REGULATORY CONSIDERATIONS FOR EVINCI™ MICROREACTOR

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Abstract

Westinghouse is designing the **eVinci™** microreactor to be licensable and deployed in the United States (U.S.) and abroad. While the deployment model detailed in the paper is generic, it is understood that licenses or regulatory approvals needed will be country-specific, and therefore, additional considerations for deployment may be considered in the future.

1. INTRODUCTION

There are several paths available to achieve regulatory approval for the eVinci microreactor. In the U.S., the final regulatory path will depend on several factors, including the eVinci microreactor design, U.S. Nuclear Regulatory Commission (NRC) rulemaking for advanced reactors, Westinghouse partnerships, and feedback from pre-application engagement with the NRC. Westinghouse has developed a standard deployment model for the eVinci microreactor as depicted in Figure 1.1. The proposed licensing path and deployment model for the eVinci microreactor can be achieved under the current NRC regulatory framework, albeit some regulations and licenses are being achieved or used in new and novel ways. A summary of the eVinci microreactor design and an overview of the anticipated regulatory framework and associated challenges needing resolution to support the unique deployment model is detailed in the paper.

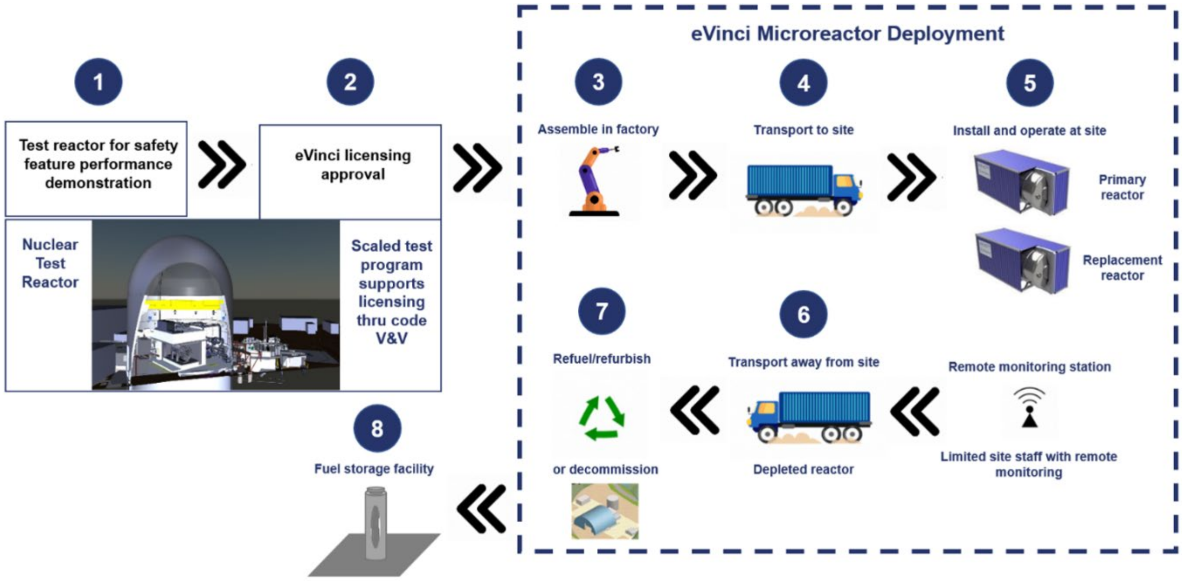

Fig. 1.1 eVinci Microreactor Deployment Model

eVinci is a trademark or registered trademark of Westinghouse Electric Company LLC, its affiliates and/or its subsidiaries in the United States of America and may be registered in other countries throughout the world.

