AN ALTERNATIVE EMERGENCY PREPAREDNESS REGULATORY FRAMEWORK FOR SMALL MODULAR REACTORS AND OTHER NEW TECHNOLOGIES

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Abstract

The U.S. Nuclear Regulatory Commission (NRC) is taking an evolutionary approach to emergency preparedness for evolutionary nuclear technologies. Evolutionary reactor designs are expected to have features that provide simplified, inherent, passive, or other innovative means to accomplish their safety and security functions. The various design features beyond those of current large light-water reactor technologies presented the opportunity to consider emergency preparedness regulations commensurate to the risk of these new designs and to find innovative ways to address the diversity in design through the use of performance-based regulation. The NRC is preparing a final rule on emergency preparedness for small modular reactors and other new technologies. The draft final rule provides a performance-based, technology-inclusive, risk-informed, and consequence-oriented regulatory framework suitable for evolutionary reactor designs. The paper discusses the benefits and challenges of shifting from the current prescriptive, compliance-based regulations to an alternative performance-based regulation.

1. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) has emergency preparedness (EP) regulations for large light-water reactors (LLWRs) that include 16 planning standards that radiological emergency plans must meet. Prior to granting a license, the NRC must make a finding of reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency. The reasonable assurance finding is based on compliance with these regulatory standards for emergency plans. Reasonable assurance is maintained through a regulatory process for controlling changes to the emergency plan and through periodic inspections, drills, and exercises. The regulatory framework for LLWRs has proven effective for over 40 years.

In 2006, the NRC staff began to explore the benefits of performance-based EP regulations as an alternative to compliance with EP planning standards as a way of achieving a high level of preparedness that focuses on results and capabilities rather than means [1]. By 2015, the agency had finalized several feasibility studies and had performed a programmatic review of the potential for a performance-based oversight regimen (regulation, inspection, and enforcement) for emergency planning and response [2–5]. In 2016, the Commission approved a rulemaking plan, and the staff began work on a regulatory framework for EP for small modular reactors (SMRs) and other new technologies (ONTs) [6]. The draft framework employs a graded approach to EP regulations in which the requirements and criteria are based on the relative radiological risk of the facility, source terms, and potential hazards, among other considerations. Licensees will be responsible for developing and maintaining the capabilities required to provide adequate protection, which may differ between facilities, depending on the facility design.

Although a performance-based, technology-inclusive, risk-informed, and consequence-oriented regulatory framework may look different from the current prescriptive requirements, the objective for EP remains the same: provide adequate protection of public health and safety by ensuring protective actions can and will be taken in a radiological emergency.

2. EVOLUTION OF THE REGULATORY FRAMEWORK

The current regulations for LLWRs specifies 16 planning standards that radiological emergency plans must meet. Additional regulations stipulate the information that emergency plans must contain to demonstrate the licensee’s compliance with specific planning elements for coping with emergencies: assessment actions, activation, notification, emergency facilities and equipment, training, maintaining EP, recovery, and protective actions. An additional part of the emergency plan is the emergency planning zone (EPZ) which defines the area surrounding the facility within which preplanning for prompt protective measures is warranted. The EPZ is a planning tool that helps to simplify protective action decision-making when such decisions may be time constrained. Planning within the EPZ also provides a basis for expansion of the response beyond the EPZ, should that prove necessary. EPZs are scalable in size and commensurate with the planning needs for the facility. The capabilities needed to ensure an effective response are requirements of the emergency plan and are distinct from the EPZ itself. As such, the EPZ size does not change the requirements for emergency planning; it only sets bounds on the planning.

