United States Nuclear Regulatory Commission

Protecting People and the Environment

NON-LIGHT WATER REACTOR LANDSCAPE

Enclosure 2

1.0 Introduction

Enclosure 1 summarizes activities underway and planned by the staff of the U.S. Nuclear Regulatory Commission (NRC) to ensure that the agency is ready to effectively and efficiently review potential applications for non-light water reactor (non-LWR) technologies. The staff has worked with various stakeholders to align the approach described in "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness,"[1] issued December 2016, with similar planning documents prepared by organizations such as the U.S. Department of Energy (DOE)[2] and the Nuclear Energy Institute (NEI).[3] The staff developed implementation action plans (IAPs) to identify specific NRC near-term[4], midterm, and long-term activities.[5] Many of the activities described in the IAPs involve interactions with stakeholders and coordination of activities related to the development of advanced reactor technologies.

Interaction with the NRC on regulatory and licensing questions is one of a number of issues that face developers of advanced reactor designs. As depicted in Figure 1 from the NRC staff's "A Regulatory Review Roadmap for Non-Light Water Reactors,"[6] issued December 2017, the challenges affecting the development, licensing, and deployment of new advanced reactor technologies include funding, public policy, research and development (R&D), licensing, and infrastructure issues (e.g., fuel cycle).

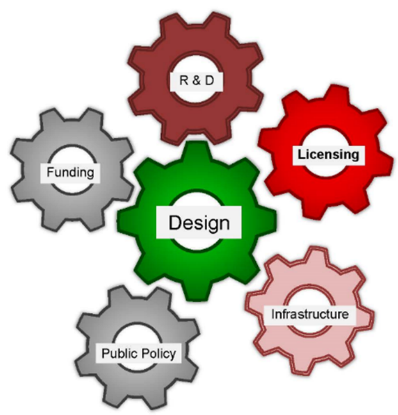

Figure 1: Interrelated technology development plans

This enclosure provides a brief overview of some of the major activities that affect the development and possible licensing and deployment of non-LWRs. The activities in the United States related to non-LWRs have generally been categorized based on reactor technologies—namely, fast reactors, high-temperature gas-cooled reactors (HTGRs), and molten-salt reactors

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[1] See "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness," issued December 2016 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML16356A670).

[2] See "Vision and Strategy for the Development and Deployment of Advanced Reactors," DOE, Office of Nuclear Energy, DOE/NE-0147, issued January 2017.

[3] See "Strategic Plan for Advanced Non-Light Water Reactor Development and Commercialization," NEI, issued May 2016.

[4] See "NRC Non-Light Water Reactor Near-Term Implementation Action Plans," issued July 2017 (ADAMS Accession No. ML17165A069).

[5] See "NRC Non-Light Water Reactor Mid-Term and Long-Term Implementation Action Plans," issued July 2017 (ADAMS Accession No. ML17164A173).

[6] See "A Regulatory Review Roadmap for Non-Light Water Reactors," issued December 2017 (ADAMS Accession No. ML17312B567).

(MSRs). The staff uses the same convention in its planning and in this enclosure to describe activities affecting the development, licensing, and deployment of non-LWR designs. The sections below describe the NRC staff's key interactions and consideration of related activities by DOE, the national laboratories, industry organizations, international organizations, and individual advanced-reactor developers.

2.0 Technology-Inclusive Activities

The near-term IAP developed by the NRC staff focus on technology-inclusive issues (i.e., those issues that apply widely to non-LWR designs, independent of the specific technologies used). Technology-inclusive activities have the broadest applicability for developing the NRC's non-LWR regulatory framework. The NRC is also identifying and will address technology-specific non-LWR policy issues through interactions with specific organizations and design-specific regulatory engagement plans, as appropriate.

Enclosure 1 describes the NRC staff's interactions with outside organizations in support of the IAPs. Examples include the collaborative effort with DOE to develop the advanced reactor design criteria and ongoing interactions with the industry-led Licensing Modernization Project (jointly sponsored by DOE and industry) to develop technology-inclusive, risk-informed, and performance-based regulatory guidance for non-LWRs for the NRC's consideration and possible endorsement. The NRC staff also routinely participates in activities related to multiple reactor designs within a technology category. Examples include interactions with technology working groups formed by the reactor developers and participation in standards development organizations. The NRC staff continues to participate in advanced reactor activities within international organizations such as the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency within the Organisation for Economic Co-operation and Development.

The activities of these organizations support aspects of non-LWR development beyond NRC's regulatory and licensing responsibilities. However, the efforts of DOE and others related to R&D, funding, infrastructure, and public policy largely define the need for and timing of NRC actions. The sections below summarize some of the major activities influencing the scope and timing of NRC strategies and plans related to non-LWRs.

2.1 U.S. Department of Energy

DOE is a primary driver for developing and deploying nuclear reactor technologies. Each of the technologies and specific reactor designs currently being developed can trace their origins to a program sponsored by DOE and its predecessor, the Atomic Energy Commission. The sections below describe some of the ongoing DOE activities related to the development and potential licensing of non-LWRs.

