

Requirements for Low Power and Shutdown Probabilistic Risk Assessment

TRIAL USE AND PILOT APPLICATION

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Comments and suggestions for revision should be submitted to:

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**The American Society of
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(This Foreword is not a part of “Requirements for Low Power and Shutdown Probabilistic Risk Assessment,” ANS/ASME-58.22-2014.)

FOREWORD

The American Society of Mechanical Engineers (ASME) Board on Nuclear Codes and Standards (BNCS) and the American Nuclear Society (ANS) Standards Board mutually agreed in 2004 to form the Nuclear Risk Management Coordinating Committee (NRMCC). The NRMCC was chartered to coordinate and harmonize standards activities related to probabilistic risk assessment (PRA) between ASME and ANS. A key activity resulting from NRMCC was the development of PRA standards structured around the Levels of PRA (i.e., Level 1, Level 2, and Level 3) to be jointly issued by ASME and ANS. In 2011, ASME and ANS decided to combine their respective PRA standards committees to form the ASME/ANS Joint Committee on Nuclear Risk Management (JCNRM).

Publication for Trial Use

Publication of this standard for trial use has been approved by the JCNRM as a stand-alone standard. However, the writing of this standard began under the ANS Risk Informed Standards Committee; hence, ANS writing guidance has been followed. The current plan is for this standard, once approved as an ANSI standard, to be incorporated into RA-S-1.1, the “Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications.”

The previous drafts of this standard have gone through several rounds of reviews by the JCNRM members, and all comments have been addressed in this version published for trial use. While the comments were resolved, there are remaining technical issues that are best resolved by testing this standard against different actual applications. This will ensure that the lessons learned from pilot applications are adequately addressed in this standard. Examples of pilot applications might include a gap analysis for an existing Low Power and Shutdown (LPSD) PRA model, or the development of new LPSD PRA models according to this standard. The JCNRM encourages any form of trial use of this proposed standard and requests feedback from trial users.

The project team and the readiness review team of this standard have identified the following potential issues, and it is hoped that these can be addressed in the trial use applications. Both the project team and the consensus ballot readiness review team believe that any of the requirements included in the LPSD Standard can be addressed with existing methods and data or supplemented by modest research of existing industry experience data. Nevertheless, the project team believes this should be verified during the trial use applications.

Potential Low Power and Shutdown PRA Standard Issues for Which Trial Use Feedback Is Desired	
Potential Issue	Background and Project Team Assessment
1. Whether the required number of plant operating states (POS) needed to satisfy the requirements of the standard are so excessive as to make the analysis impractical.	This issue was identified by comments on earlier drafts. The LPSD Standard has chosen to define specific attributes whose collective states make up the definition of each POS. These attributes were selected by experienced analysts that have performed LPSD analyses on real plants. Owner's groups have also developed guidance for developing LPSD models in which specific POSs are defined as examples. A non-mandatory appendix has been added to the standard to describe considerations in developing POSs. The project team does not believe the requirements will pose an excessive analysis burden.
2. Whether POSs are suitable when defined at a level of detail consistent with plant configurations sufficient to evaluate time-dependent risk metrics, as opposed to just considering the attributes listed in LPOS-A3.	This issue was identified by a commenter who wanted the flexibility to declare each plant configuration as a POS. This standard published for trial use allows either the use of plant configurations to define the POSs or the definition of POSs by collections of states of plant attributes to be used. POSs are widely used in existing PRA models for shutdown events.
3. Whether the requirements for at-initiator human actions analysis are reasonable and effective (at-initiator actions are human failure events that cause an initiating event; see Section 1.2.2).	This issue was first identified by a writing group member concerned about the possible omission of such considerations from earlier drafts of the standard. More recent commenters have expressed concerns that requirements added in response to this issue are too onerous. The project team believes that the available industry data for initiating events during shutdown conditions are adequate to identify the HRA contribution, although additional research to focus on this question would benefit this process. The project team believes that the main concern here is to identify and account for potential dependencies between the initial error and subsequent actions called on in response to the initial error. Such dependencies may be identified and considered to some degree by a review of operating experience to identify the conditions in which events originate. This conclusion limits the scope of the response needed to address the standard's requirements. Further research expanding the set of events reviewed would require a focused effort.
4. Whether the methods for human error probability (HEP) quantification are suitable for shutdown conditions.	This issue was first identified by a commenter concerned about the applicability of HRA methods developed for full power plant operating conditions to LPSD conditions where different sets of procedures apply. The project team notes that the methods developed for full power conditions are not restricted to full power, nor were they specifically calibrated to those conditions. This comment made more sense in past years when the procedures for shutdown conditions were less developed; however, at present, such procedures are better developed. Furthermore, The project team believes that the use of existing HRA methods for sequences initiating from full power conditions are also applicable for shutdown conditions.

Potential Low Power and Shutdown PRA Standard Issues for Which Trial Use Feedback Is Desired	
Potential Issue	Background and Project Team Assessment
5. Whether the approach to external hazards adequately captures the needed requirements for LPSD PRA for those hazards, for which only a few applications exist in the literature.	This is a general question that recognizes that plant conditions change during the different stages of a low power and shutdown evolution. The LPSD Standard acknowledged this in purposely excluding requirements for assessing internal fire hazard events as part of this version of the LPSD Standard. For other external event hazards, the standard states that these changes should be considered on a POS-by-POS basis. The project team believes that this set of requirements is appropriate and can be applied despite limited experience.
6. Whether the use of basic event risk significance summed over all POSs is a suitable measure for ranking importance for establishing modeling fidelity, or, since some models change the basic event evaluation in different POSs, whether other measures must be found.	The issue was identified by a comment in an earlier LPSD Standard ballot. Alternate metrics could be defined, and all can be handled by available software. It is a suitable question for a trial use application.
7. Whether the analyst can screen out the entire category of external hazards (e.g., earthquakes) on the basis of POS duration combined with external hazards initiating event frequencies.	This issue was identified by the readiness team review of this standard. In the introduction, Section 1.1.8.2 has been added to clarify how the screening of hazards can be accomplished for each POS, where appropriate.

This standard sets forth requirements for low power and shutdown probabilistic risk assessments (PRA) and also requirements for shutdown qualitative risk assessment (QLRA) that can be used to support risk-informed decisions for commercial nuclear power plants. This standard also prescribes a method for applying these requirements for specific applications.

The PRA requirements in this standard are intended to be used together with other PRA standards that cover different aspects of PRA scope. Specifically, they are intended to be used directly with the PRA standard developed by the ASME and the ANS (“Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,” ASME/ANS RA-Sa-2009 [1]).

While this LPSD Standard was being drafted for trial use ballot, a later addendum of the internal and external events at power standard, RA-Sb-2013, was published. It is the intent that this LPSD Standard will be revised to align with the available addenda or edition of the internal events at power standard prior to publication of the LPSD Standard as an ANSI standard.

This standard covers PRAs for both internal hazard events and external hazard events for a commercial nuclear power plant operating at low power or in a shutdown condition. Similarly, these PRA requirements are intended to be used with other standards now under development, including the

ASME/ANS PRA-methodology standards covering Level 2 (ASME/ANS RA-S-1.2) and Level 3 (ASME/ANS RA-S-1.3) risk assessments.

The PRA scope covered by this standard is limited to analyzing accident sequences initiated by “internal hazard events” (e.g., reactor trip, LOCAs, losses of service water, losses of offsite power, and internal flooding) or “external hazard events” (e.g., earthquakes, high winds, external flooding, etc.) that might occur while a nuclear power plant is operating at low power or is in a shutdown (i.e., non-power) condition. The exception to this scope is internal fire hazard, which is currently excluded from this standard due to the lack of methodology and applications in this area. Therefore, this standard covers all potential accident initiators arising at low power and shutdown conditions except for internal fires. The only other initiators explicitly excluded are accidents resulting from purposeful human-induced security threats (e.g., sabotage).

This standard’s PRA technical requirements are presented in support of a quantitative PRA for time-averaged core damage frequency (CDF) or LERF. For applications involving a specific LPSD evolution, modifications to the technical requirements are presented in Part 10.

The PRA requirements in this standard are further restricted to requirements for: (a) a full Level 1 analysis of the CDF; and (b) a limited Level 2 analysis sufficient to evaluate the large early release frequency (LERF).

The scope is also limited to analyzing accident sequences involving fuel while it is in the reactor vessel. Events involving fuel while it is in the spent fuel pool are not covered.

The shutdown QLRA requirements in this standard are for models used in support of configuration risk assessments while in a shutdown condition (e.g., modes 3 to 6 for PWRs and modes 3 to 5 for BWRs for mode definitions for plants with improved technical specifications).

The types of risk-informed PRA applications contemplated under this standard are very broad. Both regulatory risk-informed applications and applications independent of regulations are contemplated. While the NRC currently does not require the use of this standard for any specific risk-informed applications, its use is expected to be common in such applications. In this regard, this standard's approach is intended to be identical to that used in the closely related standard, ASME/ANS RA-Sa-2009 [1]. The approach and supporting logic of ASME/ANS RA-Sa-2009 [1] are relied upon heavily in this standard’s guidance in this area.

PREPARATION OF TECHNICAL INQUIRIES TO THE JOINT COMMITTEE ON NUCLEAR RISK MANAGEMENT

INTRODUCTION

NOTE FOR TRIAL USE: The text of this section describes the technical inquiry process for approved standards. However, during the trial use period, users are encouraged to provide feedback, ask questions, and interact with the LPSD project team on either a formal or informal basis. Such feedback may be provided via the Secretary, Joint Committee on Nuclear Risk Management, as noted below, or by contacting the LPSD project team chair or another member of the project team or the JCNRM.

The ASME/ANS Joint Committee on Nuclear Risk Management (JCNRM) will consider written requests for the interpretation and revision of risk management standards and the development of new requirements as dictated by technological development. JCNRM's activities in this latter regard are strictly limited to interpretations of the requirements or to the consideration of revisions to the requirements on the basis of new data or technology. As a matter of published policy, The American Society of Mechanical Engineers (ASME) does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity, and, accordingly, inquiries requiring such considerations will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the standard's requirements. If, based on the inquiry information submitted, it is the opinion of the JCNRM that the inquirer should seek assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

To be considered, inquiries will require sufficient information for JCNRM to fully understand the request.

INQUIRY FORMAT

Inquiries shall be limited strictly to interpretations of the requirements or to the consideration of revisions to the present requirements on the basis of new data or technology. Inquiries shall be submitted in the following format:

- (a) *Scope.* The inquiry shall involve a single requirement or closely related requirements. An inquiry letter concerning unrelated subjects will be returned;
- (b) *Background.* State the purpose of the inquiry, which would be either to obtain an interpretation of the standard's requirement or to propose consideration of a revision to the present requirements. Concisely provide the information needed for JCNRM's understanding of the inquiry (with sketches as necessary), being sure to include references to the applicable standard edition, addenda, part, appendix, paragraph, figure, or table;
- (c) *Inquiry Structure.* The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information and, where appropriate, composed in such a way that "yes" or "no" (perhaps with provisos) would be an acceptable reply. This inquiry statement should be technically and editorially correct;
- (d) *Proposed Reply.* State what it is believed that the standard requires. If, in the inquirer's opinion, a revision to the standard is needed, recommended wording shall be provided;
- (e) *Typewritten/Handwritten.* The inquiry shall be submitted in typewritten form; however, legible, handwritten inquiries will be considered;

- (f) *Inquirer Information.* The inquiry shall include the name, telephone number, and mailing address of the inquirer;
- (g) *Submission.* The inquiry shall be submitted to the following address: Secretary, Joint Committee on Nuclear Risk Management, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

USER RESPONSIBILITY

Users of this standard are cautioned that they are responsible for all technical assumptions inherent in the use of PRA models, computer programs, and analysis performed to meet the requirements of this standard.

