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U.S. NUCLEAR REGULATORY COMMISSION STAFF FEEDBACK REGARDING GENERAL ATOMICS ELECTROMAGNETIC SYSTEMS WHITE PAPER, "FAST MODULAR REACTOR SAFETY APPROACH AND PROBABILISTIC RISK INSIGHTS" (EPID L-2024-LRO-0046)

SPONSOR INFORMATION

Sponsor:	General Atomics Electromagnetic Systems (GA-EMS)
Sponsor Address:	16530 Via Esprillo San Diego, CA 92127
Project No.:	99902098

DOCUMENT INFORMATION

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Purpose of the White Paper: The purpose of the white paper (WP), "Fast Modular Reactor Safety Approach and Probabilistic Risk Insights," is to describe a safety approach that uses inherent and passive safety as well as probabilistic risk insights to satisfy safety and environmental protection requirements while aligning with Nuclear Energy Institute (NEI) 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" (ML19241A472), which describes the probabilistic risk assessment (PRA)-led Licensing Modernization Project (LMP) process. While the WP discusses the design safety objectives, inherent and passive safety features, radionuclide release barriers, functional safety approach, risk-informed safety approach, and probabilistic risk insights for the GA-EMS Fast Modular Reactor (FMR), the focus of the WP is on identifying preliminary initiating events (PIEs).

Action Requested: By letter dated August 21, 2024, GA-EMS submitted the WP for U.S. Nuclear Regulatory Commission (NRC) staff pre-application review; however, it stated that "[N]o specific feedback is requested." As such, the NRC staff provide high-level feedback and observations, as discussed below.

FEEDBACK AND OBSERVATIONS

The following feedback and observations provide an initial assessment of how the WP aligns with NRC regulatory guidance, such as Regulatory Guide (RG) 1.233, Revision 0, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the

Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," (ML20091L698). RG 1.233 endorses NEI 18-04.
The staff notes that the term "safety approach" is not defined in NEI 18-04 and is not used in RG 1.233. However, in the context of RG 1.233, the NRC staff considers "safety approach" as a comprehensive application of the LMP process that includes the selection of licensing basis events (LBEs), classification of structures, systems, and components (SSCs), use of PRA and risk insights, determination of special treatments, determination of defense-in-depth (DID), and iteration during the design process. Given the potential multiple interpretations of "safety approach," the NRC staff encourages GA-EMS to carefully define the intended review scope in future submittals.

The NRC staff feedback and observations are limited, or generalized, for aspects of the "safety approach" not fully addressed in the WP. These feedback and observations are not regulatory findings on any specific licensing matter and are not official agency positions. Lack of feedback regarding a certain aspect of the WP should not be interpreted as NRC's agreement with GA-EMS's position.

Regulatory Considerations

The WP identifies several regulations as containing criteria that establish limits on the risk or consequences of potential radiological releases from nuclear power plants; however, it is unclear to the NRC staff whether GA-EMS is pursuing licensing under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," or Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." Specifically, while the WP mentions 10 CFR Part 52, Subpart C, "Combined Licenses," it also mentions "documents and technical criteria that will serve as the foundation upon which the NRC staff will grant a license for a Standard Design Approval (SDA) or a Design Certification (DC)," as well as some Part 50 regulations. Notwithstanding the selection of licensing approach, the NRC staff notes that the regulations and guidance outlined in the WP generally appear to be applicable. However, the safety approach will inherently impact the determination of LBEs, safety classification of SSCs, DID, and plant design. Because these topics ultimately inform safety analysis reports and technical specifications, several other regulations may also be pertinent.

Design Information

The NRC staff acknowledges the WP includes high-level design information for the GA-EMS FMR, which is briefly summarized below.

The GA-EMS FMR helium-cooled fuel consists of uranium dioxide pellets encapsulated in silicon carbide (SiC)-clad fuel rods. These rods are arranged into a triangular pitch, forming hexagonal fuel assemblies, which are inserted into an annular core. The core is surrounded by zirconium silicide (Zr_3Si_2) and graphite for neutronics and heat transfer considerations. GA-EMS plans to develop a power conversion system (PCS) with a vertically in-line turbine-compressor-generator. The FMR includes a maintenance cooling system that can cool the reactor during planned outages and post-shutdown during events that disable the PCS. The FMR also has a safety-related, gravity-driven reactor vessel cooling system (RVCS) that cools the reactor vessel through natural circulation of water. The RVCS passively cools the FMR primarily by radiative heat transfer, aiming to remove the need for complex mechanisms associated with active cooling systems. GA-EMS intends to rely on inherent and passive safety features to meet safety objectives with no alternating current (AC)-powered safety-related systems or operator actions required in any postulated accident scenarios for the FMR. GA-EMS identifies four barriers to radionuclide release: the fuel pellet due to fission product retention, cladding, reactor pressure boundary, and steel containment. The WP notes that the effectiveness of these barriers is event-specific.