Gateway for Accelerated Innovation in Nuclear

The DOE Office of Nuclear Energy (DOE-NE) established the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to provide the nuclear community with access to the technical, regulatory, and financial support necessary to move innovative nuclear energy technologies toward commercialization. Through GAIN, DOE is making the R&D infrastructure of the national laboratories available to stakeholders to achieve faster and more cost-effective development of advanced reactor designs. The initiative is implemented by issuing vouchers to companies, including non-LWR developers that provide access to the research and analysis capabilities of the national laboratories.

DOE created the GAIN initiative in recognition of the fact that facilities needed to conduct the necessary R&D activities are very expensive to develop and maintain. Facilities at government sites have not been easily accessible by the entities trying to commercialize creative systems and components. The GAIN initiative also includes coordination between DOE and the NRC staff to help resolve potential licensing issues. Reducing the uncertainties and financial risks of

achieving technical and licensing readiness may help spur further investment in innovative nuclear energy technologies.

The GAIN initiative and other DOE activities recognize that the maturity or technology readiness levels (TRLs) vary by reactor technologies and designs. The regulatory uncertainties for specific technologies and designs generally mirror the DOE TRLs.[7] Figure 2, prepared by Idaho National Laboratory (INL) shows a representation of the resources associated with increasing technology and licensing readiness. The GAIN NE Voucher Program awarded a total of $6.2 million in 2016 and 2017 to various companies to support the development of innovative nuclear technologies. A summary of the NE Vouchers issued in 2016 and 2017 is available on the GAIN Web site (https://gain.inl.gov).

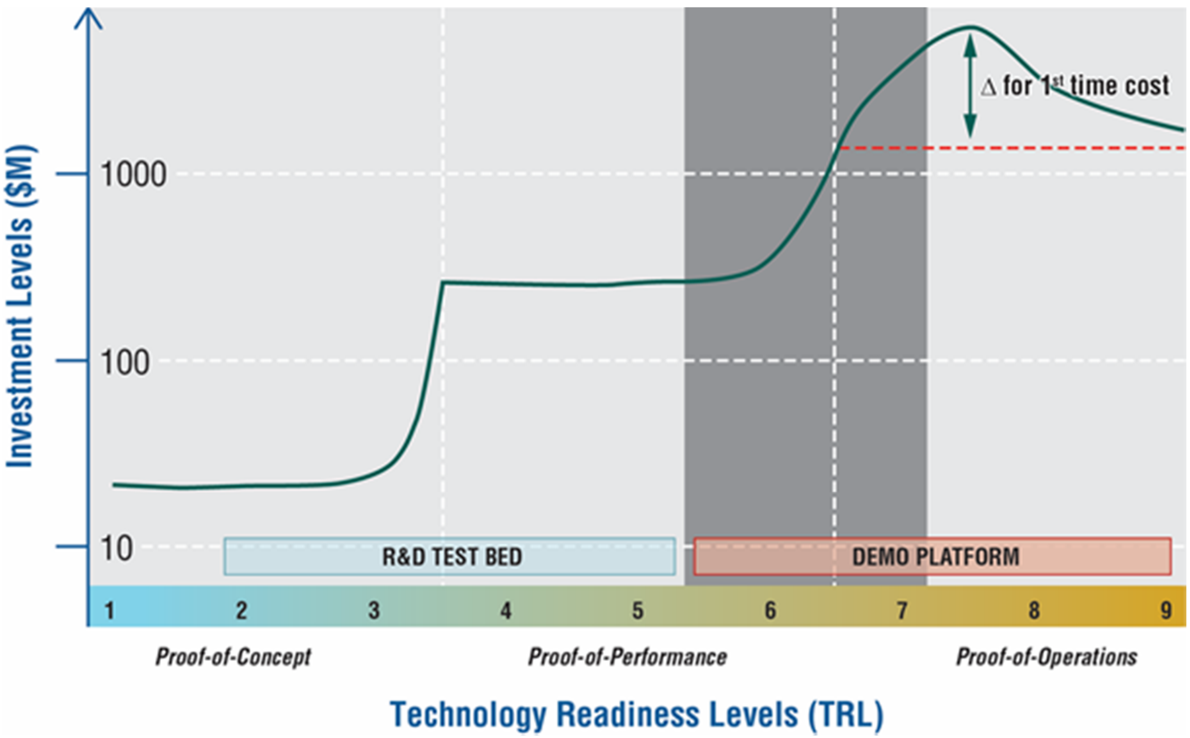

Figure 2: Investment levels for technology advancement

In October 2017, the Nuclear Innovation Alliance (NIA) issued a report that estimates TRLs for various advanced reactor technologies, entitled, "Enabling Nuclear Innovation; Leading on SMRs." The summary was compiled from various studies by national laboratories and generally estimates sodium-cooled fast reactor (SFR) and HTGR technologies at a TRL of 5 and MSR technologies at a TRL of 3.

[7] DOE Guide 413.3-4A, "Technology Readiness Assessment Guide," dated September 15, 2011, describes TRLs.