Much of the content to be included in the emergency plan is prescriptive in nature, which means that specific and measurable actions must be in place to demonstrate compliance with the regulations. For example, licensees must ensure the capability exists to assess, classify, and declare an emergency condition in 15 minutes. Most of the prescriptive requirements were informed by risk insights from pressurized-water and boiling-water reactor technologies of the 1960s and 70s. However, the current regulations include some performance-based elements, which allows an applicant or licensee the flexibility to determine the most effective and efficient method to meet the regulatory requirements for their specific design. For example, in 2011, the NRC issued a final EP rule to add performance-based requirements for emergency operations facilities (EOFs) [7]. The performance-based criteria ensure EOFs can obtain and display plant data and radiological information for each unit or plant they serve. The performance-based criteria provided regulatory flexibility from the previous prescriptive siting of EOFs to be “near the facility”; this change allowed consolidation of offsite emergency response facilities to serve multiple sites where practicable. This example illustrates the flexibility that performance-based criteria provide. However, the current regulations remain mostly prescriptive and focused on LLWR designs, which does not provide flexibility in application to different reactor designs or in adapting new technologies to support implementation of EP functions. Applying the current regulations to evolutionary designs would likely result in applicants needing to seek exemptions from the emergency planning requirements not appropriate to their specific design. The need to seek exemptions from specific regulations for evolutionary designs can be circumvented by establishing an alternative regulatory framework. Performance-based regulations are suitable for this purpose as they naturally adapt to advancements in design and technology and because EP has many performance-based attributes. While such regulations might look different from prescriptive ones, they will still provide adequate protection of public health and safety because the foundation for both is the established planning basis for EP.

3. PLANNING BASIS FOR EMERGENCY PREPAREDNESS

The established planning basis for EP is an evaluation of the consequences from a spectrum of accidents used to scope the planning efforts for the distance, time, and materials released. Similar to the principles of “time, distance, and shielding” for radiological safety, the considerations of “distance, time, and materials released” are fundamental to scope the planning efforts for radiological EP. The NRC established the planning basis principles in NUREG-0396, “Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants,” issued 1978 [8]. The established planning basis is risk-informed and consequence-oriented, as well as technology-neutral such that it can be applied to any type of facility. In the 1970s, the planning basis was applied to LLWRs using insights from design-basis accidents and available probabilistic risk assessments (notably the WASH-1400 reactor safety study [9]). These insights were used to inform the planning needed to respond to a significant radiological release from pressurized-water and boiling-water reactor technologies of that time. While there are many EP planning functions common to any type of facility, these functions vary in degree depending on the risk posed by the facility. For example, assuming an accident could cause a large early release of radionuclides when such an event is precluded by design, could result in unnecessarily planning for unwarranted large-scale evacuations. Evacuations have consequences of their own, and for a protective action to be effective its benefit needs to be greater than the risk of taking the action. It would not be appropriate to assume that the capabilities needed for an effective response to an accident in an evolutionary design are necessarily the same as those for dealing with a severe accident in a LLWR. Instead, the planning basis needs to be examined for each facility design or technology type to appropriately scope the planning effort. In a performance-based framework, an applicant or licensee can apply the planning basis to scope the preparedness efforts for the distance, time, and materials released specific to the facility under consideration.

3.1. Distance

An EPZ bounds the area surrounding a facility within which detailed preplanning is needed to implement predetermined, prompt protective actions. EPZs are used to simplify protective action decision-making when such decisions may be time constrained. EPZs are scalable in size. *However, the EPZ size does not change the requirements for emergency planning; it only sets physical bounds on the planning*. Detailed planning within the EPZ provides a basis for expansion of the response efforts beyond the EPZ, should it become necessary. Risk insights from probabilistic risk assessments led to a generic 10-mile plume exposure pathway EPZ for LLWRs. Existing NRC regulations provide for a case-by-case determination of the size of the plume exposure pathway EPZ for gas-cooled reactors and for reactors with an authorized power level less than 250 MW thermal. The same risk-informed methodology that informed the 10-mile EPZ size for LLWRs can be applied to other facilities. The methodology includes an analysis of dose vs. distance, comparing projected dose from design-basis accidents and less severe beyond-design-basis accidents to the dose criteria for recommending protective actions. The EPZ size is also informed by considering the likelihood of exceeding life-threatening doses for more severe beyond-design-basis accidents.

