ENCLOSURE 2: ADVANCED REACTOR LICENSING ACTIONS—PROGRESS SUMMARY

1.0 Introduction

This enclosure covers progress made in advanced reactor licensing during calendar year (CY) 2022 by the U.S. Nuclear Regulatory Commission (NRC) staff. Based on indications from prospective applicants, the NRC staff expects preapplication engagement and application submittals to increase in CY 2023. Significant accomplishments in 2022 include the following:

- On February 14, 2022, the NRC staff approved Abilene Christian University's Quality Assurance Program Description Topical Report.[1]

- On September 29, 2022, the NRC staff completed and published a draft environmental impact statement for the Kairos Power, LLC, (Kairos) Hermes construction permit (CP) application.[2]

- On November 18, 2022, the NRC staff completed its acceptance review of Abilene Christian University's application for a CP for its molten salt research reactor.

- On December 2, 2022, the NRC staff completed the review of one white paper from Oklo, Inc., supporting a future application.[3]

- The NRC staff completed the review of three topical reports from Kairos, which support both the Hermes Test Reactor and the future Kairos power reactor.

- The NRC staff completed the review of 19 white papers from Westinghouse Electric Company, LLC, supporting its design certification future application for the eVinci™ micro-reactor.

- The NRC staff completed the review of three white papers from Terrestrial Energy USA, Inc., supporting its future Standard Design Approval application.

- The NRC staff completed the review of two white papers from the University of Illinois at Urbana-Champaign (UIUC) supporting its future CP application for a research reactor.

- The NRC staff completed the review of one white paper and one topical report from TerraPower, LLC, supporting a future CP application for the Natrium reactor.

- The NRC staff completed the review of three white papers and one topical report from X-energy, LLC, supporting its future CP application for the Xe-100 reactor.

- The NRC staff completed the review of four topical reports from NuScale Power, LLC, that will be referenced in the Standard Design Approval application.[4]

- The NRC staff has also completed the review of one generic topical report on emergency planning zones[5] that can be referenced by a future licensing application that uses the NuScale design.

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1 Agencywide Documents Access and Management System (ADAMS) Accession No. ML22028A366
2 ML22259A126
3 ML22293B811
4 ML22325A349
5 ML22299A046

- The NRC staff completed the review of two licensing topical reports from GE-Hitachi Nuclear Energy Americas, LLC, (GE-Hitachi) to support a future licensing application for the BWRX-300 reactor.

- The NRC staff completed the review of five white papers from SMR, LLC, (Holtec) to support its future CP application for the SMR-160 reactor.

- The NRC staff collaborated with the Canadian Nuclear Safety Commission to issue in April and May 2022 two joint reports under the memorandum of cooperation on advanced reactor and small modular reactor (SMR) technical review approaches and preapplication activities. The April report addressed GE-Hitachi's containment evaluation method for the BWRX-300.[6] The May report concerned Terrestrial's methodology for developing a postulated initiating events list for the integral molten salt reactor.[7]

- The NRC and Canadian Nuclear Safety Commission also issued two interim joint reports on tristructural isotropic (TRISO) fuel qualification.[8]

2.0 Detailed Updates on Application Reviews and Preapplication Activities of Non-Light-Water Reactor Designs

2.1 Overview

Figure 1 shows some of the designs for non-light-water reactors (non-LWRs) currently in development. The figure is not intended to be inclusive of all companies that are actively pursuing the development of reactor designs within the four technology categories represented in the figure. Further, it does not cover technologies such as fusion energy systems and accelerator-driven systems.