2. SUMMARY OF THE EVINCI MICROREACTOR AND FACILITY DESCRIPTION

2.1. eVinci Microreactor Operation

The eVinci microreactor is a 15 MW_t thermal neutron spectrum reactor that delivers high temperature heat from the reactor core through heat pipes and a primary heat exchanger (PHX) to an open-air Brayton power conversion system (PCS). The reactor core is enclosed within a canister filled with an inert gas just above atmospheric pressure to protect reactor components from oxidation while enhancing heat transfer. The core design consists of graphite blocks with repeated, segmented, hexagonal unit cells oriented horizontally along the length of the core. The unit cells contain channels for fuel, burnable absorbers, alkali metal heat pipes, and shutdown rods. A cutaway illustration of the reactor core is shown in Figure 2.1. The reactor uses high-assay, low-enriched uranium (HALEU) tristructural isotropic (TRISO) fuel. The core is surrounded by a thick radial reflector that houses the control drums. The core alone, without the radial reflector, is subcritical, requiring the radial reflector to achieve criticality. Shielding attenuates gamma and neutron radiation to protect site personnel and the public during operation and transportation. The PCS receives reactor heat from the PHX and converts it from 15 MW_t to 5 MW_e (nominal) with an open-air Brayton cycle.

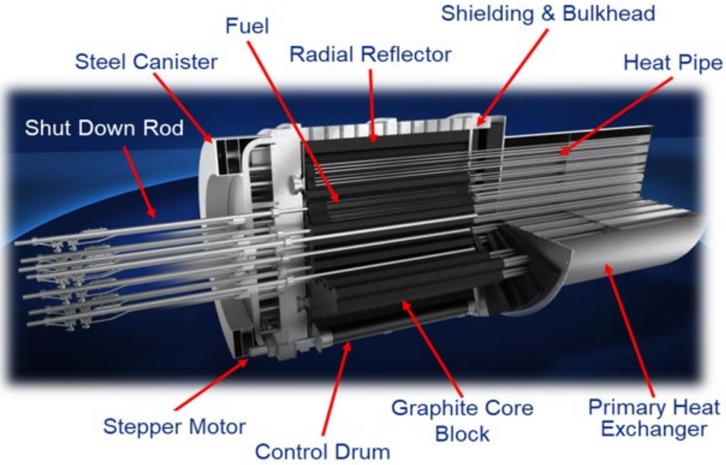

Fig. 2.1 eVinci Microreactor Cutaway

The canister system does not function as a pressure vessel but instead as an element of the functional containment. During normal operation, the canister is pressurized just above atmospheric pressure with helium to eliminate oxidation of core components and increase thermal gap conductance. The design of the microreactor allows for decay heat removal through the core block, radial reflector, canister system, and shielding. Several layers of the TRISO fuel and the canister together represent the barriers that exist to preclude the release of fission products to the environment and collectively represent the functional containment.

Reactivity control is accomplished using control drums located on the periphery of the core and burnable absorbers in the core. Reactivity is monitored using the power range and source range neutron detectors. Shutdown can be achieved by two diverse and independent means: the shutdown rods and the control drums. Additional shutdown rods are used to address hypothetical accident conditions associated with the transportation of a fuelled reactor and maintain a subcritical reactor during transportation. The reactor is installed in a transportation cask for transportation. The secondary system (i.e., the power conversion system) and support systems, including instrumentation, control, and electrical (ICE) systems, are transported in separate shipping containers. The shipping containers can be transported to remote locations via truck, rail, or waterway.

2.2. Reactor Site

The site will be prepared prior to shipment of the reactor and support systems. Prior to the reactor arriving to the site, site preparation and installation activities will commence and continue after the reactor module arrives at the site. Any necessary criticality testing will be performed after site construction and installation of the reactor.

The site layout and connection between containers are designed to enable quick deployment. An illustration of the site layout is shown in Figure 2.2

Fig. 2.2 eVinci Microreactor Site Layout Rendering

Limited onsite staff is needed to perform the necessary site activities such as operations, maintenance, and security. A remote monitoring station will be used to allow remote personnel to monitor reactor power operations. A replacement reactor module will be shipped to, and installed at, the site as the operating reactor module reaches its end of fuel life. Once the primary reactor module reaches its end of fuel life, it is shut down and the replacement reactor module will begin operation and become the new primary reactor. The shutdown reactor module is allowed to cool before being transported off site for refurbishment and refuelling or for decommissioning. Spent fuel is not required to be stored on site.