3.2. Time

Protective actions are more effective when they can be implemented in a timely manner. Timing considerations for the current LLWR regulatory framework were driven primarily from an understanding of severe accident phenomena from the WASH-1400 reactor safety study. The study indicated a major release may begin in the range of 30 minutes to as much as 30 hours after an initiating event, with a release lasting from 30 minutes to several days. Consequently, to ensure timely protective actions, the NRC requires licensees to demonstrate the capability to declare an emergency within 15 minutes and to notify offsite authorities within 15 minutes. However, when compared to traditional LLWRs, evolutionary and innovative SMRs and ONTs are designed to have slower transient response times and a relatively small and slow release of fission products associated with postulated accidents. This means that the timing of certain EP functions that facilitate initiating protective actions, such as classification, notification, and protective action recommendations, can be informed by the accident timing characteristics of the facility.

3.3. Radioactive materials released

Consideration of the radioactive materials released informs the capabilities needed for monitoring instrumentation, estimating projected dose, and identifying critical exposure pathways. Source terms for LLWRs typically assume that a large fraction of gaseous and volatile fission products is released—primarily noble gases and radioiodines—along with volatile and nonvolatile particulates (e.g., cesium). However, evolutionary designs may mitigate the potential for a large environmental release to occur through various design features such as low operating pressure, use of non-light-water-reactor technology, and advanced fuels. Emergency planning functions should be tailored to the radionuclides and exposure pathways of concern. For example, the expectation that large amounts of radioiodine could be released may result in planning for the use of potassium iodide as a supplement to protective actions such as evacuation and sheltering. However, some evolutionary designs may preclude such a release, which would simplify the planning.

4. PERFORMANCE-BASED REGULATORY FRAMEWORK

As an alternative to the current framework, the NRC staff has developed and presented to the Commission for its approval, a draft performance-based EP framework [10]. The performance-based EP framework goals are (1) to continue to provide reasonable assurance that adequate protective measures can and will be implemented by an SMR or ONT licensee, (2) to promote regulatory stability, predictability, and clarity, (3) to reduce the need for exemptions from EP requirements, (4) to recognize advances in design and technology, (5) to credit safety enhancements in evolutionary and passive systems, and (6) to credit the potential benefits of smaller sized reactors and non-light-water reactors associated with postulated accidents, including slower transient response times and relatively small and slow releases of fission products. The draft performance-based requirements continue to address the most risk-significant aspects of EP (i.e., classification, notification, accident assessment, and protective actions) and their supporting planning elements. Regulatory compliance will be verified using the results of licensee-conducted drills and exercises and inspection of a set of quantified emergency response performance objectives.

Under the draft performance-based approach, performance results serve as the primary basis for regulatory decisions. However, rather than demonstrating compliance with prescriptive criteria, under a performance-based framework, applicants and licensees would have the flexibility to determine how to meet the established performance criteria necessary for an effective EP program. The performance-based framework has four basic parts: (1) the demonstration of emergency response functions through periodic drills and exercises, (2) onsite and offsite planning activities, (3) a hazard analysis of contiguous facilities, and (4) the determination and description of the boundary and physical characteristics of the plume exposure pathway EPZ and ingestion response planning capabilities in the emergency plan.

