# The Regulatory Treatment of Low Frequency External Events: Initial Insights

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**Abstract:** To assist the developing advanced reactor industry in future licensing efforts, the DOE Advanced Reactor Demonstration Program (ARDP) Regulatory Development area initiated a project at Argonne National Laboratory to examine the regulatory treatment of external hazards as part of a risk-informed performance-based (RIPB) licensing framework. A RIPB licensing framework for advanced reactors built on establishing an affirmative safety case offers the benefits of increased flexibility regarding key design and licensing decisions based on a detailed assessment and understanding of plant risk.

This project aims to identify the benefits and challenges of such approaches for advanced reactor vendors and aid in the development of consistent and appropriate analysis methodologies. The paper summarizes project findings, focusing on the evaluation of the seismic hazard and its application to other hazards. This includes an exploration of the implementation of a RIPB approach through an example analysis. The probabilistic approach to the assessment of external hazards requires a convolution of the hazard curve and fragilities of the structures, systems, and components (SSCs) within the plant. Due to the increasing uncertainty regarding the hazard curve estimate at low frequencies, the analysis findings were primarily driven by the uncertainty in the hazard curve. Based on the findings of this assessment, additional performance-based methods were explored as potential complementary approaches, such as a PRA-based seismic margins approach. As the current 10 CFR Part 53 wording requires the quantitative health objectives (QHOs) to be met, which are the NRC's quantitative guidelines to ensure no significant risk to members of the public from plant operation, an examination between the margins-based approach and QHOs is made. This paper highlights key challenges and opportunities associated with the methods and outlines future steps to assist with their implementation.

## 1. INTRODUCTION

As the advanced (non-light water) nuclear reactor field matures and continues to move towards project realization, parallel efforts are underway to develop a risk-informed performance-based (RIPB) framework for advanced reactor licensing. A licensing pathway that permits the development of an affirmative safety case benefiting from the flexibility and detail associated with RIPB methods aids in highlighting the unique aspects and risk profiles of advanced reactors. Such an approach differs from the primarily prescriptive and conservative methods utilized to license the current operating light-water reactor (LWR) fleet.

One particular area of interest is the treatment and assessment of scenarios of a very low frequency of occurrence, which were initially considered for LWRs mainly through the application of design margin and defense-in-depth (DID) philosophy, including robust containment, large distance to population centers, etc. RIPB approaches, in contrast, attempt to evaluate these scenarios at a level of detail commensurate with their risk, which often necessitates an explicit treatment of their frequency and associated consequence. While this detailed information provides valuable insights into plant behavior and risk profile, it is only as useful as the accuracy of the associated data and analyses.

## 2. PROJECT OBJECTIVES AND SCOPE

The work presented here is a summary of the initial findings of an Argonne project under the Department of Energy Advanced Reactor Demonstration Project (ARDP) regulatory development area, and complete details regarding the project can be found in ref [1]. The purpose of the project is to assist the advanced reactor industry with RIPB licensing efforts by achieving the following objectives:

- Explore the analysis of low frequency external events when utilizing a probabilistic hazard/fragility-based approach according to the requirements of the ASME/ANS/ANSI Non-LWR PRA Standard [2].
- Examine the impact of low frequency external events on licensing decision-making as part of the development of an affirmative safety case when using RIPB approaches. Such decisions include event sequence categorization, structure, system, and component (SSC) classification, and DID evaluations.
- Assess the historical basis for current regulation and guidance regarding the treatment of low frequency external events during reactor licensing.
- Evaluate the consistency and appropriateness of available regulatory approaches for the analysis of low frequency external events and, if necessary, recommend pathways to address identified challenges.
- To the extent practical, foster the adoption of common analysis approaches and regulatory treatments for external hazards commensurate with their level of risk.

For the current work, the term "external events" refers to those event sequences with external hazard initiators. This includes all applicable external hazards for the design and site under consideration, as the ASME/ANS/ANSI non-LWR PRA standard permits the assessment of any external hazard through a probabilistic approach [2]. The term "low frequency" is defined as external events below 1E-4 per plant year, as to align with the guidance discussed in the following sections. The applicability of the presented work centered on those reactor designs with a potential source term of sufficient magnitude and form such that exceedance of associated consequence limits (discussed in Section 3) is possible and that is located at a site where the external hazard threat is of sufficient magnitude to result in such consequences potentially.