6 ML22091A201
7 ML22139A124
8 ML22030A000 and ML22101A297

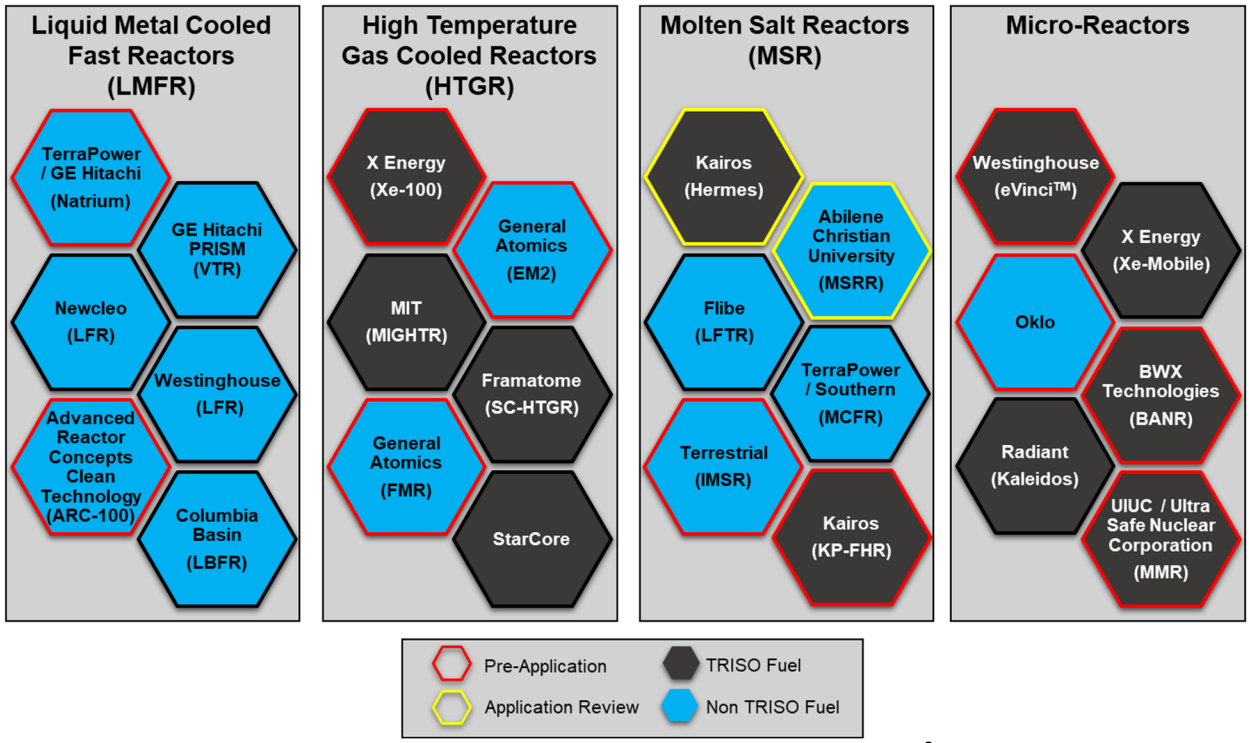

Figure 1: Overview of Non-LWR Developers[9]

2.2 Kairos Power, LLC

Kairos is developing a 140-megawatt electric (MWe) commercial fluoride salt-cooled high-temperature reactor (KP-FHR). In support of its commercial design, Kairos has submitted 11 topical reports to the NRC. Eight of these topical reports have been approved, and the Advisory Committee on Reactor Safeguards is reviewing the remaining three.

In September 2021, Kairos also submitted to the NRC a CP application for a 35-megawatt thermal (MWt) test reactor called Hermes to assist in the development of a commercial version of its KP-FHR technology. Kairos proposed to build Hermes near Oak Ridge, Tennessee as a nonpower reactor under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." The CP application was accepted for review in November 2021. The schedule for the Hermes review included final issuance of a safety evaluation and environmental impact statement in September 2023. The staff review is on schedule.

9 Acronyms used in graphic not defined elsewhere: Power Reactor Innovative Small Module (PRISM), Versatile test reactor (VTR), Lead Fast Reactor (LFR), Lead-Bismuth Fast Reactor (LBFR), Energy Multiplier Module (EM2), Massachusetts Institute of Technology (MIT), Modular Integrated Gas-cooled High Temperature Reactor (MIGHTR), Steam Cycle High Temperature Gas-cooled Reactor (SC-HTGR), Fast Modular Reactor (FMR), Liquid Fluoride Thorium Reactor (LFTR), Molten Chloride Fast Reactor (MCFR), BWXT Advanced Nuclear Reactor (BANR), Micro Modular Reactor (MMR), High Temperature Gas-Cooled Reactor (HTGR), and Integral Molten Salt Reactor (IMSR).