CORRESPONDENCE

Suggestions for improvements to the standard or inclusion of additional topics shall be sent to the following address: Secretary, Joint Committee on Nuclear Risk Management, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

COMMITTEE ROSTERS

CONTRIBUTORS TO THE REQUIREMENTS FOR LOW POWER AND SHUTDOWN PROBABILISTIC RISK ASSESSMENT

(The following is a roster of the Joint Committee on Nuclear Risk Management at the time of the approval of this standard.)

This standard was processed and approved for release as a trial use and pilot application by the ASME/ANS Joint Committee on Nuclear Risk Management. Committee approval of the standard does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, the JCNRM had the following members:

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Part 1 General Requirements for an LPSD PRA and QLRA

Text that is new in this part compared to Part 1 of Reference [1] is underlined below.

1.1 Introduction

1.1.1 Objective

This standard¹ sets forth the requirements for Low Power and Shutdown (LPSD) probabilistic risk assessments (PRA) and for LPSD Qualitative Risk Assessments (QLRA), both of which are used to support risk-informed decisions for commercial light water reactor nuclear power plants. This standard also prescribes a method for applying those parts of the requirements as necessary to support specific applications.

The discussion of requirements for LPSD PRAs is presented in Parts 1 through 10, and the discussion of the method for applying them is presented in Section 1.3. These requirements would be used for applications requiring quantitative risk-informed insights during low power and shutdown conditions. The discussion of requirements and a method for applying them for LPSD QLRA are presented in Part 11. These requirements would be used for applications in which qualitative risk-informed insights suffice, such as for plant configuration control during shutdown conditions.

1.1.2 Scope and Applicability for LPSD PRA

This standard establishes requirements for a Level 1 PRA of internal and external hazards for low power and shutdown modes. These modes include operating states ranging from those in which the plant is at power levels substantially below nominal full power (low power) to operating states in which the plant is shutdown with the reactor subcritical and the primary system depressurized and cooled sufficiently to be placed on Residual Heat Removal (RHR) cooling. This standard bases these requirements in large part on ASME/ANS RA-Sa-2009 [1]², which at present is restricted to requirements for plant operating states at-power³.

This standard has been developed to specify the requirements for an evaluation of risk during LPSD conditions. Depending on the application, these evaluations are likely to focus on two end states: (a) a full Level 1 analysis of the core damage frequency (CDF); and (b) a limited Level 2 analysis sufficient to evaluate the large early release frequency (LERF). This is consistent with Reference [1]. The emphasis for the Level 2 analysis during shutdown conditions is more on containment isolation failure than containment structural failure for many applications since there may be LPSD plant operating states where the containment has an equipment hatch removed or other large openings to permit maintenance activities. Also, the dissipated decay heat during shutdown results in a reduced source term when compared to full power (although the radiological impact of the source term decreases at a slower rate

¹ The current standard, ANS/ASME-58.22-2014, is herein referred to as “this standard.”

² Numbers in brackets refer to corresponding numbers in Section 12, “References.”

³ Reference [1] is defined to apply broadly to “at-power” plant states. The LPSD PRA Standard includes “low power” states, which could be considered part of the broad “at-power” definition. To avoid confusion, this standard defines (and applies to) “low power” states in contrast to “full power” or “nominal-full-power” states. The “low power” states are defined to include all at-power operations below nominal full power. See the definitions of these terms in Section 1.2.2.

than the decay heat does). Thus, while the definition of LERF is the same as for full power states, the determination of “large” releases must include additional considerations to those for full power.

It is recognized that alternative risk metrics to CDF and LERF have been used in many assessments of LPSD conditions. These alternative risk metrics include approaching coolant boiling in the core, depletion of coolant to the point of core uncover, and radioactivity release. For consistency with the requirements of this standard, the alternate metric(s) are to be computed as a frequency of an accident class, and the selected metric(s) are to be surrogates for both CDF and LERF. Note that one alternative metric may, by itself, be a surrogate for both CDF and LERF. The alternate metric(s) are to be justified in the context of an application, against which the scope of the PRA is to be compared against all requirements. Any deviations from the requirements herein are to be justified for the alternate metric(s). Non-mandatory Appendix 2-B discusses risk metrics further.

Furthermore, the scope of the requirements for LPSD PRA in this standard excludes sources of radioactive material other than nuclear fuel within the reactor vessel; i.e., only “core” damage accidents are considered. Thus, accidents involving nuclear fuel in the spent fuel pool, in dry storage, or in transit are excluded from the scope of this standard. Accidents involving radioactive material sources other than nuclear fuel are also excluded.

This standard’s technical requirements are presented in a manner to support a range of applications including the calculation of time-averaged⁴ CDF or LERF, consistent with Reference [1]. Additionally, alternative risk metrics may be used. This standard may also be used for LPSD PRA applications involving a specific outage. Modifications to the LPSD PRA technical requirements to support time-dependent risk metrics of a specific LPSD evolution are noted in Section 1.3.7.

The only initiating event hazards explicitly excluded from the LPSD PRA scope are accidents resulting from purposeful human-induced security breaches (e.g., sabotage) and accidents initiated by internal fires.

This standard applies to PRAs used to support applications of risk-informed decision-making related to operating power plants⁵. They may be used for plants under design or construction, for advanced LWRs, or for other reactor designs, but revised or additional requirements may then be needed.

This version of the LPSD PRA Standard provides specific requirements for the following hazard groups:

- (a) Internal Events (Part 3);
- (b) Internal Flooding (Part 4);
- (c) Seismic Events (Part 5);
- (d) High Winds (Part 7);
- (e) External Floods (Part 8);
- (f) Other External Hazards (Part 9).

In addition to providing technical requirements for detailed PRAs of these hazards, this standard provides requirements for Screening and Conservative Analyses of External Hazards (Part 6). Technical

⁴ “Time-averaged” risk metrics refer to the occurrence of low power and outage evolutions averaged over time, in contrast to risk metrics applied to a specific outage (e.g., refueling number 4). All PRAs have other elements averaged over time, such as initiating event frequencies and component failure rates.

⁵ Here, “operating power plants” means plants that have operated and, thus, have spent fuel and decay heat. An operating plant could be “operating” at-power or in shutdown.

requirements for Seismic Margin Analysis, unlike for full power operating states, are not provided for LPSD PRAs.

Many of the technical requirements for internal events in Parts 2 and 3 are fundamental requirements for performing a PRA for any hazard group and are therefore relevant to Parts 4 through 10 of this standard. They are incorporated by reference in those requirements that address the development of the plant response to the damage states created by hazard groups addressed in Parts 4 through 10. Their specific allocation to Parts 2 and 3 is partially a historical artifact of the way Reference [1] was developed, with the full power internal event requirements being developed first, and those of the remaining hazard groups being developed later. However, it also is a reflection of the fact that a fundamental understanding of the plant response to a reasonably complete set of initiating events (as defined in Section 1.2.2) provides the foundation for modeling the impact of various hazards on the plant. Hence, even though Part 3 is given a title associated with the internal event hazard group, it is understood that the requirements in this section are applicable to all the hazard groups within the scope of the LPSD PRA.

1.1.3 Structure of LPSD PRA Requirements

1.1.3.1 LPSD PRA Elements

The technical requirements for the LPSD PRA model in each section are organized by their respective LPSD PRA technical elements. The LPSD PRA technical elements define the scope of the analysis for each section of the standard.

This standard specifies technical requirements for the LPSD PRA elements listed in Table 1.1.3-1. The first element listed in Table 1.1.3-1 in the internal event hazard group, Plant Operating States (POS), is the only element unique to this LPSD PRA Standard. Otherwise, these elements are consistent with those defined in [1] for full power plant operating states. During LPSD operations, the plant physical conditions such as temperature, pressure, decay heat level, operating and maintenance configurations can vary dramatically; and these variations can significantly impact the accident progression and the resulting risk assessment. Thus, the concept of the POS was developed and implemented to identify and translate the important plant differences into states affecting the risk model. Part 2 provides the LPSD PRA Standard requirements associated with POSs, and Appendix 2.A presents a non-mandatory primer on POS analysis methodology.

Table 1.1.3-1 LPSD PRA Elements Addressed by Standard

	Hazard Group	PRA Elements
Internal Hazards	Internal Events	(a) <u>Plant Operating State Analysis (LPOS)</u> (b) <u>Initiating Events Analysis (LIE)</u> (c) <u>Accident Sequence Analysis (LAS)</u> (d) <u>Success Criteria (LSC)</u> (e) <u>Systems Analysis (LSY)</u> (f) <u>Human Reliability Analysis (LHR)</u> (g) <u>Data Analysis (LDA)</u> (h) <u>Quantification (LQU)</u> (i) <u>LERF Analysis (LLE)</u>
	Internal Flooding	(a) <u>Internal Flood Plant Partitioning (LIFPP)</u> (b) <u>Internal Flood Source Identification and Characterization (LIFSO)</u> (c) <u>Internal Flood Scenarios (LIFSN)</u> (d) <u>Internal Flood-induced Initiating Events (LIFEV)</u> (e) <u>Internal Flood Accident Sequences and Quantification (LIFQU)</u>
	Seismic Events	(a) <u>Probabilistic Seismic Hazard Analysis (LSHA)</u> (b) <u>Seismic Fragility Analysis (LSFR)</u> (c) <u>Seismic Plant Response Analysis (LSPR)</u>
	High Winds	(a) <u>High Wind Hazard Analysis (LWHA)</u> (b) <u>High Wind Fragility Analysis (LWFR)</u> (c) <u>High Wind Plant Response Analysis (LWPR)</u>
	External Floods	(a) <u>External Flood Hazard Analysis (LXFHA)</u> (b) <u>External Flood Fragility Analysis (LXFFR)</u> (c) <u>External Flood Plant Response Analysis (LXFPR)</u>
	Other External Hazards	(a) <u>External Hazard Analysis (LXHA)</u> (b) <u>External Hazard Fragility Analysis (LXFR)</u> (c) <u>External Hazard Plant Response Analysis (LXPR)</u>

1.1.3.2 High Level Requirements

A set of objectives and high level requirements (HLR) is provided for each LPSD PRA Element in the Technical Requirements section of each respective section of this standard. The HLRs set forth the minimum requirements for a technically acceptable baseline LPSD PRA, independent of an application. The HLRs are defined in general terms and present the top level logic for the derivation of more detailed supporting requirements for each of the LPSD PRA Capability Categories. The HLRs reflect not only the diversity of approaches that have been used to develop the existing LPSD PRAs, but also the need to accommodate future technological innovations.