In this work, a review of RIPB approaches to assessing external hazards is presented first in Section 3. This is followed by a discussion of the potential use of a PRA-based margins approach as a complementary tool for demonstrating regulatory compliance of certain low frequency external event sequences. Section 5 summarizes key findings, along with recommendations and next steps.

## 3. RISK-INFORMED PERFORMANCE-BASED APPROACH

### 3.1. Recent RIPB Guidance

For this project, the guidance from the Licensing Modernization Project (LMP) and Technology Inclusive Content of Applications Project (TICAP) were utilized as the RIPB licensing approach under consideration, given a recent endorsement by the NRC [3]. In addition, recent draft guidance on the RIPB treatment of external hazards was also reviewed [4]. The portions of guidance pertinent to external hazards analysis are briefly reviewed here, with complete details available in refs [5, 6].

In the LMP approach, risk information and complementary deterministic analyses are utilized as a part of the development of an affirmative safety case, which informs decisions regarding licensing basis event (LBE) selection, SSC classification, and the evaluation of DID. From the results of the PRA, which can include external hazards, LBEs are identified and categorized based on their frequency of occurrence, Anticipated Operational Occurrences (AOOs) with frequencies greater than 1E-2/yr, Design Basis Events (DBEs) with frequencies in the range 1E-4/yr to 1E-2/yr, and Beyond Design Basis Event (BDBEs) with frequencies between 1E-4/yr and 5e-7/yr. This process is also intertwined with the identification of required safety functions (RSFs) and the selection of safety-related (SR), Non-Safety Related (NST), and Non-Safety-Related with Special Treatment (NSRST) SSCs. Design Basis Accidents (DBAs) are derived from those LBEs within the DBE region and are re-evaluated to demonstrate compliance with dose criteria utilizing only SR SSCs. DID adequacy is assured through qualitative and quantitative evaluations. The quantitative guidelines follow the categorization of LBEs and satisfaction of the QHOs with sufficient margin. Qualitative guideline examples include minimizing the challenges to SR SSCs and preventing an overdependence on single barriers or systems for plant safety.

The analysis of external hazards primarily centers on the determination of design basis hazard levels[*] (DBHLs), which are the level of external hazard severity that SR SSCs are designed to withstand. The concept is to ensure that the design requirements of SR SSCs protect them against hazards with a frequency as low as 1E-4 per plant-year, which aligns with the frequency threshold for the DBE region. The licensing impact of external events of lower frequency than DBHLs is implicit within other steps of the LMP process, such as the NSRST SSC classification process and the DID adequacy evaluation.

For brevity, the details of how external events are explicitly considered within the LMP process are not presented here. However, ref [1] contains an example LMP analysis utilizing a simplified seismic PRA for an advanced reactor design. This analysis provided valuable insight regarding how low frequency external events could potentially impact licensing decision-making. The identified challenges and opportunities associated with a RIPB treatment of external events are reviewed in the following subsection.

### 3.2. Challenges and Opportunities

As previously highlighted, an example LMP analysis using a simplified seismic PRA provided insights into the application of the RIPB approach for the assessment of external hazards. The following common factors were identified regarding the probabilistic analysis of low frequency external events:

- **Increased Severity of External Hazards with a Low Frequency of Occurrence**: Following the LMP framework, event sequences of frequency as low as 5E-7 per plant year[†] are evaluated in detail for decisions regarding LBE categorization, SSC classification, and DID. At this frequency level, the severity of potential external hazards can be significant, beyond the threshold historically considered for plant design, and below the level of historical data from which to relate frequency of occurrence with hazard loads.
- **Increased Uncertainty Associated with External Hazards with a Low Frequency of Occurrence**: As the frequency of the external hazard initiators decreases, the relative uncertainty regarding their severity and frequency typically increases. The uncertainty can be quite large due to the limits of available data and uncertainty regarding the underlying phenomena. The LMP approach requires the assessment of event frequency at the $95^{th}$ percentile, which may drive events with very low median frequency but large uncertainty into the BDBE region.
- **Initiating Event Dominance on Event Sequence Frequency**: With the growing severity of external hazard initiators, the conditional failure probability of plant systems approaches one. As a result, the frequency of event sequences with multiple system failures may approach the frequency of the initiating event itself. As the initiator may have large uncertainty regarding its

[*] Referred to as Design Basis External Hazard Levels or DBEHLs in NEI 18-04.
[†] Event sequences of frequency below 5E-7 per plant year may also require consideration for the identification of cliff-edge effects and DID impact, or due to their location within the risk significant region.

frequency (as detailed in the previous bullet), the subsequent event sequences have similarly large frequency uncertainty, impacting subsequence design and licensing decisions.