Advanced Reactor Technologies Program

The DOE Advanced Reactor Technologies (ART) Program comprises several activities supporting the development and licensing of advanced reactor designs. The program includes research for fast reactor and high-temperature reactor technologies and supporting activities, such as work on consensus codes and standards, energy conversion, and decay heat removal systems. Research also continues from the Next Generation Nuclear Plant (NGNP) Program, including the Advanced Gas Reactor TRISO (Tristructural Isotropic) Fuels Program. Evaluating the feasibility and options for an advanced test or demonstration reactor are an element within the ART Program. The ART Program also includes cost-share programs to help support advanced reactor concepts. The program awarded two such cost-share projects in 2016:

- Southern Company Services—partnering with TerraPower, Electric Power Research Institute (EPRI), Vanderbilt University, and Oak Ridge National Laboratory (ORNL) to perform integrated effects tests and materials suitability studies to support development of the Molten Chloride Fast Reactor (MCFR). The ART Program award stated that the MCFR is a next-generation design with the most advanced safety features to enable its potential use across the country.

- X-energy—partnering with BWX Technology, Oregon State University, Teledyne-Brown Engineering, SGL Group, INL, and ORNL to solve design and fuel development challenges of the Xe-100 Pebble Bed Advanced Reactor. The ART Program award stated that this type of reactor also has a next-generation design and the most advanced safety features, and it is smaller than traditional nuclear reactors. These factors would potentially enable such a reactor to serve a wider array of communities—particularly densely populated areas—while ensuring public safety.

The Department of Energy Funding for Advanced Nuclear Technology Development

On December 7, 2017, DOE released a funding opportunity announcement (FOA) to support development of advanced nuclear energy technology. DOE is soliciting proposals for cost-shared projects to develop innovative, industry-driven reactor designs and accompanying technologies with high potential to advance nuclear power in the U.S. These activities may include development of technologies that improve the capability of the existing fleet, methods to improve the timelines for advanced reactor deployments, the cost and schedule for delivery of nuclear products, services, and capabilities supporting these nuclear technologies, design and engineering processes, and resolution of regulatory issues potentially impeding the introduction of these technologies into the marketplace. The cost-shared activities envisioned under this FOA would address industry-identified projects from a very broad scope of technical topical areas including, but not limited to, innovations and improvements in:

- advanced nuclear reactor designs, including small modular reactors of various technology types;
- engineering, analyses, and experimentation that would address first-of-a-kind reactor design, certification, and licensing issues;
- advanced manufacturing, fabrication, and construction techniques for nuclear parts, components, and full-scale plants, or integrated efforts that could positively impact the domestic nuclear manufacturing enterprise;
- modeling and simulation of various elements of plant life cycle;
- integration of nuclear energy into micro-grid, non-electric, and/or hybrid applications;

- other components, systems, processes, or capabilities, including dynamic convection technologies, that could result in performance and economic improvements in advanced nuclear reactor designs; and,
- efforts to address regulatory and licensing issues with the NRC.

DOE expects to make up to $30 million or more available in fiscal year (FY) 2018 awards, subject to the availability of funding. The FOA will be open for a 5-year period accepting applications on a year-round basis, with a quarterly selection process. Additional funding will be available in future years, as allocated by Congress.

Nuclear Energy University Program

DOE-NE provides significant support to universities and others by funding opportunities offered through programs such as the Nuclear Energy University Program (NEUP). DOE established the program in 2009 to consolidate university support under one initiative and to better integrate university research with DOE-NE technical programs. NEUP's mission is to engage the U.S. university community to conduct program-directed, program-supporting, and mission-supporting R&D; related infrastructure improvements; and student education support to build world-class nuclear energy and workforce capability as an integral component of DOE-NE. The NEUP awards support the sustainability of existing LWRs as well as the development of non-LWR technologies. In FY 2017, the program awarded over $31 million to support 32 university-led nuclear energy R&D projects in 23 states. Listings of current and past activities funded through the NEUP are available on the program's Web site at https://neup.inl.gov.

Nuclear Energy Enabling Technologies Program

The Nuclear Energy Enabling Technologies (NEET) Program supports the development of crosscutting technologies that directly support and complement the DOE-NE advanced reactor and fuel cycle concepts, focusing on innovative research that offers the potential for dramatically improved performance. The activities undertaken in the NEET Program complement those within the other DOE-NE R&D programs, such as ART and NEUP. In the area of NEET Crosscutting Technologies, $6 million was awarded in FY 2017 for six R&D projects led by DOE national laboratories, industry, and U.S. universities to conduct research to develop advanced sensors and instrumentation, advanced manufacturing methods, and materials for multiple nuclear reactor plant and fuel applications. Listings of the activities funded through the NEET Program are available on the program's Web site at https://www.energy.gov/ne/nuclear-reactor-technologies/nuclear-energy-enabling-technologies.