2.3 Abilene Christian University

In March 2020, Abilene Christian University submitted to the NRC a letter of intent to submit an application for a CP for a non-power molten salt research reactor.[10] The university provided an initial regulatory engagement plan (REP) on July 24, 2020 with an updated version submitted in May 2022.[11] REPs outline the activities that prospective and current applicants expect to undertake in support of an application to the NRC for a license, certified design, or standard design approval. The proposed reactor would be an up to 1 MWt, graphite -moderated, fluoride salt flowing fluid (fuel dissolved in the salt) research reactor located on the Abilene Christian University campus in Abilene, Texas. On February 14, 2022, the NRC staff approved Abilene Christian University's Quality Assurance Program Description Topical Report[12] in support of their molten salt research reactor application. On August 12, 2022, Abilene Christian University submitted its application for a CP for the molten salt research reactor.[13] The NRC staff completed its acceptance review of this application and docketed the application for detailed review on November 18, 2022. By letter dated December 16, 2022, the NRC staff outlined an 18-month review schedule for the application.[14]

2.4 University of Illinois Urbana-Champaign

In May 2021, the University of Illinois Urbana-Champaign submitted to the NRC a letter of intent to submit an application for a CP for a High Temperature Gas-Cooled Reactor.[15] UIUC submitted its latest revision of its REP on August 3, 2022.[16] In its topical report submittal titled, "Applicability of Nuclear Regulatory Commission Regulations,"[17] UIUC stated that the operating power level for its reactor will be set to a level that would meet NRC requirements for a testing facility. The reactor would use TRISO particle fuel, helium gas coolant, graphite moderator, and a molten salt secondary loop providing electrical power conversion capability for campus use. UIUC stated in its REP that there is no intention for the power production to be used as a commercial product and sold by the University, but rather as part of the facility's research and training activities. The reactor would be located on UIUC's campus in Urbana-Champaign, Illinois. The NRC received two white papers and two topical reports from UIUC. The NRC staff has provided feedback on the received white papers while the topical reports are under review. Based on the REP, UIUC will be submitting seven more topical reports through 2023 in preparation for a CP application in the second quarter of 2024.

2.5 TerraPower, LLC

The Natrium reactor currently under development by TerraPower and GE-Hitachi is a 345 MWe sodium fast reactor with gigawatt-hour-scale, molten salt energy storage. The storage can boost output to 500 MWe of power for more than 5 and 1/2 hours when needed. The Department of Energy selected the Natrium reactor for the Advanced Reactor Demonstration Program. The first Natrium reactor would be sited in Kemmerer, Wyoming, and would replace the Naughton coal-fired power station, but not on the coal plant site. TerraPower provided a REP on

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10 ML20211L857
11 ML20241A071 and ML22157A033
12 ML22028A366
13 ML22227A202
14 ML22341A615
15 ML21153A059
16 ML22216059
17 ML222343A282

June 8, 2021. TerraPower's REP outlines the proposed activities that would support licensing the Natrium reactor.[18] TerraPower convened a design overview meeting to familiarize staff with the design and the inherent safety features the company plans to rely on for its safety case. The overview meeting was held May 23–25, 2022, in Rockville, Maryland.[19] The NRC has received a total of 10 preapplication submittals from TerraPower and has completed the review of 6 of these submittals. TerraPower has informed the NRC staff that it plans to submit a CP application under 10 CFR Part 50.

2.6 X-energy, LLC

The X-energy Xe-100 reactor design is a pebble-bed high temperature gas reactor. It would be a 200 MWt (75 MWe) reactor that would be built as a standard four-pack unit. The reactor would use X-energy's proprietary version of fuel (TRISO-X) using high-assay, low-enriched uranium (HALEU). X-energy has actively engaged in preapplication activities with the NRC since 2019. X-energy is pursuing the 10 CFR Part 50 licensing approach. It plans to submit a CP application followed by an operating license application. On May 10, 2022, X-energy submitted a revised REP and later an addendum to the REP update on May 27, 2022.[20] The NRC has received a total of 15 preapplication submittals from X-energy and has completed the review of 8 of these submittals.

2.7 Westinghouse Electric Company, LLC

The Westinghouse eVinci™ reactor would be a heat-pipe micro-reactor designed to be assembled in a factory and delivered to a site. Westinghouse submitted an updated REP on December 21, 2022, that described its plans for preapplication engagement on the eVinci™ micro-reactor.[21] Westinghouse has submitted 24 white papers, and the NRC staff has provided feedback on 19 of them. Westinghouse plans to submit several topical reports for NRC staff's review in 2023. Future plans include licensing a testing facility followed by commercial licensing activities. Commercial licensing may involve a design certification and multiple licenses that could include a manufacturing license, CP, combined license, and material and transportation licenses.