3. EVINCI MICROREACTOR DEPLOYMENT MODEL

The eVinci microreactor design heavily relies on simplicity, passive features, inherently safe characteristics, high levels of automation, and lower facility risk. These design features will support streamlining of licensing of the facility, compared to traditional large light water reactors (LWRs). Approval of a standard design certification (DC) will achieve standard approval of the design, which will minimize the scope of subsequent operating site licenses. In addition, Westinghouse is looking to increase standardization for the eVinci microreactor, including standardization of items such as Technical Specifications and Operational Programs, which have typically been left to the operating site license applicant. Considering that microreactors may have non-traditional owners/operators/licensees (i.e., existing entities from outside the energy industry), who are not veterans of the nuclear industry, this additional standardization will be advantageous to their initial licensing efforts.

The eVinci microreactor deployment model consolidates activities such as manufacturing, fuel load, refuelling, refurbishment, and decommissioning to facilities separate from the operating site. This model consolidates licensing efforts and streamlines deployment.

Westinghouse has been engaged in eVinci microreactor pre-application activities with NRC for several years, including submittal of 31 technical white papers and 5 Topical Reports to date [1]. This pre-application engagement supports getting early feedback from NRC which will help streamline and optimize future licensing actions.

3.1 Deployment Model Steps

The eVinci microreactor deployment model (depicted in Figure 1.1) consists of the following steps.

3.1.1 eVinci Nuclear Test Reactor (NTR) for Safety Feature Performance Demonstration

To support commercial licensing of the eVinci microreactor, a nuclear test reactor will be developed to demonstrate the safety features of the facility in an integrated environment. The NTR will help to satisfy the U.S. regulatory requirements in Title 10 of the Code of Federal Regulations (CFR) 50.43(e) [2] for subsequent standard eVinci microreactor design licensing activities. The eVinci NTR is a scaled test being performed to establish a portion of the design basis for future full-scale eVinci microreactor deployments using the same technologies.

3.1.2 Standard Design Certification

In the U.S., Westinghouse is pursuing DC for the eVinci microreactor under 10 CFR Part 52 Subpart B [3]. The DC will allow for approval of a standard eVinci microreactor design to support future licensing actions and reduce subsequent licensing challenges for initial deployments of this novel technology. Once approved, the DC could be referenced in future license applications, as applicable.

3.1.3 Assemble in Factory

Multiple eVinci microreactor modules will be manufactured and assembled within the manufacturing facility. The manufacturing facility will receive and store the TRISO fuel compacts separately in preparation for loading into the reactor module. Each reactor module will undergo non-criticality testing throughout the manufacturing process, both before and after fuel load. Applicable inspections and testing will be performed at the manufacturing facility prior to shipment of the reactor module to the operating site. The reactor module will be prepared for shipping once the reactor is assembled, non-criticality testing is complete, and a licensee and site are identified.

The eVinci microreactor manufacturing facility will fabricate the heat pipes, assemble the reactor core components as well as the canister, integrated head, shutdown rods, and control drums into the reactor module which is then fuelled. Westinghouse intends to perform manufacturing and associated activities identified above in accordance with its NRC-approved Quality Management System (QMS).

3.1.4 Transport to Site

As licensees are identified, each reactor module will be shipped from the manufacturing facility to an operating site. Modularized packaging in transportable shipping containers enables the reactor module to be shipped via truck, train, and/or waterway. The complete eVinci microreactor equipment will be transported inside a combination of custom designed transport containers and International Standards Organization (ISO) shipping containers. The reactor module will be transported in a custom-designed reactor transportation cask (RTC) that will function as the approved Type B shipping container for the fuel within the core. A Type B package will be used as described in NRC's definition of quantities of radioactive material that can be contained in a Type B package, as defined in 10 CFR Part 71 [4]. This step in the deployment model will require a Certificate of Compliance (CoC) for the specific package per 10 CFR Part 71 Subpart D.

3.1.5 Install and Operate Reactor at Site

The operating site will be prepared prior to shipment of the reactor module. Prior to and after arrival of the reactor module at the operating site, site preparation and installation activities will commence. Any necessary criticality testing will be performed after site construction and installation of the reactor. The site layout and connection between containers are designed to enable quick deployment. Any remaining installation inspections will be closed at this time. A limited on-site staff is needed to perform the necessary site activities such as operations, maintenance, monitoring, and security. In addition, a remote monitoring station will be used to allow remote personnel to monitor reactor module operational information at multiple sites.

