling and simulation tools are accurate, robust, and useful. Broad validation assessments instill confidence that simulations capture the essential features and phenomena appearing in real, operating nuclear systems, which is essential to provide a successful transition between conventional descriptive engineering models and predictive simulation-based HPC models. Because this focus area includes not only development of validation methodologies and assessment tools, but also development and use of experimental data and benchmarks, it is necessarily cross-cutting and should involve participation from other working groups, under which experiments and specific application of computational tools may be performed. Ideally, the advanced modeling and simulation team works in conjunction with the other focus areas in order to assist in the definition of specific experiments for validation and verification purposes.

4. Nuclear Data

Nuclear data is a key input into numerous elements of reactor and fuel cycle assessment, whether it is in terms of reactor safety and performance, criticality and shielding, inventory predictions, dose, or decay heat. Use of U.S. data (typically ENDF-VII) and U.K./European data (from JEFF) inevitably yields differences in results, and to understand the basis of those differences from a nuclear data perspective is of substantial value. In particular this also relates to nuclear data gaps and needs, including nuclear data experiments, evaluations, and maintaining a skill base.

Working Group 6 – Enabling Technologies

In addition to Working Groups focused on specific technical themes (as outlined above in the other five Working Groups), there are also additional cross-cutting, or enabling technologies where both DOE and BEIS are interested in collaborating. These 'enablers' focus on four areas:

- Universities engagement
- Nuclear Science User Facilities (NSUF) and National Nuclear User Facility (NNUF) Collaboration
- Resource libraries
- Public understanding and engagement

1. Universities Engagement

Since 2012, a robust nuclear energy research collaboration program has been ongoing between U.S. and U.K. universities, jointly funded by DOE and EPSRC in pursuit of mutual objectives to advance civilian nuclear energy. This Working Group is expected to closely coordinate future opportunities to continue and expand collaborations, as funding and national priorities allow, in the following areas:

- Advanced Reactor Modeling and Simulation
- Fuels and Materials
- Advanced Reactor Systems
- Fuel Manufacture and Fuel Recycling Technologies, including Advanced Aqueous and Pyrochemical Processing
- Crosscutting Modeling and Simulation
- Used Fuel Disposition
- Innovative Waste Treatment Technologies/Robotics, Sensing and Monitoring
- Advanced instrumentation for PIE and in-pile measurements

2. Nuclear Science User Facilities (NSUF) and National Nuclear User Facility (NNUF) Collaboration

Both the United States and the United Kingdom have invested in significant civilian nuclear energy research capabilities and taken efforts to formalize processes to make these resources available to their nuclear energy research communities via NSUF and NNUF. Recent discussions have identified substantial potential benefits from and opportunities for United Kingdom and United States user facility collaboration. The Working Group is expected to closely coordinate the establishment and implementation of processes to facilitate the sharing of user facility resources by coordination and endorsement of access requests. Initial efforts are expected to focus on coordination of nuclear fuels and materials sample library and archive assets and information to demonstrate the viability and utility of user facility collaborations, leading to future expansion of user facility capability collaborations, as appropriate.