2.8 Oklo, Inc.

During 2021, the NRC staff continued to engage with Oklo to obtain detailed technical information about the safety of the design that was missing from the combined license application for the Aurora design.[22] Without this information, the staff was unable to establish a schedule for the detailed technical review or reach safety findings required for licensing the facility. On January 6, 2022, the NRC denied, without prejudice, the Oklo combined license application, based on Oklo's failure to provide information on several key topics for the Aurora design.[23]

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18 ML21159A221
19 ML22244A243
20 ML22130A666 and ML22146A405
21 ML22355A185
22 ML20075A000
23 ML21357A034

By letter dated March 29, 2022, Oklo submitted a licensing project plan for an advanced reactor.[24] A licensing project plan is similar to a REP. On November 23, 2022, Oklo submitted an update to the licensing project plan.[25] Oklo has been actively engaged in preapplication activities with the NRC since the submittal of the licensing project plan. The NRC staff has completed the review of one white paper from Oklo supporting a future application. The NRC staff and Oklo have met to discuss important topics related to their advanced reactor.

2.9 Terrestrial Energy USA, Inc.

Terrestrial is developing the integral molten salt reactor, a 442 MWt reactor using low-enriched uranium in a fuel salt form. The integral molten salt reactor integrates all primary system reactor components into a sealed and replaceable reactor core. Terrestrial first submitted a REP on December 30, 2019, with the most recent revision on June 16, 2022.[26] The NRC staff has provided feedback on all seven white papers which have been submitted by Terrestrial in support of the integral molten salt reactor design.

3.0 Detailed Updates on Application Reviews and Preapplication Activities of Light-Water Reactor Designs

3.1 NuScale US460

The NuScale US460 design is an integral pressurized-water reactor with passive safety systems. Safety-related power is not needed to shut down and maintain the power plant in a safe condition. The NuScale plant is a natural circulation, light-water SMR with the reactor core and helical coil steam generators located in a common reactor vessel in a cylindrical steel containment (module). The reactor vessel containment modules are submerged in water in the reactor building safety related pool, which is also the ultimate heat sink for the reactors. The reactor building is designed to hold up to 12 modules, each rated at 77 MWe. The pool portion of the reactor building is located below grade. On January 8, 2023, NuScale completed submittal of their Standard Design Approval application.[27] The NRC staff will complete its 60-day acceptance review by March 10, 2023. In conjunction with the Standard Design Approval application, the Carbon Free Power Project, LLC, a wholly owned subsidiary of the Utah Associated Municipal Power Systems, will be submitting a combined license application to build and operate the NuScale US460 power plant after the review and approval of the NuScale US460 Standard Design Approval application.

3.2 SMR, LLC (A Holtec International Company)

The SMR-160 is a pressurized-water reactor with passive safety systems designed by SMR, LLC, a Holtec International Company. The reactor, steam generator, and spent fuel pool are located in containment where the reactor core is well below grade. The SMR-160 has a rated electrical output of 160 MWe. On July 29, 2022, SMR (Holtec) submitted Revision 1 to its REP, which described its preapplication activities to support a future CP application.[28] On October 3, 2022, SMR (Holtec) submitted an update to its voluntary response to NRC Regulatory Issue Summary 2020-02, “Process for Scheduling and Allocating Resources for

[24] ML22088A184
[25] ML22327A260
[26] ML20023A254 and ML22178A052
[27] ML22325A349
[28] ML22210A033

Fiscal Years 2023–2025 for the Review of New Licensing Applications for Light-Water Reactors and Non-Light-Water Reactors," dated August 31, 2020, and Revision 2 to its proposed REP.[29] The NRC staff is actively engaged in preapplication discussions with SMR (Holtec) on a variety of topics to support its CP application. SMR (Holtec) has submitted five white papers for NRC staff review and the staff has provided feedback.