1.1.3.3 Supporting Requirements

A set of SRs is provided for each HLR (that is provided for each LPSD PRA technical element) in the Technical Requirements portion of each respective section of this standard. The SRs for the technical elements are presented as action statements using the three Capability Categories described below. For each Capability Category, the SRs define the minimum requirements necessary to meet that Capability Category. In these tables, some action statements apply to only one Capability Category, and some extend across two or three Capability Categories. When an action statement spans multiple categories, it applies equally to each Capability Category. When necessary, the differentiation between Capability Categories is made in other associated SRs. The interpretation of an SR whose action statement spans multiple categories is stated in Table 1.1.3-3 . It is intended that, by meeting all the SRs under a given HLR, an LPSD PRA will meet that HLR. The Technical Requirements portion of each respective section of this standard also specifies the required documentation to facilitate PRA applications, upgrades, and peer review.

This standard is intended for a wide range of applications that require a corresponding range of LPSD PRA capabilities. Applications vary with respect to which risk metrics are employed, which decision criteria are used, the extent of reliance on the LPSD PRA results in supporting a decision, and the degree of resolution required for the factors that determine the risk significance of the subject of the decision. In developing the different portions of the LPSD PRA model (e.g., system model), it is recognized that not every item will be or need be developed to the same level of detail, the same degree of plant-specificity, or the same degree of realism.

Although the range of capabilities required for each portion of the LPSD PRA to support an application falls on a continuum, three levels are defined and labeled either Capability Category I, II, or III, so that requirements can be developed and presented in a manageable way. Table 1.1.3-2 describes, for three principal attributes of any PRA, the bases for defining the Capability Categories. This table was used to develop the SRs for each HLR.

Table 1.1.3-2 Bases for PRA Capability Categories

Attributes of PRA	I	II	III
1. Scope and level of detail: The degree to which the scope and level of detail of the plant design, operation, and maintenance are modeled.	Resolution and specificity sufficient to identify the relative importance of the contributors at the system or train level, including associated human actions.	Resolution and specificity sufficient to identify the relative importance of the significant contributors at the component level <u>and</u> associated human actions, as necessary <u>[see Note (1)]</u> .	Resolution and specificity sufficient to identify the relative importance of the contributors at the component level including associated human actions, as necessary <u>[see Note (1)]</u> .
2. Plant specificity: The degree to which plant-specific information is incorporated such that the as-built and as-operated plants are addressed	Use of generic data/models acceptable except for the need to account for the unique design and operational features of the plant.	Use of plant-specific data/models for the significant contributors.	Use of plant-specific data/models for all contributors, where available.
3. Realism: The degree to which realism is incorporated such that the expected response of the plant is addressed.	Departures from realism will have moderate impacts on the conclusions and risk insights as supported by good practices <u>[see Note (2)]</u> .	Departures from realism will have small impacts on the conclusion and risk insights supported by good practices <u>[see Note (2)]</u> .	Departures from realism will have negligible impacts on the conclusion and risk insights supported by good practices <u>[see Note (2)]</u> .

NOTES:

- (1) The definitions for Capability Categories II and III are not meant to imply that the scope and level of detail includes the identification of every component and human action, but only those needed for the function of the system being modeled.
- (2) The differentiation among moderate, small, and negligible is determined by the extent to which the impacts on the conclusions and risk insights could affect a decision under consideration. This differentiation recognizes that the PRA would generally not be the sole input to a decision. A moderate impact implies that the impact (of the departure from realism) is of sufficient size that it is likely that a decision could be affected, a small impact implies that it is unlikely that a decision could be affected, and a negligible impact implies that a decision would not be affected.

The intent of the delineation of the Capability Categories within the SRs is generally that the degree of scope and level of detail, the degree of plant-specificity, and the degree of realism increases from Capability Category I to Capability Category III. However, the Capability Categories are not based on the level of conservatism (i.e., the tendency to overestimate risk due to simplifications in the LPSD PRA) in a particular aspect of the analysis. The level of conservatism may decrease as the Capability Category increases and more detail and more realism are introduced into the analysis. However, this is not true for all requirements and should not be assumed. Realism, however, does increase with increasing Capability Category.

The boundaries between these Capability Categories can only be defined in a general sense. When a comparison is made between the capabilities of any given LPSD PRA and the SRs of this standard, it is expected that the capabilities of an LPSD PRA's elements or portions of the LPSD PRA within each of the elements will not necessarily all fall within the same Capability Category, but rather will be distributed among all three Capability Categories. There may be LPSD PRA elements or portions of the LPSD PRA within the elements that fail to meet the SRs for any of these Capability Categories. While all portions of the LPSD PRA need not have the same capability, the LPSD PRA model should be coherent. The SRs have been written so that within a Capability Category, the interfaces between portions of the LPSD PRA are coherent, e.g., requirements for event trees are consistent with the definition of initiating event groups.

When a specific application is undertaken, judgment is needed to determine which Capability Category is needed for each portion of the LPSD PRA and hence which SRs apply to the applications.

Table 1.1.3-3 Interpretation of Supporting Requirements

Action Statement SR Spans:	Peer Review Finding	Interpretation of the Supporting Requirement
All Three Capability Categories (I/II/III)	Meets SR	Capable of supporting applications in all Capability Categories
	Does not meet SR	Does not meet minimum standard
Single Capability Category (I or II or III)	Meets individual SR	Capable of supporting applications requiring that Capability Category or lower
	Does not meet any SR	Does not meet minimum standard
Lower Two Capability Categories (I/II)	Meets SR for Capability Categories I/II	Capable of supporting applications requiring Capability Category I or II
	Meets SR for Capability Category III	Capable of supporting applications in all Capability Categories
	Does not meet SR	Does not meet minimum standard
Upper Two Capability Categories (II/III)	Meets SR for Capability Categories II/III	Capable of supporting applications in all Capability Categories
	Meets SR for Capability Category I	Capable of supporting applications requiring Capability Category I
	Does not meet SR	Does not meet minimum standard

The SRs specify what to do rather than how to do it, and, in that sense, specific methods for satisfying the requirements are not prescribed. Nevertheless, certain established methods were contemplated during the

development of these requirements. Alternative methods and approaches to the requirements of this standard may be used if they provide results that are equivalent or superior to the methods usually used and meet the HLRs and SRs presented in this standard. The use of any particular method for meeting an SR shall be documented and shall be subject to review by the peer review process described in Section 1.6.

1.1.4 Risk Assessment Application Process

The use of an LPSD PRA and the Capability Categories that are needed for each part of the LPSD PRA and for each of the LPSD PRA Elements will differ among applications. Section 1.3 describes the activities to determine whether a PRA has the capability to support a specific application of risk-informed decision making. Three different LPSD PRA Capability Categories are described in Subsection 1.1.3. LPSD PRA capabilities are evaluated for applicable parts of an LPSD PRA and each associated SR rather than by specifying a Capability Category for the entire LPSD PRA. Therefore, only those parts of the LPSD PRA required to support the application in question need the Capability Category appropriate for that application. For a given application, supplementary analyses may be used in place of or to augment those aspects of an LPSD PRA that do not fully meet the requirements in the Technical Requirements section of each respective part of this standard. Requirements for supplementary analysis are outside the scope of this standard.

1.1.5 PRA Configuration Control

Section 1.5 provides requirements for configuration control of an LPSD PRA (i.e., maintaining and upgrading a plant-specific LPSD PRA) such that the LPSD PRA reflects the as-built, as-operated nuclear power plant to a degree sufficient to support the application for which it is used.

1.1.6 Peer Review Requirements

Section 1.6 provides the general requirements for a peer review to determine if the LPSD PRA methodology and its implementation meet the requirements of the Technical Requirements section of each respective part of this standard. Scope-specific requirements are contained in the Peer Review section of the respective parts of this standard.

1.1.7 Addressing Multiple Hazard Groups

The technical requirements to determine the technical adequacy of an LPSD PRA for different hazard groups to support applications are presented in Parts 2 through 10. The approaches to modeling the plant damage resulting from different hazard groups vary in terms of the degree of realism and the level of detail achievable by the state of the art. For example, there are uncertainties that are unique to the modeling of the different hazards and their effects on the plant, and the assumptions made in dealing with these uncertainties can lead to varying degrees of conservatism in the estimates of risk. Furthermore, because the analyses can be resource intensive, it is normal to use screening approaches to limit the number of detailed scenarios to be evaluated and the number of mitigating systems credited while still achieving an acceptable evaluation of risk. These screening approaches are unique to each hazard group.

For many applications, it is necessary to consider the combined impact on risk from those hazard groups for which it cannot be demonstrated that the impact on the decision being made is insignificant. This can be done by using a single model that combines the LPSD PRA models for the different hazard groups or by combining the results from separate models. In either case, when combining the results from the different hazard groups, it is essential to account for the differences in levels of conservatism and levels of

detail so that the conclusions drawn from the results are not overly biased or distorted. To support this objective, the standard is structured so that requirements for the analysis of the LPSD PRA results, including identification of significant contributors, identification and characterization of sources of uncertainty, and identification of assumptions, are included in each section separately.

In some cases, the requirements for developing a PRA model in Parts 4 through 10 refer back to the requirements of Parts 2 and 3. The requirements of Parts 2 and 3 should be applied to the extent needed given the context of the modeling of each hazard group. In each section, many of the requirements that differentiate between Capability Categories, either directly or by incorporating the requirements of Parts 2 and 3, do so on the basis of the treatment of significant contributors and significant accident sequences/cut sets for the hazard group being addressed. Because, as discussed above, there are differences in the way the LPSD PRA models for each specific hazard group are developed, the requirements are best treated as being self-contained for each hazard group separately when determining significant contributors and significant accident sequences/cut sets. In other words, these are identified with respect to the CDF and LERF summed over each POS for each hazard group separately. While there may be a need in some applications to assess the significance with respect to the total CDF or LERF, this assessment has to be done with a full understanding of the differences in conservatism and level of detail introduced by the modeling approaches for the different hazard groups as well as within each hazard group.

To determine the Capability Category at which the SRs have been met, it is necessary to have a definition of the term “significant”. Consequently, the term “significant” is used in various definitions in this standard and is thereby explicitly incorporated into specific SRs. Generally, the philosophy used in Capability Category II ensures a higher level of realism for “significant” contributors. This manifests itself in SRs related to the scope of plant-specific data, detailed HRA (versus screening values), CCF treatment, documentation, and others.

The only consequence of not meeting the standard definition of “significant” for a specific SR is that the LPSD PRA would not meet Capability Category II for that SR. Thus, in the context of an application, if a hazard group is a small contributor, it should be acceptable to meet Capability Category I by using screening HEPs, not using plant-specific data for equipment reliability, etc. The applicable portion of the LPSD PRA will simply be considered as meeting Capability Category I for that specific SR for that hazard group.

Additionally, from a practical standpoint, LPSD PRA models are generally developed on a hazard group basis (i.e., a seismic PRA, a high wind PRA, etc.). While they may be integrated into a single model with multiple hazards, the development is done on a hazard group basis. In Capability Category II, this standard strives to ensure that the more “significant” contributors to each hazard group are understood and treated with an equivalent level of resolution, plant specificity, and realism, so as not to skew the results for that hazard group. The definitions also acknowledge that there may be cases where the proposed quantitative definition is inappropriate; e.g., the hazard group risk is very low, or bounding methods are used.

In summary, the definitions that use the term “significant” simply help to define how much realism is necessary to meet Capability Category II of some SRs. They are NOT intended to be definitions of what is “significant” in a particular application. Indeed, in the context of a specific application, they may be either too loose or too restrictive, depending on what is being evaluated. In the context of this standard, the decisions on applying these definitions and/or defining what is significant to a decision would be addressed in the Risk Assessment Application Process (see Section 1.3).