- **Cliff-Edge Effects:** Since the conditional failure probability of plant systems approaches one as the severity of external hazards increases, the failure of a substantial number of SSCs may occur at extreme values of the hazard curve. The exact location of such events in frequency space, which may be greatly uncertain, can result in the need for plant modifications or potentially the inability to utilize a site.

Based on these factors, the ability of plant designers to use a RIPB approach for the assessment of external hazards may be faced with the following challenges:

- **Growing NSRST Requirements from Low Frequency External Events**: There is a potential to introduce a suite of new NSRST SSC requirements based solely on the protection against low frequency external events. This may result in a substantial expansion in the number of SSCs under regulatory consideration, especially for generally passive plants with minimal SR SSCs. Such requirements could be inconsistent with the associated risk to the public when compared to the consequences of the hazard event itself.
- **Lack of External Hazard Analysis Guidance**: Many external hazards have historically been evaluated utilizing deterministic, subjectively conservative methods rather than probabilistic approaches. Therefore, detailed guidance on performing probabilistic analyses may not be available. Lack of an experience base in the application of probabilistic methods to these hazards could lead to added uncertainty regarding the obtained results, with a consequence of increased conservatism in any design or licensing decisions.
- **Lack of Code/Standard Design and Analysis Guidance**: While an extensive library of codes and standards exists for the design of SSCs and protection against external events, the severity of the external hazard initiators under consideration may be beyond the scope of available standards. Specifically, attempting to determine the ability of SSCs to perform their required functionality under such extreme conditions may be difficult to ascertain and outside normal design analysis practices.

Conversely, the use of detailed RIPB approaches for the analysis of external hazards also provides the following opportunities:

- **Detailed Insights of SSC Importance and Requirements:** The risk-informed aspect of the approach provides detailed insights into the specific event sequences impacting plant safety. Through this process, the importance of particular SSCs can be determined, and their role within the safety case clarified.
- **Ability to "Right-size" Requirements:** Since the specific role of SSCs in terms of plant safety can be ascertained, associated requirements can be "right-sized" or developed in an appropriate and consistent manner.
- **Basis for Alternatives to Historical Treatments:** In the development of reactor regulation, certain deterministic and/or conservative requirements were established to address uncertainties associated with events outside the scope of detailed analysis. In contrast, the availability of detailed assessments of such events can provide the justification for reducing conservatism.

## 4. PERFORMANCE-BASED MARGINS ASSESSMENT

In an attempt to address the challenges associated with the RIPB assessment of external hazards, the utilization of a PRA-based margins approach was examined as a potential complementary tool for demonstrating regulatory compliance of a reactor design.

## 4.1. Background on PRA-Based Margins Approach

In the current NRC regulatory structure for reactor licensing, beyond design basis seismic events can be assessed through the use of a PRA-based margins approach, which was first recommended in SECY-93-087 [7]. As will be outlined below, the approach utilizes the Safe Shutdown Earthquake (SSE) as the basis of the evaluation. The SSE is defined in terms of both a peak ground accelerations (PGA)‡ and response spectrum. Beginning in 1997, the SSE determination was guided by RG 1.165 [8], which stated that new reactors should be designed to earthquake levels (in terms of annual probability of exceedance) that are more conservative than the median design ground motions for a set of the current operating fleet [9], which was evaluated to be an annual exceedance frequency of 1E-5 per year based on the median hazard curve of 28 sites. In 2010, RG 1.165 was superseded by RG 1.208 [10], which provided a performance-based approach to defining a site-specific ground motion response spectrum (GMRS) based on the method in ASCE 43-05 [11]. The approach is fundamentally different than that in RG 1.165. As RG 1.165 utilized a hazard-consistent approach, RG 1.208 uses a derivation of the risk-consistent methodology in ASCE 43-05 [10], where uniform hazard response spectra (UHRS) are defined at different annual exceedance frequencies.