Nuclear Energy Advanced Modeling and Simulation Program

The mission of the DOE-NE Nuclear Energy Advanced Modeling and Simulation (NEAMS) Program is to develop, apply, deploy, and support state-of-the-art predictive modeling and simulation tools for the design and analysis of current and future nuclear energy systems. Current activities include efforts to extend modeling and simulation capabilities beyond SFRs and LWRs to support liquid-fueled, MSRs, HTGRs, and fluoride-salt-cooled high-temperature reactors. The NEAMS Program is organized along three product lines: the Fuels Product Line, the Reactors Product Line, and the Integration Product Line. The activities conducted by the NEAMS Program are available on the program's Web site at https://energy.gov/ne/downloads/nuclear-energy-advanced-modeling-and-simulation-neams-program-plan. The NEAMS Program closely aligns with the NRC staff's efforts under

Strategy 2, "Acquire/develop sufficient computer codes and tools to perform non-LWR regulatory reviews," within the near-term IAP.

Advanced Research Projects Agency-Energy (ARPA-E)

In October 2017, DOE announced up to $20 million in funding for projects as part of a new Advanced Research Projects Agency-Energy (ARPA-E) program: Modeling-Enhanced Innovations Trailblazing Nuclear Energy Reinvigoration (MEITNER). MEITNER projects seek to identify and develop innovative technologies that can enable designs for lower cost, safer, advanced nuclear reactors. The MEITNER Program seeks transformative technologies to allow advanced reactor designs that achieve lower construction costs and autonomous operations while also improving safety. Additional information related to the funding opportunity announcement is available on the ARPA-E Web site at https://arpa-e.energy.gov/?q=arpa-e-programs/meitner.

2.2 Industry Efforts, Nongovernmental and International Organizations

A number of organizations are involved in advocating for the development of advanced reactor designs and representing developers of non-LWR designs during interactions with the NRC staff. The staff also continues to interact with stakeholders, such as individual members of the public and nongovernmental organizations such as the Union of Concerned Scientists (UCS). The organizations that are meeting with the NRC staff, issuing reports, and otherwise potentially coming to the attention of the NRC include NEI and EPRI, as well as other organizations, such as NIA and the Nuclear Infrastructure Council (NIC). The NRC staff interacts with industry groups and nongovernmental organizations such as the following:

- NEI has formed an Advanced Reactor Working Group and Advanced Reactor Regulatory Task Force, which includes reactor vendors, suppliers, and utilities interested in supporting the development of advanced reactors. NEI coordinates activities and works as the primary interface between the industry and the NRC staff on most matters associated with advanced reactors. NEI has prepared white papers and other documents to help identify and address advanced reactor policy issues, such as emergency preparedness, physical security, and the nuclear fuel cycle. NEI has also issued guidance for the developers of non-LWR designs in areas such as preparing regulatory engagement plans. Enclosure 1 contains additional information on the topics addressed by NEI documents.

- NIA assembles companies, investors, experts, and stakeholders to advance nuclear energy innovation and support commercialization through advocating energy policy and funding. NIA issued the reports, "Strategies for Advanced Reactor Licensing," and "Leading on SMRs," that deal not only with licensing issues but also with matters such as public policy and funding. NIA also prepared the paper, "Clarifying 'Major Portions' of a Reactor Design in Support of a Standard Design Approval," which is incorporated by reference in the NRC staff's "Regulatory Roadmap for Non-Light Water Reactors."

- NIC is a business consortium of more than 50 companies that advocates for nuclear energy and promotes the domestic supply chain for power plants and fuel cycle facilities. NIC interfaces with Federal agencies such as the U.S. Department of Commerce, organizes workshops for nuclear suppliers, and routinely interacts with the NRC staff during workshops and periodic stakeholder meetings.

- EPRI's Advanced Reactor Technology Program has focused on the possible deployment of non-LWRs and particularly small modular LWRs. EPRI has established the Advanced Reactor Strategic Program and Technical Advisory Group to interface with stakeholders from the industry, government, and academia. The planned development of an Advanced Reactors Owner-Operator Requirements Guide could be useful for the NRC staff as well as for developers in terms of standardizing terms and attributes for non-LWR technologies. EPRI plans to publish the initial version of this guide in spring 2018.

- Technology working groups (TWGs) comprise developers of reactor designs with some common features such as neutron spectrums (e.g., fast or thermal), reactor coolant, and fuel forms. The current TWGs related to non-LWRs are for HTGRs, fast reactors, and MSRs. The primary focus of the TWGs is currently interactions with DOE on R&D activities. The NRC staff interacts with the TWGs within standards development organizations and directly on some technology-specific issues, such as plans for qualifying reactor fuels.

- Standards development organizations, such as the American Nuclear Society and American Society of Mechanical Engineers, are developing consensus codes and standards to support advanced reactors, including non-LWRs. The NRC staff participates in these activities. Enclosure 1 contains additional information on these activities under Strategy 4, "Facilitate industry codes and standards needed to support the non-LWR life cycle (including fuels and materials)."