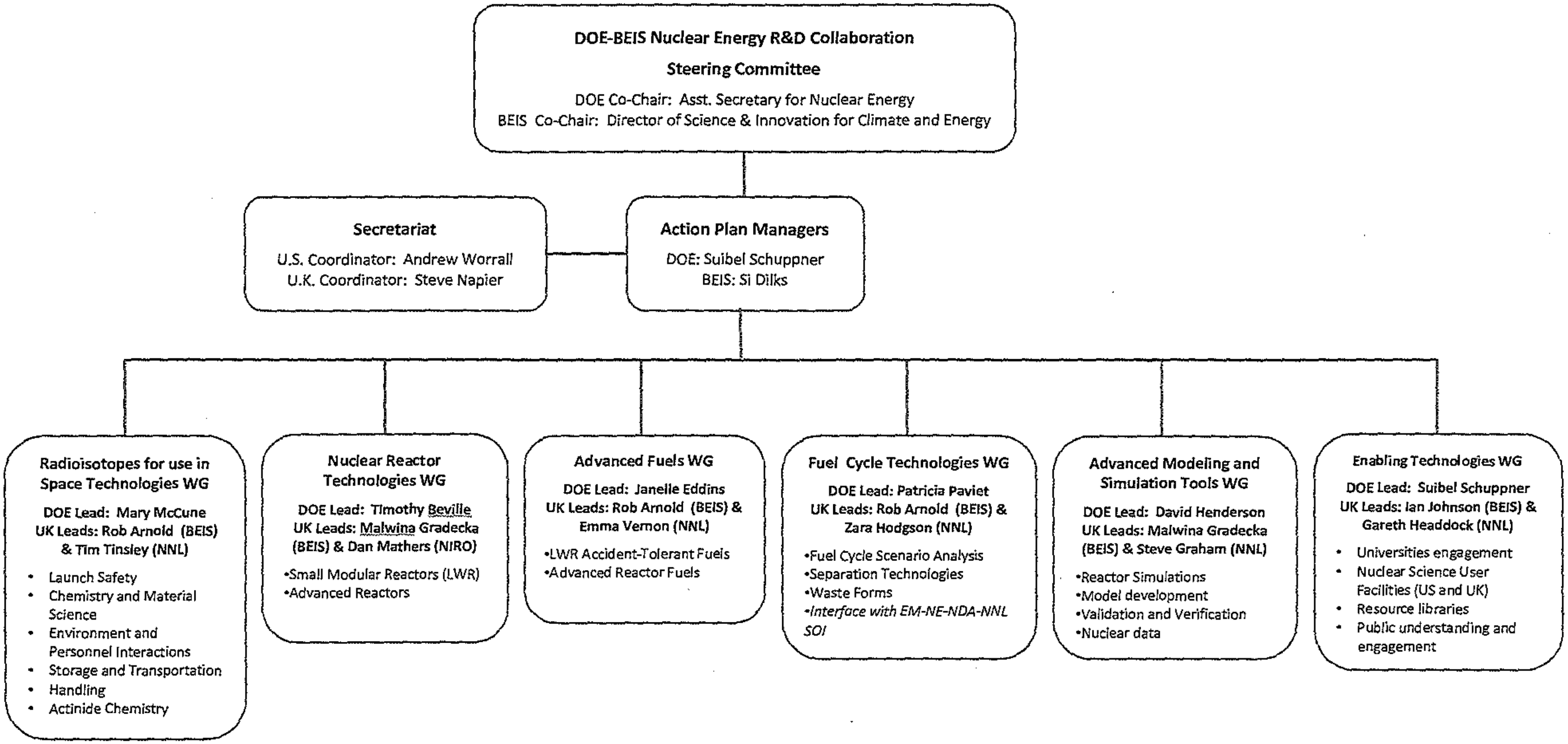
3. Resource Libraries

Over several decades the United States and the United Kingdom have been actively involved in the development and demonstration of a range of nuclear fuel cycle and reactor technologies. This has involved the production, irradiation, and testing of a broad spectrum of fuels and materials, with a number of these programs having ended over the last 10-20 years or more. These experimental programs were not only resource intensive (cost and manpower), but potentially will never be repeated, and as such there is significant opportunity to share the results of those irradiation programs e.g. material properties data, irradiation performance data, and specifications used. The key activities include: identification of programs and data of mutual interest; determining the ownership, format, and location of the key data and materials; determining whether the data and materials are suitable for sharing, and identifying a means by which to capture and share the data and materials. These activities should be managed and coordinated through the NSUF and NNUF.

4. Public Understanding and Engagement

In both the United States and the United Kingdom, the nuclear sector has made progress over recent years in engaging with the public to understand the important issues and concerns around proposed developments and new build within the industry. This has resulted in a more open and transparent approach to public engagement. Maintaining and strengthening this conversation with the public is essential for these developments at a national and local level. Seeking to listen and understand the public's views and concerns, should enable the industry to address them, and gain support for the political mandate and the industrial backing to deliver the transformation in energy infrastructure over the extended timescales required. The Working Group therefore is expected to work with leadership on how to implement best practices and how to communicate effectively with the public, building on experiences in the United States and United Kingdom

Annex 2: Organizational Chart



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