3.3 GE-Hitachi Nuclear Energy Americas, LLC

The GE-Hitachi BWRX-300 is a water-cooled, natural circulation SMR with passive safety systems designed to operate at approximately 300 MWe. The design of the BWRX-300 is based on the NRC-design-certified 1,520 MWe economic simplified boiling-water reactor and the Global Nuclear Fuels (GNF) existing and licensed GNF2 fuel design. GE-Hitachi has been engaged with the NRC staff in preapplication activities since September 26, 2019. GE-Hitachi has submitted five topical reports to date that include innovative design concepts and key safety licensing issues. The NRC staff has completed the review of all five submitted reports. GE-Hitachi is expected to submit four additional topical reports for staff review in 2023.

The Tennessee Valley Authority entered into an agreement with GE-Hitachi to support its planning and preapplication engagement for the potential deployment of a BWRX-300 SMR at the Clinch River site near Oak Ridge, Tennessee.

The Canadian utility Ontario Power Generation selected the BWRX-300 SMR for the Darlington nuclear site and will work with GE-Hitachi to deploy the reactor as early as 2028. In addition, the Canadian utility SaskPower has selected the BWRX-300 SMR for potential deployment in Saskatchewan in the mid-2030s.

The Canadian Nuclear Safety Commission is also participating in preapplication activities with the NRC regarding the BWRX-300 SMR, pursuant to the 2019 memo of cooperation on advanced reactor and SMR technologies and pursuant to the Collaborative Information Sharing Charter approved by the respective regulatory agencies for the specific review of the BWRX-300 SMR.

4.0 Detailed Updates on Application Reviews and Preapplication Activities of Advanced Fuel Production Facilities

Advanced reactor designers are considering several fuel types, including fuels based on TRISO particles, metallic uranium alloys, and liquid salt fuels. The NRC staff is conducting preapplication interactions to support the fuel cycle for advanced reactor technologies. X-energy submitted, "TRISO-X Fuel Fabrication Facility License Application Submittal,"[30] on April 5, 2022. Kairos has indicated it will submit an application for the "Kairos Power Atlas Fuel Fabrication Facility,"[31] which would be a Category II fuel facility to produce HALEU TRISO fuel. The facility is expected to be located near the Hermes reactor. Kairos has continued preapplication discussions with the NRC staff.

In June 2021, the NRC staff approved a license amendment authorizing American Centrifuge Operating, LLC, a subsidiary of Centrus Energy Corp., to demonstrate commercial production of

[29] ML20202A496 and ML22276A084
[30] ML22101A200
[31] ML22028A087

HALEU at the American Centrifuge Plant in Piketon, Ohio, fuel enrichment facility for the duration of the 3-year Department of Energy/American Centrifuge Operating contract, which initially had an expiration date of May 31, 2022.[32] The approval authorized production of up to 600 kilograms (kg) of HALEU in the form of uranium hexafluoride (UF_6) enriched to 19.75 percent uranium-235 by weight. In April 2022, the Department of Energy extended the demonstration contract with provisions for an increased cost-sharing arrangement. In April 2022, American Centrifuge Operating submitted an amendment request to the NRC to extend the NRC's approval for the HALEU demonstration program through November 30, 2022, which the NRC approved in August 2022.[33] On November 10, 2022, the Department of Energy announced an approximately $150 million cost-shared award to American Centrifuge Operating to produce HALEU at the American Centrifuge Plant. The award includes a $30 million cost share during the first year in which American Centrifuge Operating will complete the installation of the 16 operating centrifuge cascades and produce, by December 31, 2023, at least 20 kg of 19.75 percent enriched HALEU in the form of UF_6 (Phase 1). On November 30, 2022, American Centrifuge Operating submitted an amendment request to the NRC for Phase 1.[34] Phase 2 will involve production of 900 kg UF_6 HALEU by the end of 2024. Phase 3, which will be subject to appropriations, will involve three 3-year option periods at a production rate of 900 kg UF_6 HALEU per year.[35]

The NRC staff is engaged in additional preapplication engagements with four commercial vendors on production of HALEU for advanced reactor fuels. These interactions have included informal exchanges and one formal letter of intent concerning license applications or amendments to permit HALEU production.[36] The NRC staff has received and is reviewing several initial licensing requests for the enrichment, fabrication, and transportation of HALEU, and it anticipates receiving HALEU-related license amendment applications from existing facilities.

32 ML21138A827
33 ML22123A143 and ML22208A057
34 ML22340A477
35 ML22353A529
36 ML21292A180