In SECY-93-087, the seismic margins approach recommendation included the consideration of a sequence-level high-confidence of low probability of failure (HCLPF) for all sequences leading to core damage or containment failure at a value twice that of the SSE [7]. In other words, the HCLPF value§ of the seismic fragilities of those event sequences leading to core damage or containment failure was to be compared to a ground motion of twice the SSE as an evaluation of beyond design basis accident performance. In response, EPRI recommended the use of a 1.5 multiplier, which was seen as more consistent with the operating fleet [7]. In the Staff Requirements Memorandum (SRM), in response to SECY-93-087 [12], the commission approved a multiplier value of 1.67 of the SSE.

In 2010, DC/COL-ISG-020 [13] further clarified the implementation of the PRA-based seismic margins analysis for new reactor applications. The event sequences considered in the margins analysis should include those leading to core damage or containment failures, including applicable sequences leading to the following containment failures:

(1) loss of containment integrity,
(2) loss of containment isolation, and
(3) loss of function for prevention of containment bypass. The operating modes to be considered include at power (full power), low power, and shutdown.

Further guidance regarding the performance of HCLPF assessments and the viewpoint of the NRC on related technical aspects can be found in the Japan Lessons-Learned Project document [14].

The current project explored the use of a PRA-based margins approach as a complementary tool for demonstrating the regulatory acceptability of certain event sequences identified using a RIPB approach. In essence, low frequency external event sequences that may lie close to or exceed the LMP framework's consequence targets could be re-evaluated using a PRA-based margins approach. If the HCLPF value of the event sequence is greater than 1.67 times the SSE (or potentially DBHL as an alternative), then no further actions are needed to address the event from a regulatory perspective. The simplified seismic PRA example mentioned in Section 3.1 was evaluated using this framework (with complete details in ref [1]), and the challenges and opportunities associated with the approach were noted.

‡ PGA is typically determined based on the horizontal spectrum acceleration at 100Hz.
§ HCLPF is measure of seismic ruggedness. HCLPF is defined as the earthquake motion level at which there is a high (95 percent) confidence of a low (at most 5 percent) probability of failure.

### 4.2. Challenges and Opportunities

The exploration and demonstration of a PRA-based seismic margins approach identified several key challenges that are discussed below:

- **Appropriate Consequence Metric:** Given the limited applicability of CDF for advanced reactors, additional development is necessary to identify an appropriate consequence metric for the analysis of beyond design basis external events. Development must also include consideration of consistency with the consequence limit of the DBHLs in the LMP framework. The onset of offsite early health effects is a potential, appropriate surrogate consequence measure.
- **Design Basis Level Consistency:** DC/COL-ISG-020 utilizes the current performance-based approach for SSE determination outlined in RG 1.208 as the foundation of the PRA-based margin analysis. LMP does not directly use SSE but instead establishes DBHLs. Given that multiple approaches are available for DBHL selection, there may be inconsistencies if the DBHL is utilized as the basis of the PRA-based margins assessment.
- **Applicability to Other Hazards:** A goal of advanced reactor licensing pathway development should be to create a more consistent and uniform approach to external hazards analysis compared to current regulatory practice for LWRs. Therefore, additional consideration is warranted regarding how a similar PRA-based margins approach could be utilized for other external hazards.

Several key benefits were identified during the exploration and demonstration of the PRA-based margins approach, discussed below:

- **Reduced Dependency on the Low Frequency Range of the Hazard Curve:** The greatest benefit of the PRA-based seismic margins approach is that the basis of the analysis is not dependent on the low frequency area of the seismic hazard curve, where confidence in the estimates is reduced. Instead, the evaluation is conducted utilizing information from the hazard curve at frequency values better supported with data and analysis.
- **Maintains Detailed Event Sequence Insights:** The utilization of a PRA-based margins approach retains many of the detailed insights of a RIPB approach through sequence-level analyses. The importance of individual SSCs can still be ascertained through analysis of the sequence-level fragility curves.
- **Complementary Analysis:** The PRA-based margins approach may offer an alternative pathway to demonstrate regulatory compliance for low frequency event sequences identified through RIPB analyses. In this way, the margins approach is one of the options available to justify the associated licensing decision-making.

## 5. FINDINGS, RECOMMENDATIONS, AND NEXT STEPS

### 5.1. Key Findings

This paper summarizes the preliminary findings of an exploration of regulatory treatment of low frequency external events as part of an advanced reactor RIPB framework. The focus of which is on advanced reactor designs that contain sufficient radionuclide inventory and are sited at locations with sufficient external hazard threat to require or desire detailed probabilistic external hazard analysis. A comparison was made between implementing a RIPB approach following guidance from the LMP and TICAP, and a PRA-based seismic margins approach under the current NRC-approved methodology to examine beyond design basis seismic events for new reactors, with complete details available in ref [1].