- Other groups are involved in the promotion or assessment of advanced reactor technologies within broader public policy questions related to energy supplies and protecting the environment. Examples include the think tank, "Third Way," which periodically publishes lists of advanced reactor developers and other nongovernmental organizations, such as "Clear Path" and "Clean Air Task Force," which generally advocate advanced nuclear technologies as part of efforts to reduce environmental impacts from producing energy. The NRC staff has had limited interactions with these organizations but reports and recommendations from these groups sometimes include regulatory reforms.

- Since its founding in 1969, UCS has interacted with the NRC on a wide variety of technical and policy issues associated with nuclear power. The UCS has been actively participating in advanced reactor stakeholder meetings and has provided presentations to offer its view on topics such as consequence based security approaches.

In addition to these domestic activities, the NRC staff participates in several international activities related to the development and licensing of non-LWRs. A number of IAEA initiatives support the development and deployment of non-LWR technologies and develop tools and guidance documents for use by Member States:

- IAEA, in collaboration with the International Project on Innovative Nuclear Reactors and Fuel Cycles and the Generation IV International Forum, established the Sodium-Cooled Fast Reactor Task Force. This task force collaborates with international designers, governmental organizations, and regulators to develop safety design criteria and safety design guidelines for SFRs. IAEA also has a coordinated research activity on modular HTGR (MHTGR) safety design criteria.

- In addition to specific technical areas, IAEA and organizations such as the World Nuclear Association publish useful summaries of non-LWR designs and the status of programs in various countries. The NRC staff continue to participate in the NEA Committee on Nuclear Regulatory Activities, including the Group on the Safety of Advanced Reactors.

Enclosure 1 contains additional information on these activities under Strategy 6, “Develop and implement a structured, integrated strategy to communicate with internal and external stakeholders having interests in non-LWR technologies.”

3.0 Non-Light Water Reactor Technologies

For the purpose of NRC non-LWR readiness activities, the staff has considered HTGRs, liquid-metal fast reactors (LMFRs), and MSRs, in which the fuel may or may not be dissolved in the coolant, as the designs of interest in the near term. This choice is based on the NRC's experience and is not intended as a "down-select" of the potential non-LWR designs currently being explored by industry and DOE. This design set will be reviewed frequently during execution of the near-term IAP and will be informed by the plans of prospective applicants to prioritize activities and to make effective use of the NRC's resources. Figure 3 summarizes the diversity of designs currently being developed.[8]

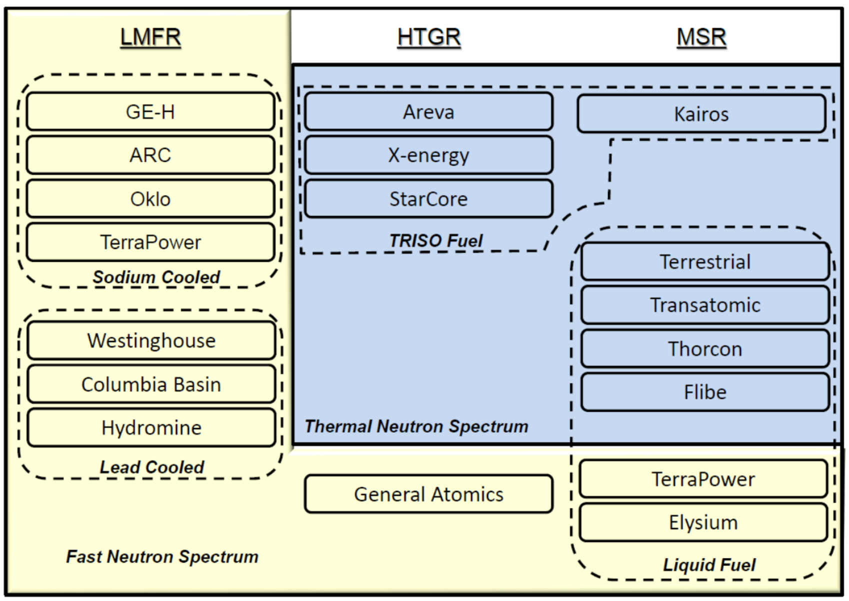

Figure 3: Companies developing non-LWR designs

3.1 Fast Reactors

The United States has had a long history of R&D focused on commercial demonstration and development of fast reactors—with most of the activities dedicated to LMFRs and SFRs specifically. Current activities related to the development of non-LWR technologies also include possible fast reactor designs within the HTGR and MSR categories, as shown in Figure 3. Figure 4 provides a summary from NUREG/KM-0007, "NRC Program on Knowledge Management for Liquid-Metal-Cooled Reactors," issued April 2014[9], of the key historical domestic LMFR projects. Fast reactors within the gas-cooled or molten-salt technologies have been largely limited to design and smaller scale R&D activities.

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8 The list of companies in this figure is taken from the members of technology working groups listed in Table 1. The list does not include technologies such as fusion energy or accelerator-driven systems and may not be inclusive of all companies actively developing designs even within the list categories of fast reactors, LMFRs, HTGRs, and MSRs.