4.1. Demonstration of emergency response functions

The first part of the performance-based framework defines a set of emergency response functions required to adequately implement a radiological emergency response plan. These functions are easily observable and measurable, which makes them suitable for demonstration. As such, each function will have a minimum performance threshold captured in a performance objective to be demonstrated in periodic drills and exercises:

- Event classification and mitigation. Assess, classify, monitor, and repair facility malfunctions.
- Protective actions. Establish protective actions for onsite personnel and recommend them to offsite authorities as conditions warrant.
- Communications. Establish and maintain communications with the emergency response organization and notify other response personnel and organizations.
- Command and control. Establish and maintain effective command and control of emergency response operations.
- Staffing and operations. Establish onshift and augmenting emergency response staffing to implement the response functions.
- Radiological assessment. Assess radiological conditions in and around the facility, core or vessel damage, and radiological releases during emergencies.
- Re-entry. Develop and implement re-entry plans for accessing the facility after the emergency.
- Critiques and corrective actions. Critique performance of emergency response functions and identify corrective actions after drills, exercises, and actual emergencies.

4.2. Onsite and offsite planning activities

The second part of the framework defines activities to be described in the radiological emergency plan that are required to implement a response according to the plan. These are required planning activities rather than performance objectives because they are either not easily observable or measurable in drills or exercises. Onsite planning activities include the following:

- Prepare and issue public information during emergencies.
- Implement the emergency plan in conjunction with the licensee’s safeguards contingency plan.
- Establish voice and data communications with the NRC for emergencies.
- Identify emergency facility(ies) where effective direction and control can be exercised in an emergency.
- Provide site familiarization training for offsite support agencies responsible for responding to the site during an emergency.
- Establish methods for maintaining the emergency plan, contacts and arrangements, procedures, and the evacuation time estimate up to date, including periodic reviews by the onsite and offsite organizations.

If the EPZ extends beyond the site boundary, the plan needs to include these additional activities:

— Make contacts and arrangements with offsite response organizations responsible for responding during emergencies and establish the means of notification.
— Identify the protective measures to be taken to protect public health and safety.
— Determine an evacuation time estimate of the areas within the EPZ.
— Locate primary and backup offsite response facilities to coordinate onsite and offsite response.
— Provide the means of making and communicating offsite dose projections to coordinating agencies.
— Describe the means by which information is provided to the public concerning emergency preparedness, the public alert notification system, and any prompt actions that the public needs to take.
— Establish general plans and methods for re-entry during and after an emergency.
— Create drill and exercise programs that test and implement major portions of the planning, preparations, and coordination between onsite and offsite response organizations.

4.3. Hazard analysis

The draft final rule requires the applicant to include a hazard analysis of contiguous or nearby facilities and other credible hazards that could adversely impact the implementation of emergency plans in the application. Evolutionary and innovative SMRs and ONTs have potential uses beyond electrical generation, including desalination and the production of district heat, hydrogen, and medical isotopes. While LLWRs are typically sited away from population centers, SMRs and ONTs may be sited closer to or co-located with other industrial facilities or LLWRs. Therefore, it is important to capture the potential impacts of industrial plants, other reactors, transportation systems, or a combination of these or other facilities on the implementation of an emergency plan. The hazard analysis must identify site-specific, credible hazards from other facilities that may require additional EP considerations (e.g., notification requirements, emergency action levels associated with external hazards) that would otherwise not be needed if that facility were not nearby. The hazard analysis ensures the plan addresses the combined radiological and industrial hazards important to EP.

4.4. Emergency planning zone and ingestion pathway capabilities

The performance-based framework also includes provisions for a plume exposure pathway EPZ. The need for a plume exposure pathway EPZ is determined through the use of two criteria. The first criterion is that the plume exposure pathway EPZ is the area within which public dose is projected to exceed 10 millisieverts total effective dose equivalent over 96 hours from the release of radioactive materials from the facility, considering accident likelihood and source term, timing of the accident sequence, and meteorology. The second criterion is that the plume exposure pathway EPZ is the area where predetermined, prompt protective measures are warranted.