1.1.8 LPSD Requirements for External Hazards

1.1.8.1 Scope of External Hazards in Parts 5 to 9

External hazards are covered in this standard in separate sections grouped by “hazard group.” Within the scope, included in Parts 5, 6, 7, 8, and 9, are both natural external hazards (e.g., earthquakes, high winds, and external flooding) and human-made external hazards (e.g., airplane crashes, explosions at nearby industrial facilities, and impacts from nearby transportation activities) that occur while the plant is at low power or shutdown in any of the considered LPSD evolutions.

Internal floods during LPSD evolutions are categorized as internal hazards rather than external hazards; they are instead covered in Part 4. Appendix 6-A of the ASME/ANS PRA Standard [1] contains an extensive list of the external hazards generally considered within an external hazards PRA and hence within the scope here. That appendix is incorporated here by reference.

1.1.8.2 Screening of External Hazards

There are many external hazards that might affect a nuclear plant during low power or shutdown conditions, but not all of them would contribute significantly to the overall risk for any given plant. As explained in Section 6-1.1 of the ASME/ANS PRA Standard [1], it is necessary for the analysis team to ascertain:

“... which of these many external events can be screened out so that no further PRA analysis is needed. This allows the team to focus on those external events that remain (unscreened) within the analysis. Experience reveals that earthquakes can never be screened out using the methods herein; that sometimes high winds and external flooding can be screened out but sometimes they require further analysis, either a bounding analysis, a semi-quantitative analysis, or perhaps even a full PRA; and that occasionally one or more other external events also require a full PRA.”

It is important to note that, consistent with the Initiating Events discussion and requirements in Part 3 of this standard, it may be feasible to screen out any specific external hazard for a given POS based on the combination of POS duration and hazard frequency or on other considerations. Concerning earthquakes specifically, a comment is in order about the quotation from the ASME/ANS PRA Standard [1] in the paragraph above: “Experience reveals that earthquakes can never be screened out.” This sentence is intended to explain that for full power operation, the category of earthquake-initiated accidents can never be screened out entirely. However, in the context of LPSD analysis covered by this standard, it is possible that for a specific POS, the analyst may screen out the entire category of earthquakes on the basis of POS duration combined with earthquake frequency while retaining the highest risk POSs from earthquake-initiated accidents. This screening out requires a defined basis; see SR LPOS-B2. See also SR’s LIE-C6 and LIE-C6a, which permit screening POS-and-initiating-event combinations for internal events.

For high winds and external flooding, either or both of these may be screened out at a specific site for a particular POS, in whole or in part, depending on the circumstances and including possible seasonal-variation considerations. If not screened out, high winds and external flooding may be analyzed using either the specific technical requirements in Parts 7 and 8, respectively, or the general technical requirements for “other external hazards” in Part 9.

Part 6 of the ASME/ANS PRA Standard [1] contains a full discussion of the considerations involved in this screening analysis and in various approaches to conservative bounding analysis as well as the rationale, the HLRs, and the SRs. These requirements, notated by EXT, are found in Part 6 of the

ASME/ANS PRA Standard [1]. The HLRs and SRs cover various types of successive screening activities and conservative analysis activities. The analyst needs to consider any special circumstances that would differentiate a given LPSD POS from the full-power situation.

1.1.8.3 Structure of an External Hazard PRA

The following discussion applies to any external hazard that is not screened out as discussed above in Section 1.1.8.2.

The PRA of an “external hazard” during LPSD conditions consists of the following seven broad categories of analysis work. For each of these, the discussion below notes the character of the technical requirements in this standard and their relation to similar technical elements either in the ASME/ANS PRA Standard [1] (i.e., full power external events PRA) or elsewhere in this standard. The ASME/ANS PRA Standard [1] Appendix 5-A, “Seismic PRA Methodology – Primer,” provides useful background information for all of the external hazards PRA work covered in this section.

- (a) Hazard analysis. This is the analysis of the hazard “size” vs. hazard “annual frequency” for a specific external hazard.

Relation to Technical Requirements in ASME/ANS PRA Standard [1]: The LPSD external-event hazard analysis is identical to that for full power operation. Technical Requirements are already in the ASME/ANS PRA Standard [1] in Section 5-2 for earthquakes (designated as SHA), in Section 7-2 for high winds (designated as WHA), in Section 8-2 for external floods under (designated as XFHA), and in Section 9-2 for other external hazards (designated as XHA). Seasonal variations in certain external hazards may need to be accounted for on a case-by-case basis.

- (b) Identification of each POS included in the external-events PRA analysis. This consists of identifying each POS, assessing whether it may be screened out compared to other POSs, and including a sufficiently detailed specification of that POS (or groups of POSs) to enable the rest of the analysis to proceed. The remaining five technical elements in items (c) through (g) below are each to be accomplished separately for every POS or group of POSs identified here.

Relation to Technical Requirements elsewhere in this standard: The work of identifying the POSs is identical to that for LPSD internal-events quantitative PRA analysis. HLRs and SRs for this aspect of PRA are presented in Part 2 of this standard.

- (c) Identification of the relevant list of SSCs. This is the list of SSCs whose functions are important for the particular POS (or group of POSs) and that could be affected by the external hazard, either as part of the “initiating event” being studied or otherwise. The identification work explicitly involves using systems analysis methods to identify the SSCs along with information about the plant configuration so as to identify which SSCs are important to that POS and which SSCs could be affected by the hazard. This list of SSCs is identified through the collaborative work of systems-analysis and fragility-analysis experts for each hazard type. A plant walkdown is usually required to verify or confirm the information about plant configuration. Note that some non-safety SSCs may need to be considered, and that many safety-related SSCs may be disabled in certain POSs.

Relation to Requirements in the ASME/ANS PRA Standard [1]: The work of identifying the potentially affected SSCs in LPSD conditions is nearly identical to that for full power operation, including a specialized walkdown when appropriate. The relevant HLRs and SRs

are in the ASME/ANS PRA Standard [1]; they are discussed in detail in that standard in Section 5-2 for earthquakes (designated under SPR), in Section 7-2 for high winds (designated as WPR-A), in Section 8-2 for external floods (designated as XFPR-A), and in Section 9-2 for other external hazards (designated as XPR-A).

- (d) Fragility analysis. This is the analysis of the fragility (probability of “damage” vs. “size” of hazard) for each SSC on the list from (c) above. This work must include the analysis of correlated damage, if appropriate (such as for groups of SSCs affected by the same flooding in a room.)

Relation to Technical Requirements in the ASME/ANS PRA Standard [1]: The fragility analysis work is conceptually identical to that for full power operation, although the scope of the analysis of course must be tailored to the POS and its configuration. The relevant HLRs and SRs are in the ASME/ANS PRA Standard [1], as discussed in detail for earthquakes in Section 5-2 (designated as SFR), for high winds in Section 7-2 (designated as WFR), for external floods in Section 8-2 (designated as XFPR), and for other external hazards in Section 9-2 (designated as XFR).

- (e) Identification of the character of the “hazard-induced initial damage states” caused by the hazard. This identification needs to be done as a function of hazard “size” and of the POS. Here, a “hazard-induced initial damage state” is intended to mean a set of specified initial damage or other effects on the plant such as “loss of system X, combined with failure of shear wall Y.” This explicitly involves addressing each POS (or group of POSs) separately, because the combination of failures or problems resulting from the hazard may be unique to that POS.

Relation to Technical Requirements in the ASME/ANS PRA Standard [1]: HLRs and SRs for the work of identifying the character of all “initiating events” caused by the external hazard during LPSD states are already in the ASME/ANS PRA Standard [1]; they are discussed in detail for earthquakes in Section 5-2 (designated as SPR), for high winds in Section 7-2 (designated as WPR-A), for external floods in Section 8-2 (designated as XFPR-A), and for other external hazards in Section 9.2 (designated as XPR-A). The analyst needs to account not only for the POS, but also for any special effects of the given external hazard such as damage that might be caused by the external hazard that would not otherwise be modeled in the LPSD PRA along with any special activities or configurations such as whether the reactor vessel head is off or whether crane use involving heavy-loads could be affected by an earthquake or high winds.

- (f) Systems analysis. This is the development of initiating-event systems analysis and event-tree/fault-tree systems analysis, accounting for any special analysis features as needed. These special analysis features are likely to differ in many POSs from the models for internal events analysis and might include special effects of the external hazard on the structure of the systems analysis or special types of initiating events that would need tailored treatment in the analysis.

Relation to Technical Requirements in the ASME/ANS PRA Standard [1]: The systems analysis work is similar to that for external hazards PRA for full power operation. It must be addressed separately for each POS (or group of POSs). The relevant HLRs and SRs for this element are in the ASME/ANS PRA Standard [1], as discussed in detail for earthquakes in Section 5-2 (designated as SPR), for high winds in Section 7-2 (designated as WPR-A), for external floods in Section 8-2 (designated as XFPR-A), and for other external hazards in Section 9-2 (designated as XPR-A).

- (g) Integration of hazard analysis with SSC fragility analysis and with systems analysis to quantify CDF and LERF. This portion of the analysis consists of integrating the intermediate results of the earlier phases to quantify CDF and LERF values.

Relation to Technical Requirements in the ASME/ANS PRA Standard [1]: The integration work is identical to that for external hazards PRA for full power operation. The HLRs and SRs for this element are in the ASME/ANS PRA Standard [1]; they are discussed in detail for earthquakes in Section 5-2 (designated as SPR-E), for high winds in Section 7-2 (designated as WPR-B), for external floods in Section 8-2 (designated as XFPR-B), and for other external hazards in Section 9-2 (designated as XPR-B).

In addition to the technical elements above, an additional and vital task is the documentation of the work. Requirements for documentation are also included throughout this standard.

1.1.8.4 High Winds PRA and External Flooding, LPSD PRA

The ASME/ANS PRA Standard [1] contains separate sections with technical requirements for high winds PRA (Part 7) and external flooding PRA (Part 8). It also contains guidance that permits the analyst to use either the requirements in these specific sections or the more general requirements that cover any other external hazard, found in Part 9 of that standard. As noted just above in Section 1.1.8.2, this approach is also followed here.

1.1.8.5 High Level Requirements for a Specific External Hazard for Each POS Separately

All of the requirements in Parts 5 through 9 are to be carried out separately for each POS (or set of POSs) identified as relevant.

1.2 Acronyms and Definitions

The list of acronyms and definitions from Reference [1] is adopted for this standard by reference. Additional acronyms and definitions are provided in this section to ensure the understanding of terms as they are used in this standard.