9 See NRC Program on Knowledge Management for Liquid-Metal-Cooled Reactors," issued April 2014 (ADAMS Accession No. ML14128A346).

Table C.7 U.S. LMR Projects after 1950

- Experimental Breeder Reactor-I (EBR-I)
  - Operated 1951–1964
  - World's first electricity from a nuclear plant
- Experimental Breeder Reactor-II (EBR-II)
  - Critical 1961, power operation 1964–1994
  - Major contribution to fuels and materials testing
- Enrico Fermi Nuclear Generating Station (Fermi)
  - Operated 1963–1972
  - First attempt at commercial LMR plant
- Southwest Experimental Fast Oxide Reactor (SEFOR)
  - Operated 1969–1972
  - Definitive measurement of oxide-fueled LMR Doppler feedback
- Fast Flux Test Facility (FFTF)
  - Operated 1980–1992
  - Established world record for fuel performance
- Clinch River Breeder Reactor (CRBR)
  - Design began 1969, 1982 NRC site preparation approval
  - Funding cut off by Congress 1984
- Extensive design studies for commercial LMRs
- 1964 1000-MW(e) designs
  - Separate designs developed by GE, Westinghouse, Combustion Engineering, and Allis-Chalmers
  - Oxide and carbide fuel studied
  - Varying core aspect ratios and layouts
- 1967–69 Follow-on 1000-MW(e) studies
  - Focus on U-Pu oxide fuel
  - Loop and pool configurations
  - Different core configurations
- Reduced effort with focus on FFTF and CRBR
- 1977 President Carter deferred commercialization tasks, emphasized non-proliferation
- Studies such as Advanced Liquid Metal Reactor (ALMR) continued at lower level
- Current Global Nuclear Energy Partnership (GNEP) studies reflect renewed interest in LMRs

Figure 4: U.S. LMFR experience

Table C-8 in NUREG/KM-0007 summarizes experimental, demonstration, and commercial fast reactors outside the United States. Major programs and operating plants have existed in China, France, Germany, India, Japan, the Russian Federation, and the United Kingdom. Currently operating LMFRs include research and larger experimental reactors in the Russian Federation and experimental reactors in India and China. Additional LMFRs are under construction in India and are planned for China and the Russian Federation. More specific information can be found in the IAEA publication, “Nuclear Power Reactors in the World,” issued May 2017.

DOE has an active R&D program for fast reactor technologies and related activities associated with the nuclear fuel cycle. Ongoing research being conducted primarily at Argonne National Laboratory (ANL) includes testing materials and components, developing ultrasonic monitoring techniques, and improving modeling and simulation capabilities. Other ANL activities focus on knowledge preservation, including the collection and organization of information from databases related to research activities conducted at EBR-II, FFTF, TREAT, and other facilities. The GAIN initiative and NEUP also support R&D activities related to fast reactors. DOE's Nuclear Energy

Advisory Council and others cite the potential benefits of a test or demonstration fast reactor in areas such as materials testing as a rationale for DOE to begin a process to design and construct a new fast reactor.

Companies currently involved in the design of fast reactors include the following:

- Sodium Cooled
  - GE Hitachi - PRISM
  - Advanced Reactor Concepts (ARC) - ARC-100
  - Oklo, Inc.- OKLO
  - TerraPower - Traveling Wave Reactor Lead or Lead-Bismuth Cooled
  - Westinghouse - Lead-cooled Fast Reactor
  - Columbia Basin - Lead-Bismuth SMR

    Hydromine – Lead Cooled
- Gas Cooled
  - General Atomics - Energy Multiplier Module
- Molten Salt
  - TerraPower, LLC - MCFR
  - Elysium Industries - Molten Chloride Salt Fast Reactor (MCSFR)

Other participants in the fast reactor TWG include Duke Energy, Exelon, and Southern Company.

The NRC has had experience with fast reactors though the preapplication reviews of the Power Reactor Innovative Small Module (PRISM) (see NUREG-1368, "Preapplication Safety Evaluation Report for the PRISM Liquid-Metal Reactor," issued February 1994[10]) and SAFR (see NUREG-1369, "Preapplication Safety Evaluation Report for the Sodium Advanced Fast Reactor (SAFR) Liquid-Metal Reactor," issued December 1991[11])), as well as the licensing reviews performed for the Clinch River Breeder Reactor Project (see the summary in NUREG/KM-0007). The staff had very limited interactions around 2010 with Toshiba related to the 4S (Super-Safe, Small and Simple) reactor design. Current activities include preapplication discussions with Oklo, Inc., participation in standards development organizations, and interactions with DOE and the fast-reactor TWG.

3.2 High-Temperature Gas-Cooled Reactors

The U.S. nuclear energy program has a long history of R&D focused on the commercial demonstration and development of HTGRs. Figure 5 is a summary of U.S. licensing and prelicensing interactions with HTGR designers from the HTGR Technology Course provided to the NRC staff in 2010.

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10 See NUREG-1368, "Preapplication Safety Evaluation Report for the PRISM Liquid-Metal Reactor," issued February 1994 (ADAMS Accession No. ML063410561).