The first criterion facilitates performance of a dose vs. distance analysis to determine the size of the EPZ. The NRC developed proposed guidance for informing the EPZ size based on the methodology developed in NUREG-0396 [8]. The proposed methodology includes guidance for accident and source term selection, meteorological input, atmospheric transport modelling, exposure parameters, and dose criteria. The proposed guidance also addresses the use of uncertainty analyses and considerations for accident likelihood and timing as they relate to EPZ size determination. For example, it may be possible to exclude accident sequences from EPZ size determinations due to an extremely low likelihood of occurrence, or due to the extended time available for initiating protective actions associated with the accident sequence. However, even if these accident sequences are excluded from the EPZ size determination, the same accident sequences—particularly the accident sequence characteristics such as the timing and materials released—would still be used to inform other EP functional capabilities (e.g., classification, notification, assessment) to ensure that some capability for response exists for even the most unlikely accidents.

The second criterion specifies the functional requirement for an EPZ. Because SMRs and ONTs are expected to have accident timing characteristics different from LLWRs, an assessment of the functional criteria will determine whether an EPZ is needed to support the planning. For example, planning for prompt protective measures, such as evacuation of predetermined areas within the EPZ, may not be required based on an analysis of the time available to act before dose criteria for protective actions are exceeded. As such, it could be demonstrated through analysis that a site-boundary EPZ is adequate. However, a site-boundary EPZ, or no EPZ, does not imply public protective actions are precluded. As previously stated, the EPZ does not change the requirements for planning. To meet the second criterion, an applicant must demonstrate sufficient time and capability exist (e.g., assess the accident, perform dose projections, and provide protective action recommendations) to initiate protective measures without the need for detailed preplanning. The second criterion places the emphasis on capabilities over prescriptive distances for ensuring action is taken when needed.

The EP regulations for LLWRs also specify a 50-mile ingestion pathway planning zone (IPZ). The IPZ is intended to facilitate addressing the longer-term concern for ingestion of contaminated food and water. However, the 50-mile IPZ developed in the 1970s is specific to the accident characteristics of LLWRs of that time [8]. Furthermore, in the U.S., Federal and state resources have developed significantly since the 1970s and are often available on scene in 24 hours or less. These resources include the Federal Radiological Monitoring and Assessment Center (FRMAC); the Advisory Team for Environment, Food and Health (Advisory Team); and mobile sampling and testing laboratory resources. The performance-based framework acknowledges these advances and the availability of these resources. In lieu of an IPZ, the draft final rule requires applicants and licensees to describe the ingestion pathway capabilities available to state and local emergency response agencies.

5. PERFORMANCE-BASED BENEFITS AND CHALLENGES

The objective of EP is to provide dose savings in the event of a significant radiological release. This objective remains the same regardless of the regulatory framework used to establish the capabilities needed to ensure that protective actions can and will be taken. The prescriptive and performance-based frameworks are both based on the established planning basis for EP. The planning basis provides a common foundation to ensure EP includes an adequate level of protection for public health and safety commensurate with the risk of the facility. The difference in the frameworks lies in how the capabilities are specified to be met in regulation. A prescriptive framework has specific EP requirements for a particular type or class of facilities. This provides regulatory certainty and produces uniformity in emergency plans. Such uniformity also facilitates inspection of the emergency plan for regulatory compliance. The downside is that prescriptive requirements lack flexibility. A performance-based, technology-inclusive framework overcomes this by establishing performance objectives that provide flexibility to the applicant or designer as to how the outcome is to be accomplished. By focusing on the outcome, and not the method, regulatory clarity and predictability can be achieved for any technology. Although this will likely result in less uniformity in plans among facilities of different designs, design differences can be negated by focusing on performance metrics for the emergency response functions defined above, rather than how the function is accomplished.