1.2.1 Acronyms

BWR: boiling water reactor
 CDDP: conditional core damage probability
 CCF: common cause failure
 CDF: core damage frequency
 CLERP: conditional large early release probability
 CT: completion time
 DID: defense-in-depth
 DHR: decay heat removal
 EDG: emergency diesel generator
 EOP: emergency operating procedure
 FMEA: failure modes and effects analysis
 HEP: human error probability
 HFE: human failure event
 HLR: high-level requirement

HPSI: high-pressure safety injection
HRA: human reliability assessment
HRE: higher risk evolution
HVAC: heating, ventilation, and air conditioning
LER: large early release
LERF: large early release frequency
LOCA: loss-of-coolant accident
LOOP: loss of offsite power
LPSD: low power and shutdown
LPSI: low-pressure safety injection
NA: not available
NPP: nuclear power plant
OPDRC: operations with the potential to drain the reactor cavity
OPDRV: operations with the potential to drain the reactor vessel
PDS: plant damage state
POS: plant operating state
PRA: probabilistic risk assessment
PSHA: probabilistic seismic hazard analysis
PWR: pressurized-water reactor
QLRA: qualitative risk assessment
RCIC: reactant core isolation cooling
RCS: reactor coolant system
RHR: residual heat removal
RSR: residual heat removal
SG: steam generator
SGTR: steam generator tube rupture
SR: supporting requirement
SSCs: structures, systems, and components
TS: technical specifications
USNRC: U.S. Nuclear Regulatory Commission

1.2.2 Definitions

accident class: A grouping of accident sequences with similar characteristics such as common POS, initiating event type, or containment challenge; e.g., accident sequences initiated by a transient with a loss of decay heat removal, loss of coolant accidents, station blackout accidents, and containment bypass accidents.

accident sequence: A representation in terms of an initiating event defined for a set of initial plant conditions (characterized by a plant operating state) followed by a sequence of failures or successes of events (such as system, function, or operator performance) that can lead to undesired consequences with a specified end state (e.g., core damage or large early release).

activity: A planned interaction with the plant such as the performance of maintenance to re-align the plant operating configuration or to change the plant operating parameters, e.g., power level.

at-initiator human failure event: A type of initiating event; human failure events that cause or contribute to an initiating event (e.g., the human failure events that directly involve plant personnel actions at the time of the initiating event, including actions correctly performed but which are based on erroneous indications). This group does not include malicious acts such as sabotage.

cold shutdown: A set of POSs during which the reactor is subcritical with the primary system depressurized at relatively low temperature (< 200°F) and the reactor vessel intact (head on) with heat removal via RHR shutdown cooling. Cold shutdown is defined by the Technical Specifications (Mode 5 for PWRs, Mode 4 for BWRs) for the condition with the primary temperature below 200°F and with the reactor vessel head tensioned.

conditional core damage frequency: The frequency per year of core damage given the occurrence of a specific plant configuration at a given instant in time; e.g., a plant operating state, external hazard damage state, or a component out of service.

conditional core damage probability (CCDP): The probability of core damage given the occurrence of a specific plant configuration (e.g., a plant operating state, external hazard damage state, or a component out of service) over a limited period of time.

conditional large early release probability (CLERP): The probability of large early release given the occurrence of a specific plant configuration (e.g., a plant operating state, external hazard damage state, or a component out of service) over a limited period of time.

controlled manual shutdown: A POS evolution during which the reactor power level is decreased from full power to low power and finally to zero power with control rods inserted.

defense in depth: The concepts of providing access controls and multiple physical barriers to radionuclide release, successive measures to prevent an accident or mitigate the consequences of an accident, and the use of redundancy and diversity to accomplish key safety functions.

demand-based initiating event: An initiating event that is linked to a specific activity as opposed to occurring randomly in time over the POS duration. For example, in a PWR, the initiator “over-draining while reducing RCS level to mid-loop” that leads to a loss of decay heat removal would be considered a demand-based initiating event since the activity for drain down to mid-loop has been associated with historical over-draining events.

end state: The set of conditions at the end of an accident sequence that characterizes the impact of the sequence on the plant or the environment. In most PRAs, end states typically include success states (i.e., those states with negligible impact), plant damage states for Level 1 sequences, and release categories for LERF sequences. For QLRA purposes, end state is also the term used to describe the end points of decision trees describing the status of key safety functions.

forced outage: An unscheduled plant shutdown that is required due to administrative or hardware issues. See “outage types” for further discussion.

full power or nominal full power: A POS during which the reactor power is at or near its normal designed value. In this POS, the primary system configuration (power level, pressure, temperature, boundaries, etc.) is maintained essentially constant. The “low power” state is defined to include all at-power operations below nominal full power.

higher risk evolution: Outage activities, plant configurations, or conditions during shutdown where the plant is more susceptible to an event causing the loss of a key safety function

hot shutdown: A set of POSs during which the reactor is subcritical with the primary temperature between 200°F and 350°F and with the reactor vessel intact. Hot shutdown is defined by the Technical Specifications (Mode 4 for PWRs, Mode 3 for BWRs).

hot standby: A POS (or set of POSs) during which the reactor is subcritical with the primary temperature above 350°F and the reactor vessel intact. Hot standby is defined by the Technical Specifications (Mode 3 for PWRs, not used for BWRs).

initiating event: A perturbation during a plant operating state that challenges plant control and safety systems and whose failure could potentially lead to core damage or core damage with radioactivity release. An initiating event could require a response or degrade the reliability of a normally operating system, cause a standby mitigating system to be challenged, or require that the plant operators respond in order to mitigate the event or to limit the extent of plant damage caused by the initiating event.

interfacing systems LOCA (ISLOCA)⁶: A LOCA when a breach occurs in a system that interfaces with the RCS, where isolation between the breached system and the RCS fails. An ISLOCA is usually characterized by the over-pressurization of a low-pressure system when subject to RCS pressure and can result in containment bypass.

key safety functions: The minimum set of safety functions that must be maintained to prevent core damage and/or large early release. These include reactivity control, reactor pressure control, reactor coolant inventory control, decay heat removal, and containment integrity in appropriate combinations to prevent core damage and large early release. This is the definition from ASME/ANS RA-Sa-2009 [1] for full power conditions. This term is assumed to be equivalent to “critical safety functions,” as used in other references. The term “key safety functions” is used in this standard for consistency with ASME/ANS RA-Sa-2009 [1], except in Section 11. The term “key safety functions” for LPSD QLRA is instead taken from NUMARC 91-06 [2], as presented in Section 11.2.3.

LOCA: Loss of coolant accident. This includes “traditional” full power accident initiators such as pipe break and relief valve opening, while it also includes maintenance-induced flow diversions, RCS boundary failure due to drain-down events, and other potential losses of RCS inventory that are unique to shutdown conditions (and are typically more likely than pipe breaks at low system pressure).

low power: A POS (or set of POSs) during which the reactor is at reduced power below nominal full-power conditions. In these POSs, the power level may be changing as the reactor is shutting down or starting up, or the power level may be constant at a reduced level. The power level that distinguishes nominal full power from low power is the power level below which there may be a significant increase in the likelihood of a plant trip, e.g., taking manual control of feedwater level.

LPSD evolution: A series of connected or related activities such as a reduction in power to a low level or plant shutdown followed by the return to full-power plant conditions. LPSD evolutions are modeled as a series of POSs. Outage types are sub-types of an LPSD evolution, though not all LPSD evolutions involve an outage. A refueling outage is a specific example of an LPSD evolution. Reducing power to 30% in order to conduct maintenance or an operational activity is another example of a low power evolution. LPSD evolutions may be described by a transition down to the POS where the activity is conducted followed by a transition back to full power.

⁶ Events can occur during shutdown that have similar consequences to those at-power — bypass of containment and loss of RCS coolant from the containment sump. However, during shutdown, these events may evolve quite differently; e.g., maintenance-induced drain-down of RCS outside containment through RHR suction valves that are open to support the decay heat mode rather than passive boundary failures. Since these events are analyzed much differently, the term ISLOCA is not used for such drain-down events, but is reserved for events that involve passive boundary failures.

mid-loop: A POS (or set of POSs) in a PWR during which the water level in the reactor vessel is drained below the top of the hot legs. This evolution occurs to support primary system maintenance such as steam generator tube inspection during a refueling outage. This is termed “hot” or “early” mid-loop when it occurs early in an outage prior to fuel offload with relatively high decay heat levels. This is contrasted with “cold” mid-loop or “late” mid-loop, which refer to this evolution occurring towards the end of the outage following fuel reload.

mode: Status of plant operation, as defined by plant technical specifications.

outage: The entire set of POSs with the plant subcritical. This term is used interchangeably with the term “shutdown” (see discussion under “shutdown”).

outage types: Term used to describe the general cause of the plant being subcritical. Different outage types result from maintenance and refueling requirements that necessitate different LPSD evolutions and resulting POSs. For example, a “refueling” outage type leads to cold shutdown with some or all of the fuel elements transferred out of the reactor pressure vessel. In contrast, a “maintenance” outage conducted at cold shutdown to repair steam piping would be a different outage type.

per calendar year: Units for CDF or LERF, the calculation of which includes contributions from each POS and takes into account the fraction of time spent in that POS normalized to one calendar year. Thus, the results from each POS per calendar year can be summed to give the total quantitative risk results. Also, note that the total risk “per calendar year” does not represent any actual year of operation since it includes all possible POSs, some which may occur only in outages that occur less frequently than yearly.

plant condition: A measureable or observable parameter related to plant system state, e.g., RCS temperature, core decay heat level, Mode 4, SI secured, train A RHR running, or head off. A specific set of plant conditions is used to define the plant operating state modeling elements, and a larger set of plant conditions is used to define plant configurations.

plant configuration: The status of a specific set of plant conditions that includes all those used to define a plant operating state plus specific equipment alignments and equipment outages. These plant conditions include mode, primary system conditions (e.g., temperature, pressure), primary system status (e.g., mid-loop operation, vessel level during shutdown), equipment alignment (e.g., number of pumps operating, number of pumps in standby), and equipment out of service for test and maintenance. For configuration risk management, other conditions external to the plant may be defined, e.g., weather, grid-related activities, etc. One or more plant configurations may occur within the same plant operating state because they are defined in terms of more plant conditions.

plant operating state (POS): A standard arrangement of the plant during which the plant conditions are relatively constant, are modeled as constant, and are distinct from other configurations in ways that impact risk. POS is a basic modeling device used for a phased-mission risk assessment that discretizes the plant conditions for specific phases of an LPSD evolution. Examples of such plant conditions include core decay heat level, primary water level, primary temperature, primary vent status, containment status, and decay heat removal mechanisms. Examples of risk impacts that are dependent on POS definition include the selection of initiating events, initiating event frequencies, definition of accident sequences, success criteria, and accident sequence quantification.

qualitative risk assessment (QLRA): As applied to outage risk assessment, the use of defense-in-depth principles to support risk assessment and risk management for shutdown operations applicable to hot standby, hot shutdown, cold shutdown, and refueling modes of operation.

refueling outage: An outage type that occurs on a periodic basis during which a portion of the spent nuclear fuel is replaced with new (unburned) fuel.

representative LPSD evolution: A category of LPSD evolutions used for evaluating time-averaged CDF during LPSD conditions, often using a separate model for each representative category. For most LPSD PRAs performed to date, the representative LPSD evolutions consist of refueling outages, controlled shutdowns, and forced outages resulting in safe, stable states such as hot shutdowns and cold shutdowns with and without RCS draining.

shutdown: The collection of POSs during which the reactor is subcritical. This term is interchangeable with the term outage. Also see the related term, “controlled shutdown.”