11 See NUREG-1369, "Preapplication Safety Evaluation Report for the Sodium Advanced Fast Reactor (SAFR) Liquid-Metal Reactor," issued December 1991 (ADAMS Accession No. ML063410547).

US HTGR Licensing and Pre-licensing History

US Program	Licensing Period	Organization	Stage
Peach Bottom-1	1958-1966	PECO	OL Issued Decommissioned
Ft. St. Vrain (Prismatic)	1966-1972	PS Colo.	OL Issued Decommissioned
Summit (Prismatic)	1972-1975	GA	CP-LWA Submitted
MHTGR (Prismatic)	**1986-1995**	**DOE/GA**	**Pre-App Review**
Exelon DC (Pebble)	**2001-2002**	**Exelon**	**Pre-App Review**
PBMR DC (Pebble)	**2006-current**	**PBMR (Pty.) Ltd**	**Pre-App Review**
NGNP (Prismatic/Pebble)	**2009-current**	**DOE**	**Pre-App Review**

Idaho National Laboratory 3 PBMR

Figure 5: U.S. HTGR licensing and prelicensing history

Figure 6 is taken from the same course given to the NRC staff and summarizes experimental, demonstration, and commercial HTGRs outside the United States. In addition to those listed in Figure 6, a large number of gas-cooled reactors with carbon dioxide coolant and with other differences from the HTGR subcategory of gas-cooled reactors have operated in various countries, and such reactors continue to operate in the United Kingdom. Major programs and operating HTGR plants have existed in the United Kingdom, Germany, and Japan. Currently operating HTGRs include research reactors in Japan and China. A significant update since 2010 shows that China is currently constructing power reactor HTGRs, which could go into operation in 2018. More specific information can be found in the IAEA publication, "Nuclear Power Reactors in the World," issued May 2017.

Non-US HTGR Licensing and Pre-licensing History

International	Licensing Period	Country /Organization	Stage
Dragon	1959-1964	UK /OECD/NEA	OL Issued Decommissioned
HTTR (Prismatic)	1985-1998	Japan	OL Issued
AVR (Pebble)	1959-1967	Germany /FJZ	OL Issued Decommissioned
THTR (Pebble)	1979-1983	Germany	OL Issued Decommissioned
HTR Modul (Pebble)	**1987-1990**	**Germany /Siemens**	**Pre-App Review**
HTR-10 (Pebble)	1994-1995	China / CNNC	OL Issued
PBMR-400 (Pebble)	1999-current	South Africa /PBMR (Pty) Ltd.	CP App Review

INL Idaho National Laboratory 4 PBMR

Figure 6: Non-U.S. HTGR licensing and prelicensing history

DOE has an active R&D program for HTGRs. The Energy Policy Act of 2005 established the NGNP to demonstrate the production of electricity or hydrogen with a high-temperature nuclear energy source. The initial goal was for a plant to be operational by 2021. The NGNP involved collaborative work between DOE and private companies and advanced the design and consideration of potential uses for HTGR technology. Various issues, including the falling price of natural gas, resulted in a reduction of the scope of the project in 2011 to focus on R&D. Ongoing research primarily at INL includes testing materials and components, irradiating and testing TRISO fuel particles, and improving modeling and simulation capabilities. DOE programs such as the GAIN initiative and NEUP also support R&D activities related to HTGRs.

Companies currently involved in the TWG for HTGRs include Areva, BWXT, Duke Energy, Kairos Power, Starcore, and X-energy. These companies and others are also members of the NGNP Industry Alliance consortium, which promotes the development and commercialization of HTGR technologies.

The NRC conducted a preapplication review of the conceptual design of the MHTGR beginning in 1986. The staff documented the results of its review in NUREG-1338, “Draft Preapplication Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor,” issued March 1989[12]. The MHTGR reactor plant design is a small, modular, graphite-moderated, helium-cooled, high-temperature, thermal-powered reactor plant design that derived some of its features from the Fort St. Vrain plant, which was licensed by the Atomic Energy Commission in

12 See NUREG-1338 “Draft Preapplication Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor,” issued March 1989 (ADAMS Accession No. ML052780497).

the early 1970s and ceased operation in 1989. The NRC directed its review approach and criteria toward meeting the guidance in the Commission's 1986 and 1994 advanced reactor policy statements. The review consisted of an indepth analysis of the potential licensing issues associated with the MHTGR's design features, potential policy issues, and technical issues, as well as confirmatory R&D programs and plans for prototype testing. In 1996, Congress eliminated funding for the MHTGR program, and the NRC terminated its review activities.

Exelon Generation Company (Exelon) began preapplication discussions with the NRC on the licensing of the Pebble Bed Modular Reactor (PBMR) in the United States in 2001. The PBMR is a pebble-bed, helium-cooled, thermal HTGR design. The preapplication interactions included an NRC review of a series of Exelon-prepared white papers on licensing and technical topics. Exelon subsequently ended interactions, and the NRC did not prepare a preliminary safety evaluation report. PBMR (Pty) Limited, a South Africa-based firm established in 1999 to develop and market small-scale, high-temperature reactors both in South Africa and internationally, conducted preapplication discussions with the NRC on the PBMR design in the early 2000s. These discussions included the NRC review of a series of white papers from PBMR (Pty) Ltd. Ultimately, PBMR (Pty) Ltd. did not submit a licensing application.