Compliance with the performance-based framework will be accomplished by inspection and oversight of: (1) performance objective metrics for each emergency response function, (2) an approved methodology to develop the objectives, and (3) performance acceptability or successful achievement thresholds for the emergency response functions. For example, the methodology used to develop performance objectives and metrics could be as follows:

$$Performance\ Objective\ Metric\ (\%) = \frac{Number\ of\ correct\ opportunities}{Number\ of\ opportunities} \times 100$$

A framework that focuses on outcomes as opposed to prescriptive requirements allows applicants and licensees the flexibility to determine the most effective and efficient method to accomplish the required outcome. Oversight is a multipronged approach including directly evaluating licensee exercise performance; verifying the licensee's capacity to be self-critical in identifying the emergency response organization's performance weaknesses and take the necessary corrective actions; and ensuring the accuracy of the licensee's tracking of performance metrics. This type of oversight and inspection allows inspection efforts more fully focus on response-related performance as opposed to the current focus on plan maintenance and compliance.

A major advantage of the performance-based framework is the potential to scale response capabilities commensurate with the risk of the facility. Designs that feature simplified, inherent, and passive safety features, when compared to traditional LLWRs, are expected to have slower transient response times and relatively small and slow releases of fission products associated with postulated accidents. Therefore, the amount of design effort expended toward safety enhancements may have an inverse relationship to the commensurate level of EP required. This does not mean that EP can be designed out or that EP would not be required for a certain level of design safety. Emergency planning will always be required as the final, independent layer of defence in depth.

A performance-based framework is also consistent with comprehensive all-hazard EP. All-hazard planning recognizes that while all hazards are unique, there are common capabilities needed for effective response in any emergency that are independent of the hazard. Radiological emergency planning is part of all-hazard planning as it relies on shared response capabilities and common protective actions such as evacuation and sheltering-in-place used frequently for hazards such as fires, floods, and hurricanes. In the United States, comprehensive (all-hazard) EP under the National Preparedness System starts with identifying hazards and assessing risk, followed by steps to estimate, build, sustain, and validate core capabilities [11]. The performance-based framework factors in risk assessments of the radiological hazard and those posed by contiguous or nearby facilities comparable to the all-hazard process used in the U.S. [12]. The performance-based approach sets performance and capability targets appropriate to the facility, which not only meet NRC regulatory requirements but also contribute to the core capabilities of the whole community, in support of the U.S. National Preparedness Goal [13].

6. OVERSIGHT AND REASONABLE ASSURANCE

The 16 planning standards for LLWRs became regulation in 1980, along with the implementation guidance in NUREG-0654, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants," which contains approximately 200 assessment criteria that describe an acceptable method of meeting the planning standards [14]. The initial inspection and oversight of compliance with the 16 planning standards was through a direct inspection of each of the capability criteria committed to by the licensee in its NRC-approved emergency plan. The direct inspection process did not have a performance component; it only verified that the capability specified in the plan existed or identified the lack of a capability. The direct inspection process was replaced in 2000 with a performance-based, risk-informed baseline inspection program using a defined minimum level of required inspection of licensee performance. While the oversight program has successfully served to ensure adequate EP for over 20 years, there is room for further innovation and focus on licensee performance outcomes. Although development of the inspection process that will ultimately be used for the draft final rule has not been completed, inspection and oversight of the performance-based framework is expected to focus on the assessment of licensee performance in drills or exercises and the review of a licensee's documentation of performance objectives and identified corrective actions.

7. SUMMARY

Evolutionary technologies present the need for evolutionary approaches to regulation. This is particularly true for EP regulations, which are based on considering the consequences of a spectrum of accidents specific to a particular facility. Recognizing the diversity in design and enhanced safety and security potential for evolutionary technologies, the NRC staff has worked to develop a performance-based, technology-inclusive, risk-informed, and consequence-oriented EP framework for SMRs and ONTs. This effort was enhanced through public participation, including public meetings and assessment of comments received during an open and transparent rulemaking process. The NRC staff is also considering the use of this framework for licensing advanced reactors. While this alternative performance-based framework for EP may look different from the current prescriptive requirements for LLWRs, it is based on established principles for radiological EP. The proposed performance-based framework will accommodate any future evolutionary reactor or nuclear technology and will provide reasonable assurance through continuous demonstration that an effective level of EP is maintained to provide adequate protection of public health and safety.

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