significant accident sequence: One of the set of accident sequences resulting from the analysis of a specific hazard group defined at the functional or systematic level that, when rank-ordered by decreasing frequency, sum to a specified percentage of the core damage frequency for that hazard group or that individually contribute more than a specified percentage of the total core damage frequency summed over all the POSs in that hazard group.⁷ For this version of the standard,⁸ the summed percentage is 95%, and the individual percentage is 1% of the applicable hazard group CDF (see Part 3, Requirements LIE-B3, LHR-H1, LQU-B2, LQU-C1, LQU-D1, LQU-D5, and LQU-F2.) For hazard groups that are analyzed using methods and assumptions that can be demonstrated to be conservative or bounding, alternative numerical criteria may be more appropriate and, if used, should be justified.

significant basic event: A basic event that contributes significantly to the computed risks for a specific hazard group summed over all the POSs in that hazard group. For internal events, this includes any basic event that has a Fussell-Vesely importance greater than 0.005 or a RAW importance greater than 2 (see Part 3, Requirements LDA-C13, LDA-D1, LDA-D3, LDA-D5, LDA-D8, LHR-D2, and LHR-G1.) For hazard groups that are analyzed using methods and assumptions that can be demonstrated to be conservative or bounding, alternative numerical criteria may be more appropriate and, if used, should be justified.

significant contributor: In the context of

- (a) an internal events accident sequence/cut set, a significant basic event, POS, LPSD evolution, or an initiating event that contributes to a significant sequence;
- (b) accident sequences/cut sets for hazard groups other than internal events, the following are also included: the hazard source, hazard intensity, and hazard damage scenario;
- (c) an accident progression sequence, a contributor that is an essential characteristic (e.g., containment failure mode, physical phenomena) of a significant accident progression sequence that, if not modeled, would lead to the omission of the sequence.

significant plant operating state (POS): One of the set of accident classes specified by a given POS and hazard group that when rank ordered by decreasing frequency, sum to a specified percentage of core

⁷ For purposes of determining significance, the rank ordering for each hazard group can also be based on a subset of the entire PRA scope (e.g., for just one POS or accident class) since such a rank ordering will be more restrictive than when applied to the entire scope.

⁸ Alternative criterion may be appropriate for specific applications. In particular, an alternative definition of “significant” may be appropriate for a given application where the results from PRA models for different hazard groups need to be combined.

damage frequency or large early release frequency for that hazard group or that individually contribute more than a specific percentage of core damage frequency or large early release frequency for that hazard group. For this version of the standard, the summed percentage is 95%, and the individual percentage is 1% of the applicable hazard group CDF or LERF.

Note that the evaluation of significance in terms of CDF or LERF for each specific hazard group that is to be combined over all LPSD evolutions and all POSs is also implicitly required in the definitions for the following terms from Reference [1] that are not repeated here, i.e., significant accident progression sequence, significant containment challenge, significant accident progression sequence, and significant cut set.

startup: A POS during which the reactor power level is increased from low power to full power following a plant outage.

startup mode: A plant mode defined by the Technical Specifications (Mode 2) during which the power level is less than 5% with the reactor critical for PWRs or the position (e.g., startup) of the Mode Selector Switch for BWRs.

time-averaged CDF: A risk metric for the expected number of core damage events per calendar year summed over all modeled LPSD evolution types. No one specific evolution is to be considered an “average” LPSD evolution; rather, an average LPSD evolution of each LPSD evolution type is one whose POS durations and equipment outage durations in each POS are consistent with the data from plant operation averaged over many years from all LPSD evolutions of that same type. LPSD evolution types are described in Part 2 and non-mandatory Appendix 2.A.

time-dependent CDF: The computation of CDF (expected number of core damage events per unit of time) at one particular time and for a single plant configuration in one POS. The plant configuration is characterized by the specific plant system alignments and maintenance conditions at that point in time rather than by time-averaged maintenance alignments. The average of the time dependent CDF over a year is the time-averaged CDF for that year. When averaged over a long period of time, the result is equivalent to the time-averaged CDF, i.e., one of the risk metrics of a baseline PRA.

1.3 LPSD Quantitative Risk Assessment Application Process

1.3.1 Purpose

The risk assessment application process is accomplished according to the requirements found in Section 1-3 (“Risk Assessment Application Process”) of the ASME/ANS PRA Standard [1].

This section summarizes the required activities to determine the capability of a PRA needed to support a particular risk-informed application. As stated in the ASME/ANS PRA Standard [1]:

“For a specific application, PRA capabilities are evaluated in terms of Capability Categories for individual Supporting Requirements rather than by specifying a single Capability Category for the whole PRA. Depending on the application, the required PRA capabilities may vary over different parts of this standard. The SRs relevant to the different portions of a PRA within the scope, across the elements, and possibly within each element, may be required to have different Capability Categories to support the application, and some portions of a PRA may be irrelevant to the application.”

Section 1-3 of the ASME/ANS PRA Standard [1] describes a five-stage process for applying the standard to a specific issue. While this process is the same for LPSD as for full power conditions, two specific examples from shutdown conditions are provided below.

1.3.2 Identification of Application and Determination of Capability Categories

1.3.2.1 Identification of Application

Define the application by:

- (a) Evaluating the plant design change or operational change being assessed;
- (b) Identifying the SSCs and plant activities affected by the change including the cause-effect relationship between the plant design change or operational change and the LPSD PRA model;
- (c) Identifying the LPSD PRA scope and risk metrics that are needed to assess the change.

Example A: A change in technical specifications (TS) is proposed that redefines the requirements for an operable residual heat removal (RHR) system for a PWR with a large dry containment while in Mode 4. This change extends the TS requirement for the completion time (CT) of actions to be taken if the RHR subsystem(s) are inoperable. The changes in TS and/or procedures that are involved need to be identified in detail.

In order to assess the impact of the proposed change in the TS, the SSCs affected by the proposed change, such as the RHR system and cross-tie lines, need to be identified. The plant RHR system has two redundant loops, each having two full capacity RHR pumps and an RHR heat exchanger. The RHR system removes heat from the RHR heat exchangers during shutdown cooling mode of RHR system operation. The RHR system consists of two loops, each of which supplies cooling water to its respective heat exchanger. The operability requirements are determined by the POS.

The proposed change in the completion time impacts the core damage frequency (CDF) by increasing the time that an RHR loop can be out of service. This change is evaluated by considering the impact on system unavailability and on the frequency of sequences involving unavailability of either one or both RHR loops (depending on the POS).

Example B: A plant located along the southeastern U.S. seaboard has always scheduled its refueling outages in the springtime when hurricanes, which mostly occur later in the year, are too rare to be of great concern. This coming year, it will be forced to take a three-month outage for major repairs, and the time chosen is April to June. This is still well before the usual “hurricane season.” However, three months before the outage is to begin, delivery problems with major equipment force a delay so that the three-month outage must occur from August to October, which is right in the middle of the season with the highest hurricane potential. The plant already performed a hurricane PRA for full power, but has not done one for outage conditions.

The plant has approved technical specifications in place for outages that consider actions needed in case of a hurricane, but these are not “risk-informed.” Therefore, although the plant would certainly use these technical specifications to assure that it is in full compliance with all applicable regulations, the plant management desires to use an LPSD PRA to assess whether any special vulnerabilities that had not been considered or that might require additional protective measures might exist during the outage. Using such a PRA, the plant

can schedule outage actions and manage specific activities to minimize hurricane-induced risks.

The CDF for the three-month outage period during “hurricane season” is not known, nor are the principal contributors to whatever extra “risk” might exist. Therefore, an LPSD PRA for hurricanes is needed to provide these insights. The scope of that LPSD PRA is to be guided by the insights gained from the existing full power hurricane PRA, which has already identified those buildings, structures, and other SSCs that contribute importantly to the leading accident sequences from a hurricane that might occur at full power. This full power PRA must be adapted for the shutdown condition and must cover those shutdown POSs that the plant will be in during the “hurricane season.” It is possible that hurricane risk had been eliminated from the full power PRA on the basis that hurricanes always come with warning time, and that the plant would shut down if a hurricane threatened. Obviously, this logic would not apply at shutdown, although actions might be taken to put the plant in a safer configuration. In this event, a hurricane PRA would need to be developed.

The management decides that CDF is the appropriate measure to use, and that LERF is not as significant because the containment would be closed long before the hurricane arrived. The plant management is also interested in whether any equipment not previously identified might be found to be vulnerable to damage from a postulated hurricane.

Note that for this application, it is not expected that the LPSD PRA would be used to support any regulatory action. The application is to support the plant management's desire to better understand a wide range of possible hurricane-caused risks, for example, risks to its investment even if there is no important additional “CDF”-related risk.

1.3.2.2 Determination of Capability Categories

Parts 3 to 9 of this standard set forth SRs for three PRA Capability Categories whose attributes are described in Subsection 1.1.3. For the application, determine the Capability Category for each part of the PRA needed to support the application considering each applicable POS. This determination dictates which SRs are used to evaluate the capabilities of each part of the PRA to support the application. To determine these capabilities, an evaluation is performed of the application to assess the role of the PRA in supporting that application.

Example A (continued): Continuing with the RHR loop completion time change example, the proposed change is a risk-informed application to justify a change to an operating license in accordance with the NRC Regulatory Guides 1.174 [3] and 1.177 [4]. If the plant has a baseline CDF and LERF of 1.0×10^{-5} /yr. and 1.0×10^{-6} /yr., respectively, including CDF and LERF contributions from both full power and LPSD conditions, and it is expected that the changes in CDF can be shown to be small, then the parts of the PRA that are impacted by changes in RHR loop unavailability may be determined to require PRA Capability Category II, whereas the remaining parts of the LPSD PRA needed to determine CDF are determined to only require PRA Capability Category I. Hence, the initiating events, accident sequences, data parameters, system models, human actions, and quantification process for those sequences and cut sets impacted by the completion time changes are in PRA Capability Category II, and the remaining parts of the PRA needed to evaluate CDF are in Capability Category I. The LERF is determined to be not needed for this application based on a qualitative evaluation and hence does not have to meet any of the Capability Categories.

Example A Variation: If the above example application was being evaluated at a plant with a baseline core damage frequency greater than 1.0×10^{-4} /yr. or baseline LERF greater than 1.0×10^{-5} /yr., or the changes in CDF or LERF were expected to be important such that the degree of confidence in the risk evaluation needed to be much greater than in the previous example, it may be determined that those parts of the LPSD PRA impacting the change might need to be upgraded. In addition, in this example, it might be necessary to expand the application to include a determination of LERF to confirm that the impacts on LERF are acceptable. This need might mean the expansion of the applicable SRs in the LERF PRA element in comparison with the previous example.

Example B (continued): Continuing with the hurricane-season example above, the plant management decides that it desires a high-winds-hurricane LPSD PRA that generally meets Capability Category II requirements so as to have a high confidence that the PRA will be able to determine whether any special risk-management measures are needed. A few aspects of the plant (specifically, some of the trains of safety equipment) are judged not to be important to CDF initiated by high winds based on the full power high-winds-hurricane quantitative PRA, and a LPSD PRA that generally meets Capability Category I requirements is judged adequate for those aspects.

1.3.3 Assessment of PRA for Necessary Scope, Results, and Models

For each specific application, the user of this standard must assess whether the PRA has the necessary scope, results, and models to support that application. To do so, the user determines if the PRA provides the results needed to assess the plant change or operational change. In identifying the LPSD PRA scope required, the user considers the LPSD evolutions, plant operating states, and hazard groups defining the sequences affected by the plant design change or operational change. If some aspects of the PRA are insufficient to assess the change, they then need to be upgraded according to the SRs of Parts 3 through 9 for the appropriate Capability Category; alternatively, supplementary analyses may be generated.