Consistent with the Energy Policy Act of 2005, the NRC actively participated with DOE on research and preapplication regulatory activities for DOE's NGNP project. A joint DOE/NRC working group developed the strategy for licensing the NGNP. "The Next Generation Nuclear Plant Licensing Strategy: A Report to Congress," filed in August 2008 (ADAMS Accession No. ML082290017), documents this strategy. The report identifies NRC licensing requirements for LWRs that could present a challenge to licensing non-LWR technologies. The challenges identified in the report helped inform the staff's development of the IAPs discussed in Enclosure 1.

3.3 Molten-Salt Reactors

The current interest in non-LWRs includes activities by a number of companies and DOE to develop MSR designs. ORNL first developed and tested MSR technology in the United States in the 1950s and 1960s with the Aircraft Reactor Experiment and Molten-Salt Reactor Experiment. Those activities were discontinued, and DOE focused its R&D activities on reactor technologies other than MSRs. The Generation IV International Forum selected MSR technology as one of the advanced reactor technologies warranting consideration and further R&D.

The companies currently in the MSR TWG include the following:

- TerraPower, LLC - MCFR
- ThorCon Power - ThorCon molten salt reactor
- Terrestrial Energy, Inc. - Integral Molten Salt Reactor (IMSR)
- Flibe Energy - liquid-fluoride thorium reactor
- Transatomic Power – advanced molten salt reactor
- Elysium Industries - MCSFR

Other participants in the MSR TWG include Duke Energy, Exelon, Southern Company, and Tennessee Valley Authority.

The NRC has no experience in licensing MSRs. The staff's initial focus for this technology has been to acquire or develop sufficient knowledge, technical skills, and capacity to support the

future licensing of MSRs. Enclosure 1 describes the training and knowledge management initiatives related to MSRs in IAP Strategy 1, “Acquire/develop sufficient knowledge, technical skills, and capacity to perform non-LWR regulatory reviews.” The NRC contracted with ORNL to develop and deliver training to provide an overview of MSR technology. Approximately 90 NRC staff members attended one of three 2-day training sessions in calendar year 2017. The first session was video recorded and is available for staff review. ORNL placed its presentation materials in ADAMS, and they are available on NRC’s public Web site.

Current activities include planning discussions with MSR developers and initial assessments of technology-specific issues, such as the qualification of liquid-fueled MSRs. The staff is interacting with the Canadian Nuclear Safety Commission (CNSC), which is having preapplication discussions with developers of MSRs and other non-LWR designs. The CNSC recently completed the first phase of a vendor design review for Terrestrial Energy’s IMSR. Additional information related to the vendor design review is available on the CNSC Web site at http://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm.

DOE has an active R&D program for MSR technologies. Ongoing research being conducted primarily at ORNL includes developing and testing materials. DOE programs such as the GAIN initiative and NEUP largely support R&D activities related to MSRs.

Table 1

GAIN TECHNOLOGY WORKING GROUPS (TWG)

Molten Salt Reactor	
Duke Energy	*Charlotte, North Carolina*
Elysium Industries	*Boston, Massachusetts*
Exelon Corporation	*Chicago, Illinois*
Flibe Energy, Inc.	*Huntsville, Alabama*
Southern Company	*Birmingham, Alabama*
TerraPower, LLC	*Bellevue, Washington*
Terrestrial Energy USA Ltd.	*New York, New York*
Thorcon USA	*Stevenson, Washington*
Transatomic Power Corporation	*Cambridge, Massachusetts*
High Temperature Gas Reactor	
AREVA NP, Inc.	*Lynchburg, Virginia*
BWX Technologies, Inc.	*Lynchburg, Virginia*
Duke Energy	*Charlotte, North Carolina*
Kairos Power	*Oakland, California*
StarCore Nuclear	*Montreal, Canada*
X-Energy, LLC	*Greenbelt, Maryland*
Fast Reactor	
Advanced Reactor Concepts, LLC	*Chevy Chase, Maryland*
Columbia Basin Consulting Group, LLC	*Kennewick, Washington*
Duke Energy	*Charlotte, North Carolina*
Elysium Industries	*Boston, Massachusetts*
Exelon Corporation	*Chicago, Illinois*
General Atomics	*San Diego, California*
General Electric-Hitachi	*Wilmington, North Carolina*
Hydromine, Inc.	*New York City, New York*
Oklo, Inc.	*Sunnyvale, California*
Southern Company	*Birmingham, Alabama*
TerraPower, LLC	*Bellevue, Washington*
Westinghouse Electric Co., LLC	*Cranberry Township, Pennsylvania*

Note: GAIN, DOE, EPRI, and NEI participate in all of the TWG teams.