General Feedback and Observations

The NRC review of the WP identified that additional information would be needed to determine if the proposed methodology is consistent with the LMP process in areas such as LBE identification and PRA development. However, the initial approach to PIE selection based upon literature appears as a valid starting point as presented. The following provides general observations on the WP and approach:

- The WP states that FMR licensing will follow NEI 18-04 and then describes how the Safety in Design (SiD) methodology per the Electric Power Research Institute's (EPRI's) Project Capstone Report 3002015752, "Program on Technology Innovation: Early Integration of Safety Assessment into Advanced Reactor Design," will be used. While the WP describes the SiD methodology as consistent with NEI 18-04 principles, the NRC staff has not reviewed or endorsed the SiD methodology. In addition, the SiD methodology appears to focus on hazard analysis with limited discussion in the WP regarding additional information needed to implement latter steps in the LMP process.

- The approach of surveying literature for PIEs for the purposes of informing a larger scale PRA is appropriate and integral to the LMP approach outlined in NEI 18-04. However, the SiD methodology, as incorporated in this WP, does not: (1) detail an iterative approach through a PRA process, (2) couple event categorization with SSC classification, (3) perform safety function integration, (4) perform DID analysis, or (5) provide quantitative risk insights based on a frequency-consequence (F-C) target curve analysis. While the SiD methodology may be informative, the WP contains limited information on its design-specific implementation.

- Though both mitigative and preventive SSC classifications yield PRA safety functions, additional information would be needed to assess this aspect of the LMP methodology for the GA-EMS FMR design.

- Tools like failure modes and effects analysis (FMEA), hazard and operability studies (HAZOPs), or master logic diagrams (MLDs) are useful for early stages of safety assessment; however, additional information would be needed on how this information is used in the PRA and the latter steps of the LMP process to garner additional NRC staff feedback.

- It is unclear from the WP how PIE and LBE identification processes will be developed beyond historic reviews and subsequently feed into SSC classification and evolve iteratively through design and licensing.

- The WP lists PIEs and passive safety definitions but contains minimal information on how an evolving PRA is tied to the iterative design.

<u>Specific Feedback and Observations</u>

4.1 LMP Process Overview

The LMP process involves multiple steps, many of which are considered iterative. The LMP process proposes initial LBEs; design development; PRA development; identifies and revises anticipated operational occurrences (AOOs), design basis events (DBEs), and beyond design basis events (BDBEs); identifies required safety functions and SSCs; selects design-basis accidents and hazard levels; performs LBE evaluations; completes design development; and finalizes LBEs and SSCs. The WP only partially covers these steps and how the iterative process will be implemented. The NRC staff notes the following:

- Design development and analysis are only discussed in general terms and are not tied to SSCs, initiating events, or LBEs.

- The WP does not describe the PRA development process comprising a safety approach; qualitative tools like FMEA and MLDs are mentioned as part of an eventual PRA, but in themselves do not constitute a complete PRA.

- The approach for identifying and revising AOOs, DBEs, or BDBEs is not included in the WP. Although literature-based frequency data is included, the WP does not categorize events, investigate source terms, develop event trees, utilize F-C target curves, or identify GA-EMS FMR specific frequencies.

- While required safety functions and SSCs are mentioned in section 7, "Probabilistic Risk Insights," of the WP, there is limited discussion on how the SiD results inform the PRA and process for SSC classification.

4.2 Propose initial list of LBEs

The WP outlines a phased approach under the SiD methodology but contains limited detail on screening, expansion, and validation of PIEs. The NRC staff notes the following:

- Phase I compiles PIEs from literature and screens them for relevance but does not identify design-specific events or discuss design-specific frequencies.

- Phase II aims to expand PIEs through FMEA, but additional information is needed to support staff evaluation of this area.

- Phase III organizes preliminary PIEs but remains qualitative, deferring quantitative risk analysis.

- While the WP acknowledges that GA-EMS has identified an initial list of PIEs and intends to adhere to NEI 18-04 by starting with the application of the SiD methodology, the NRC staff would need additional information to assess the completeness of PIE identification for the GA-EMS FMR design.

4.3 Fundamental Safety Functions

The WP uses fundamental safety functions (FSFs) to "tie the FMR requirements to their relevant barriers and PIEs," but there is limited information on how this information will be utilized as part of the LMP process for the GA-EMS FMR. Specifically, the NRC staff notes:

- The WP relates PIEs to FSFs but does not specify how this informs PRA or SSC classification.

- The WP further delineates the FSFs into subcategories with limited discussion of the LMP end use case.

- Despite referencing F-C target curves and SSC classification, the WP contains limited details on design-specific events, event categorization, safety functions, and PRA methodology.

4.4 Passive Safety

The WP emphasizes that passive safety characteristics, such as natural circulation for heat removal, negative reactivity temperature coefficients, and lack of reliance on powered safety-related systems, are integral to the GA-EMS FMR design, but it does not quantify their effectiveness or integrate them into a PRA. The NRC staff observes:

- Additional information on how the design's inherent safety features are reflected in the PRA (e.g., through event trees and detailed analysis) would be helpful to support conclusions regarding such capabilities.

- A description of the quantitative analysis supporting effectiveness of the four release barriers across PIEs and LBEs, and how DID is achieved, would be helpful to support LMP implementation.

- Further quantitative analysis is necessary to assess alignment with NRC regulations and NEI 18-04, should GA-EMS pursue it.

In conclusion, the WP provides useful information related to PIE identification; however, additional information is needed to illustrate how this information will be used as part of the LMP process to ensure the GA-EMS FMR design meets applicable regulatory requirements.

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