Example A (continued): The proposed change in the RHR completion time has been determined to affect the RHR unavailability. This unavailability is determined by the RHR pumps, the RHR service water pumps, the RHR heat exchangers, control valves, cross-tie lines with motor-operated valves, and the Emergency Core Cooling System (ECCS) fill system supplied by the Core Spray system to keep the RHR lines filled and the RHR discharge headers pressurized to approximately 85 psig (6.9×10^5 Pa) at all times during plant operation. Thus, the scope of the Systems Analysis and Data elements of the PRA must include each of these SSCs.

Example B (continued): After the new high-winds-hurricane LPSD PRA for the outage condition has been completed using Capability Category II requirements everywhere except for a few LPSD PRA aspects that were judged to require only Capability Category I requirements, the leading contributors are examined. Certain safety systems that are not important for hurricane-induced CDF during full power operation and hence were analyzed using only Capability Category I requirements turn out to be much more important than anticipated; if these LPSD PRA insights are correct, the management would find it appropriate to invest in extra high-winds protection before entering the extended hurricane-season outage. The plant management decides to upgrade the LPSD PRA analysis of these safety systems using Capability Category II and Capability Category III requirements (e.g., for SR WFR-A1 calling for the use of plant-specific data and incorporating the findings of a walkdown) so as to gain even higher confidence in the numerical results of the analysis.

The user determines whether the SSCs or plant activities affected by the plant design or operational change are modeled in the LPSD PRA. If the affected SSCs or plant activities were not modeled, the user then needs either to upgrade the LPSD PRA to include the SSCs in accordance with the SRs of Part 4 for their corresponding Capability Categories or to generate supplementary analyses (see Subsection 3.6).

Example A (continued): Continuing with the previous Example A, the action to be taken when the required RHR loop(s) are out of service is to “verify an alternate method of decay heat removal is available”. Besides various alignments using cross-ties, this alternative may include the Fuel Pool Cooling and Reactor Water Cleanup systems if their success criteria were met, e.g., late after shutdown when the decay heat level is low. Thus, either the PRA must include systems models, data, and success criteria to represent these alternates, or supplementary analyses, which are outside the scope of the standard, may be used.

Example B (continued): Continuing with the high-winds-hurricane example, the new LPSD PRA did not model the structural failure from high winds of certain switchgear equipment inside the auxiliary building because it was judged that it could not be damaged. After completing the new LPSD PRA, an unexpected structural vulnerability of a shear wall adjacent to that equipment is found possibly to cause damage to the switchgear. Either the LPSD PRA must be modified to account for this issue, or a supplemental engineering analysis must be performed to demonstrate that the failure of the switchgear cannot lead to unacceptable consequences.

1.3.4 Determination of the Standard’s Scope and Level of Detail

The user determines if the scope of coverage (i.e., the LPSD evolutions, plant operating states, and hazard groups modeled) and level of detail of the SRs stated in Parts 3 through 9 for the corresponding Capability Categories determined in Section 1.3.2.2 are sufficient to assess the application under consideration.

If it is determined that the standard lacks certain specific requirements, their importance to the application is assessed. If the absent requirements are not important, the requirements of the standard are sufficient for the application. The bases for determining the sufficiency of this standard is documented. If the absent requirements are important, supplementary requirements may be used.

1.3.5 Comparison of LPSD PRA Model to Standard

The user determines if each part of the LPSD PRA satisfies the SRs at the appropriate Capability Category needed to support the application. The results of the peer review may be used. If the LPSD PRA meets the SRs necessary for the application, the LPSD PRA is acceptable for the application being considered. The basis for this determination is to be documented.

If the LPSD PRA does not satisfy an SR for the appropriate Capability Category, the user then determines if the difference is significant. Acceptable requirements for determining the significance of this difference include:

- (a) The difference is not applicable or does not affect quantification relative to the impact of the proposed application; or
- (b) Modeled accident sequences accounting for at least 90% of CDF/LERF, as applicable, are not affected by appropriate sensitivity studies or bounding evaluations. Note that this is 90% of the total CDF/LERF in any one POS or POS group. These studies or evaluations should measure the

aggregate impact of the exceptions to the requirements in Parts 4 through 9 as applied to the application.

Determination of significance will depend on the particular application being considered and may involve determinations made by an expert panel. Note: a short POS duration (e.g., less than one percent of a calendar year) may be insufficient grounds for screening the POS unless it can be shown, for example, that there are no demand-related initiating events (independent of duration) that may be important contributions to CDF/LERF.

If the difference is not significant, the *LPSD PRA* is then acceptable for the application. If the difference is significant, the user then either upgrades the *LPSD PRA* to address the corresponding SRs stated in Parts 4 through 9, or generates supplementary analyses (see Subsection 1.3.6). Any upgrade of the PRA is done and documented in accordance with Section 1.5.

Example: *The examples provided under Section 1.3.3 are applicable.*

1.3.6 Use of Supplementary Analyses/Requirements

In the event that the scope of either the LPSD PRA or the standard is insufficient, supplementary analyses or requirements may be used. These supplementary analyses will depend on the particular application being considered but may involve deterministic methods such as bounding or screening analyses and determinations made by an expert panel. They are to be documented.

Examples of sources for a supplementary analysis: *Supplementary requirements are drawn from other recognized codes or standards whose scopes complement that of this standard and which are applicable to the application; however, they may be generated by an expert panel if no such recognized code or standard can be identified.*

If it has been determined that the PRA has sufficient capability, its results can be used to support the application. If not, the results of supplementary analyses, some of which may respond to supplementary requirements, can also be used to support the application. Such supplementary analyses/requirements are outside the scope of this standard.

1.4 LPSD PRA Technical Requirements

1.4.1 Purpose

Consistent with Reference [1], the purpose of this section is to provide requirements by which adequate PRA capability can be identified when an *LPSD PRA* is used to support applications of risk-informed decision making. The specific focus of this section is the set of unique and specific requirements by which an adequate LPSD PRA can be identified.

1.4.2 Process Check

Consistent with Reference [1], the process of reviewing analyses and/or calculations used directly by the LPSD PRA or used to support the LPSD PRA shall be performed by knowledgeable individuals who did not perform those analyses or calculations. Documentation of this review may take the form of hand-written comments, signatures or initials on the analyses/calculations, formal sign-offs, or other equivalent methods.

1.4.3 Use of Expert Judgment

The requirements for the use of expert judgment outside the LPSD PRA analysis team are the same as those described in Section 1-4.3 of Reference [1] and are incorporated by reference.

1.4.4 Derivation of PRA Requirements

Consistent with Reference [1], objectives were established for each technical element used to characterize the respective scope of a PRA. These objectives form the basis for the development of the high level requirements for each element that were used, in turn, to define the supporting requirements.

In setting the HLRs for each element, the goal was to derive, based on the objectives, an irreducible set of firm requirements applicable to PRAs that support all levels of application to guide the development of SRs. This goal reflects the diversity of approaches that have been used to develop existing PRAs and the need to allow for technological innovations in the future. An additional goal was to derive a reasonably small set of HLRs that capture all the important technical issues that were identified in the efforts to develop this standard.

The HLRs generally address attributes of the PRA element such as:

- (a) scope and level of detail;
- (b) model fidelity and realism;
- (c) output or quantitative results (if applicable);
- (d) documentation.

Three sets of SRs were developed to support the HLRs in the form of action statements for the various Capability Categories in the standard. Therefore, there is a complete set of SRs provided for each of the three PRA Capability Categories.

1.4.5 PRA Requirements

Consistent with Reference [1], tables of HLRs and SRs for the technical elements are provided for each PRA scope. The SRs are numbered and labeled to identify the HLR that is supported. For each Capability Category, the SRs define the minimum requirements necessary to meet that Capability Category. In these tables, some action statements apply to only one Capability Category, while some extend across two or three Capability Categories. When an action spans multiple categories, it applies equally to each Capability Category. When necessary, the differentiation between Capability Categories is made in other associated SRs. The interpretation of a Supporting Requirement whose action statement spans multiple categories is stated in Table 1.1.3-3. It should be noted that some action statements span Capability Categories II and III because the authors were unable to specify a distinguishing requirement for Capability Category III at this time. It is intended that by meeting all the SRs under a given HLR, a PRA will meet that HLR.

1.5 LPSD PRA Configuration Control

This section repeats the language from Section 1.5 of Reference [1], except that PRA is replaced by LPSD PRA.

1.5.1 Purpose

This section provides requirements for the configuration control of an LPSD PRA to be used with this standard to support risk-informed decisions for nuclear power plants.

1.5.2 LPSD PRA Configuration Control Program

AN LPSD PRA Configuration Control Program shall be in place. It shall contain the following key elements:

- (a) a process for monitoring LPSD PRA inputs and collecting new information;
- (b) a process that maintains and upgrades the LPSD PRA to be consistent with the as-built, as operated plant;
- (c) a process that ensures that the cumulative impact of pending changes is considered when applying the LPSD PRA;
- (d) a process that maintains configuration control of computer codes used to support LPSD PRA quantification;
- (e) documentation of the program.

1.5.3 Monitoring LPSD PRA Inputs and Collecting New Information

The LPSD PRA Configuration Control Program shall include a process to monitor changes in the design, operation, maintenance, and industry-wide operational history that could affect the LPSD PRA. These changes shall include inputs that impact operating procedures, design configuration, initiating event frequencies, system or sub-system unavailability, and component failure rates. The program should include monitoring of changes to the LPSD PRA technology and industry experience that could change the results of the LPSD PRA model.

1.5.4 LPSD PRA Maintenance and Upgrades

The LPSD PRA shall be maintained and upgraded such that its representation of the as-built, as-operated plant is sufficient to support the applications for which it is being used.

Changes in LPSD PRA inputs or the discovery of new information identified pursuant to Subsection 1.5.3 shall be evaluated to determine whether such information warrants LPSD PRA maintenance or LPSD PRA upgrade (see Section 1.2 for the distinction between LPSD PRA maintenance and LPSD PRA upgrade). Changes that would impact risk-informed decisions should be incorporated as soon as practical. Changes that are relevant to a specific application shall meet the SRs pertinent to that application as determined through the process described in Subsection 1.3.5.

Changes to an LPSD PRA due to LPSD PRA maintenance and LPSD PRA upgrade shall meet the requirements of the Technical Requirements section of each respective part of this standard. Upgrades of an LPSD PRA shall receive a peer review in accordance with the requirements specified in the Peer Review section of each respective section of this standard but limited to aspects of the LPSD PRA that have been upgraded.

1.5.5 Pending Changes

This standard recognizes that immediately following a plant change (e.g., modifications, procedure changes, plant performance [data]) or upon the identification of a subject for model improvement (e.g., new human error analysis methodology, new data update methods), an LPSD PRA may not represent the plant until the subject plant change or model improvement is incorporated into the LPSD PRA. Therefore, the LPSD PRA configuration control process shall consider the cumulative impact of pending plant changes or model improvements on the application being performed. The impact of these plant changes or model improvements on the results of the LPSD PRA and the decision under consideration in the application shall be evaluated in a fashion similar to the approach used in Section 1.3.