A replacement reactor module will be shipped to (using the same transportation strategy discussed in Section 3.1.4) and installed at the operating site as the operating reactor module reaches its end of core life. Once an operating reactor module reaches its end of core life, it is shut down and the replacement reactor module will begin operation. It is anticipated this reactor module turnover will occur with a minimal interruption of power service as the replacement reactor module will have undergone performance testing and system turnover prior to shutdown of an operating reactor module as it is installed in an adjacent structure. The operating site layout is designed to allow for rapid reactor replacement. When the original reactor module has reached its end of core life and the replacement reactor module is ready to operate, all necessary piping, monitoring, and electrical connections will be connected to the replacement reactor module. The Passive Heat Removal System (PHS) will be available in both reactor bays, to ensure that the operated reactor module can have decay heat removed before it is prepared for transportation off-site.

3.1.6 Transport Away from Site

The operated reactor remains at site for a prescribed cooldown period to ensure personnel can perform uncoupling and radiation levels are acceptable for transportation. After this cooldown period, the operated reactor is transported away from the site to a centralized facility to be either refuelled and refurbished or decommissioned. The RTC will be an approved Type B shipping container for the fuel within the reactor module core. It is recognized that there are different requirements for packaging for fresh fuel as opposed to irradiated fuel. This is accommodated as a single RTC is designed for both Type A and Type B requirements. As such, any shielding necessary for a Type B package will be incorporated into the design.

3.1.7 Refuel/Refurbish or Decommission

The operated reactor module can be refuelled and refurbished or decommissioned at a dedicated centralized facility separate from the operating site. After the reactor module is refuelled and refurbished, it will be transported back to an operating site for future operations. As described in Section 3.1.3, non-criticality testing would be done in this centralized facility for refuelled and refurbished rectors before transport to an operating site for installation and operation. Follow-on transportation activities of a refuelled and refurbished reactor would follow Section 3.1.4. Potential solutions for irradiated fuel storage include the use of dry storage casks at the centralized facility or storage casks shipped to a Consolidated Interim Storage Facility (CISF).

4. EVINCI MICROREACTOR LICENSING

In the U.S., the eVinci microreactor can be licensed under the existing NRC regulatory framework. To enact the deployment model as depicted in Figure 1.1 in the most efficient manner, a number of policy issues have been identified that need resolution. The following subsections discuss a subset of the higher priority policy issues facing microreactor deployments. To support resolution of these items, Westinghouse has held pre-application discussions with NRC, submitted 31 white papers, and engaged in industry initiatives and NRC public meetings on these topics.

In addition, the eVinci microreactor design includes a number of new and novel technical features. To support early engagement on these new and novel features, strategies and plans have been developed, which have been communicated to NRC through the aforementioned white papers. Discussions have been held with NRC on these white papers and written feedback has been received, which is informing ongoing work within the eVinci microreactor program. In addition, targeted areas have been identified for Topical Report submittal, to support early NRC engagement and resolution on some of these novel features prior to submittal of a DC application.

4.1. Fuel Load in Manufacturing Facility

The ability to load fuel into a reactor module at the manufacturing facility is integral in support eVinci microreactor deployment. The existing NRC regulatory framework would require either an Operating License under 10 CFR Part 50 [2] or a Combined License under 10 CFR Part 52 Subpart C [3] to achieve this. The current regulatory framework for a Manufacturing License under 10 CFR Part 52 Subpart F does not allow for fuel load to occur under such a license.

To address this, NRC staff has issued SECY-24-0008 [5] in January 2024 which provides an option for a manufactured reactor module to be loaded with fuel at a manufacturing facility under a 10 CFR Part 70 special nuclear material (SNM) license [6] and a 10 CFR Part 52 Subpart F Manufacturing License [3], with the inclusion of features to preclude criticality. This could occur as long as a manufactured reactor module with installed features to preclude criticality is not considered "in operation" while fuel is loaded. Rather, operation would begin when the features to preclude criticality are removed at the operating site. SECY-24-0008 is currently with the NRC Commission to vote on this proposal. Westinghouse has engaged with NRC, voicing our support for approval of this option. Additionally, Westinghouse has submitted a joint report for NRC and the Canadian Nuclear Safety Commission (CNSC), "Factory Manufacturing and Assembly of the eVinci™ Microreactor," [7] requesting review which covers topics related to this policy issue.