The RIPB approach was found to be feasible and offered insights into plant performance that could be utilized to inform key licensing decisions and tailor SSC requirements. In addition, the detailed analysis of low frequency external events can also provide justification for the removal of historic conservatisms, which were primarily aimed to address uncertainties regarding such scenarios. However, there are challenges associated with the detailed probabilistic treatment of low frequency external events due to the inherent uncertainty associated with external events of long return periods. This uncertainty, primarily driven by the uncertainty in the hazard curve, could potentially result in the need for additional analyses or plants modifications. These actions may not be justifiable in terms of actual plant risk reduction, given the low frequency of the events and uncertain nature of the results.

The PRA-based seismic margins approach was assessed as a possible avenue for demonstrating regulatory acceptability of certain low frequency external event sequences. The main benefits of this approach are that the dependence of the analysis on the low frequency portion of the hazard curve and associated uncertainties is removed, but the insights regarding event sequences and SSC importance are retained. The approach could potentially be utilized to demonstrate the regulatory acceptability of a design and forego any further analyses or plant modifications. There are challenges associated with the implementation of the PRA-based margins approach, and potential solutions were explored in this work.

### 5.2. Recommendations

Based on the preliminary findings summarized here, several recommendations have been established to assist the development and application of RIPB licensing frameworks. This includes a central recommendation regarding the use of a PRA-based margins assessment for the analysis of low frequency external events, with supporting recommendations regarding its implementation.

- **Central Recommendation**: As part of the LMP framework, consider the potential use of a PRA-based margins approach as one of the complementary tools available for demonstrating the regulatory acceptability of low frequency external event sequences.
    - **Reasoning**: There are many avenues available to the plant designer to demonstrate the regulatory acceptability of specific LBEs. A PRA-based margins approach can be a useful additional tool for the assessment of certain low frequency external event LBEs. The PRA-based margins approach alleviates the dependence on the low frequency range of the hazard curve, where confidence in the estimates is low, and uncertainty is large. The approach is also consistent with current regulatory guidance for new reactor licensing. The margins assessment utilizes the PRA developed as part of the LMP process and can be applied to specific event sequences of interest. The central benefits of a RIPB approach are retained, such as the ability to determine the importance of specific events, SSCs, and uncertainties, and to tailor SSC requirements. In addition, all the information and insights from the probabilistic LMP process are preserved.
- **Supporting Recommendation #1**: Establish an appropriate consequence metric for use as part of a PRA-based margins analysis that is consistent with existing aspects of the LMP method. The consequence metric should utilize offsite dose as the parameter of interest and represent a magnitude of release similar to the historical concept of "large" release.
    - **Reasoning**: Current regulatory guidance on the application of a PRA-based margins approach utilizes the consequence metric of CDF, which is generally not applicable for non-LWRs. In contrast, the LMP approach uses offsite dose directly as the central consequence metric. Similarly, LMP has a consequence threshold of 25 rem offsite dose for design basis hazard levels (DBHLs). As low frequency external events analyses are inherently *beyond* design basis, the consequence threshold should be greater than 25 rem. Although a quantitative consensus value has not been established, an appropriate consequence metric should generally align with the historical concept of a "large" release. The lethal dose of radiation expected to cause death to 50 percent of an exposed population within 30 days ($LD_{50/30}$) dose, ranging from 350 to 500 rem

[15], would likely provide the key insights necessary from the analysis and also demonstrate compliance with the early fatality safety goal.

- **Supporting Recommendation #2**: The methodology outlined in RG 1.208 for SSE determination is an acceptable approach for the selection of the ground motion value (PGA) to be used as the basis of the PRA-based margins approach.
  - **Reasoning**: The implementation of the PRA-based margins assessment in DC/COL-ISG-020 utilizes the SSE determined by RG 1.208 as the foundation of the analysis. If a PRA-based margins approach is used as part of LMP, the same RG 1.208 methodology should be adopted for the determination of the reference ground motion. The method in RG 1.208 is performance-based and analogous to that of ASCE 43-05. In addition, the use of this approach maintains consistency with current NRC guidance but retains the ability to specify the seismic design basis for individual SSCs separately through the LMP process and associated RIPB guidance.

## 5.3. Next Steps

The next steps for the project include coordination with the development of 10 CFR Part 53, a comparison to the utilization of the quantitative health objectives (QHOs), and the assessment of the PRA-based margins approach for non-seismic external hazards. Each of these topics is briefly reviewed here. In addition, central to the project is the continued coordination with stakeholders (industry, the NRC, standard bodies, etc.) towards the goal of developing consensus methods.

### 5.3.1 Draft Part 53

The NRC is currently developing 10 CFR Part 53 that would establish a technology-inclusive regulatory framework for use by applicants for new commercial advanced nuclear reactors. As of writing, the proposed Part 53 framework consists of two alternate pathways for potential plant licensees as a technology inclusive application. Framework A, which generally aligns with the RIPB LMP approach, emphasizes risk insights and metrics, and Framework B, which emphasizes design criteria and allows for more bounding approaches in the PRA spectrum. The RIPB methods and solutions discussed here are likely of most interest to those vendors implementing Framework A. However, the PRA-based margins approach may have general applicability to vendors utilizing a bounding-type analysis under Framework B. In addition, the newly proposed rule language contains new requirements, such as explicit requirements for meeting the QHOs for early and latent health effects, as well as additional considerations of beyond-design-basis events that show an evolution from Part 50/52 licensing.

### 5.3.2 QHO Requirements

Initial discussions with the advanced reactor industry about the study's preliminary findings raised important questions regarding the proposed PRA-based margins approach and the use of the QHOs as a constraint on facility risk, given their potential inclusion as a regulatory requirement under Part 53 (discussed above). The inclusion of the QHOs as explicit regulatory requirements means that advanced reactor vendors must demonstrate compliance with the cumulative risk criteria, including the impact of external hazard risk. An assessment comparing the regulatory conclusions that would be derived from the PRA-based margins approach versus the QHOs is currently being undertaken. However, there are some initial insights regarding the approaches.

First, the QHO criterion associated with early fatality risk of less than 5E-7 per plant year is utilized to derive the consequence target of the LMP frequency versus consequence (F-C) curve at 750 rem at 5E-7 per plant year, in addition to being a formally integrated risk target of LMP. However, there are differences in the details of the calculation for the LMP LBE identification and categorization and the integrated risk criteria. The early fatalities QHO is calculated based on the *mean* risk of early fatality within 1 mile of the exclusion area boundary (EAB). The LBE identification and categorization calculations performed as part of the LMP process utilize 95th percentiles of frequency and consequence when accounting for uncertainty. In addition, the consequence metric of the LMP F-C curve is the 30-day total effective dose equivalent (TEDE) at the EAB. This consequence analysis is not dependent on population distribution or population size, while the results of the early fatality QHO calculation can vary greatly depending on the specific radionuclide dispersion pattern and the impacted population[**]. The use of mean values and the dependency on population distribution likely make the early fatality QHO less restrictive than the current application of the LMP F-C curve[††]. Therefore, LBEs located at consequence values near or exceeding the F-C curve may still satisfy the early fatality QHO when using mean values and accounting for population factors. Similar to these findings, the PRA-based margins approach outlined here does not utilize mean values and does not depend on population distribution for consequence calculations. Further analysis is currently exploring different use-cases and the conclusions derived from utilizing the QHOs versus the PRA-based margins approach.

### 5.3.3 Other External Hazards

The preliminary assessment summarized here focused on the seismic hazard, given its importance and general applicability. Similarly, the PRA-based margins approach was created to address beyond design basis seismic events during new reactor licensing. However, given that the current project also hopes to facilitate common methods across external hazards, further analysis is underway to examine the use of the PRA-based margins approach for other external hazards. This is not a new idea, as past studies have examined the use of the approach for external hazards such as flooding [16]. There are many factors to assess when considering the use of the PRA-based margins approach for other external hazards, such as whether the underlying assumptions are applicable to the hazard. For example, there may be physical limits on the severity of the hazard that make the utilization of a multiplier factor unreasonable.


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[**] For example, radionuclide dispersion analysis could demonstrate near-certain early fatalities in one direction but if the majority of the population resides in the opposite direction from the plant, the early fatality QHO could be easily satisfied.

[††] Although the QHOs would be a formal regulatory requirement, while the LMP F-C is guidance for decision-making.

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