4.2. Licensing of Replacement Reactor Modules

Traditionally, large LWRs have received an operating license for each reactor or nuclear power plant. However, the eVinci microreactor deployment model includes the potential for multiple reactor modules to operate at one operating site over the site's lifetime. In addition, there will be structures on the site that will remain for the lifetime of the operating facility, covering operation of multiple reactor modules. To license each reactor module individually consistent with existing practice for large LWRs would be inefficient and costly, especially with the increased standardization being pursued through the eVinci microreactor design. This represents another policy issue to resolve to streamline the licensing process.

NRC identified this as a potential policy issue in SECY-24-0008, Enclosure 1 but has not yet put forth a strategy for final resolution. The next steps for NRC include consideration of whether other licensing approaches for multi-module sites described in SECY-11-0079 [8], which was issued for small module reactors (SMRs), such as a single license for multiple modules or a master facility license alternative, could provide efficiencies for licensing replacement modules at an operating site. There is precedence in licensing of identical reactor designs on the same site under 10 CFR Part 50 Appendix N [2] that could be leveraged for multi-module licensing.

4.3. Staffing

Existing NRC regulations provide minimum requirements for staffing for operators and security. These staffing numbers are based on large LWRs and are not reflective of the simplicity, passive features, inherently safe characteristics, high levels of automation, small footprint, and lower facility risk associated with the eVinci microreactor. While exemptions can be pursued on a license-by-license basis for microreactor staffing levels, it is inefficient for large fleet deployments of microreactors.

NRC identified operations and security as a potential policy issue in SECY-24-0008, Enclosure 1, in relation to remote operations. However, even with operators onsite, there are additional policy issues to resolve. Initial pre-application discussions with NRC on operations and physical security for the eVinci microreactor occurred through several white papers. The eVinci microreactor will put forth an operations staffing strategy using NUREG-1791 [9] for exemption request.

4.4. Storage of Spent Fuel

Existing NRC regulations in 10 CFR Part 72 [10] define spent fuel as "fuel that has been withdrawn from a nuclear reactor following irradiation, has undergone at least one year's decay since being used as a source of energy in a power reactor, and has not been chemically separated into its constituent elements by reprocessing. Spent fuel includes the special nuclear material, byproduct material, source material, and other radioactive materials associated with fuel assemblies." This definition is inconsistent with the eVinci microreactor deployment model, which has the irradiated fuel remaining in the reactor module during cooldown at the operating site and during transport to the centralized facility for refurbishment and refuelling or decommissioning. This may require an exemption from NRC regulations to enact the deployment model.

NRC identified this as a potential policy issue in SECY-24-0008, Enclosure 1 but has not yet put forth a strategy for final resolution. The next step for NRC is engagement with stakeholders on specific strategies for handling and storage of irradiated and spent fuel generated in factory-fabricated microreactors. Initial pre-application discussions with NRC on the strategy for the eVinci microreactor occurred through several of the submitted white papers.

5. CONCLUSION

As described in the paper, the eVinci microreactor deployment significantly differs from traditional large, LWR nuclear power plants. The deployment model for eVinci microreactor presents a set of licensing challenges related to fuelling of the reactor, licensing of replacement reactor modules, staffing, and the storage of spent nuclear fuel. Licenses must be obtained from regulatory agencies regarding these items. Due to the new and novel nature of eVinci microreactor, careful planning and consideration must go into the licensing, manufacturing, testing, transportation, and installation at operating sites. Westinghouse has analysed the licensing strategies to enact the eVinci microreactor deployment model and has identified topics where cooperative regulatory reviews could provide feedback to improve the efficiency and effectiveness of eVinci microreactor deployment. Additionally, Westinghouse maintains that improved cooperation between regulatory bodies could improve the efficiency and effectiveness for eVinci microreactor deployment. Westinghouse will follow regulatory and policy developments associated with advanced reactors and microreactors that could further inform eVinci microreactor deployment and support further engagements with regulators to facilitate improved cooperation.

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