1.5.6 Use of Computer Codes

The computer codes used to support and to perform LPSD PRA analyses shall be controlled to ensure consistent, reproducible results.

1.5.7 Documentation

Documentation of the Configuration Control Program and of the performance of the above elements shall be adequate to demonstrate that the LPSD PRA is being maintained consistent with the as-built, as-operated plant.

The documentation typically includes:

- (a) a description of the process used to monitor LPSD PRA inputs and collect new information;
- (b) evidence that the aforementioned process is active;
- (c) descriptions of proposed changes;
- (d) description of changes in an LPSD PRA due to each LPSD PRA upgrade or LPSD PRA maintenance;
- (e) record of the performance and results of the appropriate LPSD PRA reviews (consistent with the requirements of Section 1.6.6);
- (f) record of the process and results used to address the cumulative impact of pending changes;
- (g) a description of the process used to maintain software configuration control.

1.6 LPSD PRA Peer Review

This section repeats the language of Section 1-6 of Reference [1], with the exception of the underlined text and that PRA is replaced by LPSD PRA.

1.6.1 Purpose

This section provides requirements for peer review of an LPSD PRA to be used in risk-informed decisions for commercial nuclear power plants. LPSD PRAs used for applications shall be peer reviewed. Peer reviews for this purpose shall be performed against the requirements in those sections of this standard applicable to the portions of the LPSD PRA that are being used to support such applications. The peer review shall assess the LPSD PRA to the extent necessary to determine if the methodology and its implementation meet the requirements of this standard. Another purpose of the peer review is to determine strengths and weaknesses in the LPSD PRA. The peer review need not assess all aspects of the LPSD PRA against all requirements in the Technical Requirements section of each respective part of this

standard; however, enough aspects of the LPSD PRA shall be reviewed for the reviewers to achieve consensus on the adequacy of methodologies and their implementation for each LPSD PRA technical element.

1.6.1.1 Frequency

Only a single complete peer review is necessary prior to using an LPSD PRA. In addition, Section 1.5 of this standard requires peer review for upgrades of an LPSD PRA. When peer reviews are conducted on LPSD PRA upgrades, the latest review shall be considered the review of record. The scope of an additional peer review may be confined to changes to the LPSD PRA that have occurred since the previous review.

This applies to a specific-outage model as well as to a time-averaged CDF or LERF LPSD PRA model. Only a single complete peer review is required for a specific-outage model. This specific-outage model could be used for subsequent outages without additional peer review as long as the changes required for the subsequent outages are classified as PRA maintenance changes rather than PRA upgrades.

1.6.1.2 Methodology

The review shall be performed using a written methodology that assesses the requirements of the Technical Requirements section of each respective part of this standard and addresses the requirements of the Peer Review section of each respective part of this standard.

The peer review methodology shall consist of the following elements:

- (a) process for selection of the peer review team;
- (b) training in the peer review process;
- (c) an approach to be used by the peer review team for assessing if the LPSD PRA meets the supporting requirements of the Technical Requirements section of each respective part of this standard;
- (d) a process by which differing professional opinions are to be addressed and resolved;
- (e) an approach for reviewing the LPSD PRA configuration control;
- (f) a method for documenting the results of the review.

1.6.2 Peer Review Team Composition and Personnel Qualifications

1.6.2.1 Collective Team

The peer review team shall consist of personnel whose collective qualifications include:

- (a) the ability to assess all the LPSD PRA technical elements of the Technical Requirements section of each respective part of this standard, as applicable, and the interfaces between those elements;
- (b) the collective knowledge of the plant nuclear steam supply system (NSSS) design, containment design, and plant operation.

1.6.2.2 Individual Team Members

The peer review team members individually shall:

- (a) be knowledgeable of the requirement in this standard for their area of review;
- (b) be experienced in performing the activities related to the LPSD PRA Elements for which the reviewer is assigned.

To avoid any perception of a technical conflict of interest, the peer review team members shall have neither performed nor directly supervised any work on the portions of the LPSD PRA being reviewed.

1.6.2.3 Review Team Members for LPSD PRA Upgrades

When a peer review is being performed on an LPSD PRA upgrade, reviewers shall have knowledge and experience appropriate for the specific LPSD PRA technical elements being reviewed. However, the other requirements of this section shall also apply.

1.6.2.4 Specific Review Team Qualifications

The peer reviewer shall also be knowledgeable (by direct experience) of the specific methodology, code, tool, or approach (e.g., accident sequence support state approach, MAAP code, THERP method) that was used in the LPSD PRA technical element assigned for review. Understanding and competence in the assigned area shall be demonstrated by the range of the individual's experience in a number of different, independent activities performed in the assigned area as well as the different levels of complexity of these activities. Note that the peer review may be best conducted separately for each part of the standard, and that each of these peer reviews could then need its own team and schedule.

- (a) One member of the peer review team (the technical integrator) shall be familiar with all the LPSD PRA technical elements identified in the section of this standard under review and shall have demonstrated the capability to integrate these LPSD PRA technical elements. When more than one part is under review, a separate technical integrator may be used for each part.
- (b) The peer review team shall have a team leader to lead the team in the performance of the review. The team leader need not be the technical integrator.
- (c) The peer review should be conducted by a team with a minimum of five members and shall be performed over a minimum period of one week. If the review is focused on a particular LPSD PRA technical element such as a review of an upgrade of an LPSD PRA technical element, then the peer review should be conducted by a team with a minimum of two members and performed over a time necessary to address the specific LPSD PRA Element.
- (d) Exceptions to the requirements of this paragraph may be taken based on the availability of appropriate personnel to develop a team. A single-person peer review shall only be justified when the review involves an upgrade of a single technical element and the reviewer has acceptable qualifications for the technologies involved in the upgrade. All such exceptions shall be documented in accordance with Subsection 1.6.6 of this standard.

1.6.3 Review of LPSD PRA Technical Elements to Confirm the Methodology

The peer review team shall use the requirements of the Peer Review section of each respective part of this standard for the LPSD PRA technical elements being reviewed to determine if the methodology and the implementation of the methodology for each LPSD PRA technical element meet the requirements of this standard. Additional material for those technical elements may be reviewed depending on the results obtained. These suggestions are not intended to be a minimum or comprehensive list of requirements. The judgment of the reviewer shall be used to determine the specific scope and depth of the review in each LPSD PRA technical element.

The results of the overall LPSD PRA including models and assumptions along with the results of each LPSD PRA technical element shall be reviewed to determine their reasonableness given the design and operation of the plant, e.g., investigation of cut set or sequence combinations for reasonableness.

The HLRs and the composite of the SRs of the requirements section of each respective part of this standard shall be used by the peer review team to assess the completeness of an LPSD PRA technical element. Whenever a requirement herein refers back to the ASME/ANS Standard [1], the work to fulfill that requirement is subject to the peer review requirements herein as if the underlying ASME/ANS requirement were written out in full in this standard. Work previously performed and peer reviewed for full power conditions still needs to be peer reviewed to ensure that the requirements of this standard are also met, but previously performed peer reviews can be relied on, as appropriate.

1.6.4 Expert Judgment

The use of expert judgment to implement requirements in this standard shall be reviewed using the considerations in Section 1.4.3.

1.6.5 LPSD PRA Configuration Control

The peer review team shall review the process including implementation for maintaining or upgrading the LPSD PRA against the configuration control requirements of this standard.

1.6.6 Documentation

1.6.6.1 Peer Review Team Documentation

The peer review team's documentation shall demonstrate that the review process appropriately implemented the review requirements.

Specifically, the peer review documentation shall include the following:

- (a) identification of the version of the LPSD PRA reviewed;
- (b) a statement of the scope of the peer review;
- (c) the names of the peer review team members;
- (d) a brief resume on each team member describing the individual's employer, education, LPSD PRA training, and PRA and LPSD PRA technical element experience and expertise;
- (e) the technical elements of the LPSD PRA reviewed by each team member;

- (f) a discussion of the extent to which each LPSD PRA technical element was reviewed, including justification for any supporting requirements within the peer review scope that were not reviewed;
- (g) results of the review identifying any differences between the requirements in the Technical Requirements section of each respective part of this standard, Section 1.5 of this standard, and the methodology implemented, defined to a sufficient level of detail that will allow the resolution of the differences;
- (h) identification and significance of exceptions and gaps relative to the standard's requirements in sufficient detail to allow the resolution of the gaps that the peer reviewers have determined to be material to the PRA;
- (i) an assessment of LPSD PRA assumptions that the peer reviewers have determined to be relevant;
- (j) at the request of any peer reviewer, differences or dissenting views among peer reviewers;
- (k) recommended alternatives for resolution of any differences;
- (l) identification of the strengths and weaknesses that have a significant impact on the LPSD PRA;
- (m) an assessment of the Capability Category of the SRs (i.e., identification of what Capability Category is met for the SRs);
- (n) identification of the written process that was used to conduct the peer review.

1.6.6.2 Resolution of Peer Review Team Comments

Resolution of Peer Review Team comments shall be documented. Exceptions to the alternatives recommended by the Peer Review team shall be justified.

Part 2 Plant Operating State Analysis

2.1 Overview of POS Analysis for LPSD PRA

This Part 2 establishes technical requirements for POS analysis for internal events. There is no equivalent to this part in the ASME/ANS PRA Standard for full power conditions (Part 2 of ASME/ANS RA-Sa-2009 [1]). POS analysis is not a separate hazard group. It is presented here in a separate part in order to preserve the section numbering which follows for internal events. The POS analysis presented in this part for internal events is therefore utilized in Parts 3 through 9 for each of the hazard groups.

2.1.1 Introduction

LPSD PRA involves the analysis of LPSD evolutions during which plant conditions are changing, which is different than the steady state conditions typically modeled in full power PRAs. The activities taking place during LPSD evolutions produce different combinations of equipment availability and capacities, thus creating different sets of initial plant conditions for the modeled initiating events. The frequencies of accident sequences that progress to core damage or large early release can also be impacted by these changing conditions. In theory, these differences mean a separate PRA model would need to be developed for each point in time as the plant conditions change. To reduce the complexity of LPSD PRA models, time intervals are identified and defined as POSs within each LPSD evolution, during which the plant conditions are assumed constant. This section introduces the concept of LPSD evolutions and POSs. Non-mandatory Appendix 2.A provides additional details regarding POS analyses.

2.1.2 LPSD Evolutions

A necessary first step in the identification of applicable POSs is to choose the LPSD evolutions to be represented in the analysis. AN LPSD evolution is formally defined in Section 1.2, and its definition is repeated here along with examples for convenience.

LPSD evolution: a series of connected or related activities such as a reduction in power to a low level or plant shutdown followed by the return to full-power plant conditions. LPSD evolutions are modeled as a series of POSs. Outage types are sub-types of an LPSD evolution, though not all LPSD evolutions involve an outage. A refueling outage is a specific example of an LPSD evolution. Reducing power to 30% in order to conduct maintenance or an operational activity is another example of a low power evolution. LPSD evolutions may be described by a transition down to the POS where the activity is conducted followed by a transition back to full power.

There are a number of types of LPSD evolutions for commercial nuclear reactors. Those selected for analysis in an LPSD PRA are a function of the model scope and intended PRA applications. Consistent with the PRA Capability Categories described in Table 1.1.3-2, the choice of LPSD evolutions and the level of detail in their analyses are dependent on the needed level of detail, plant specificity, and realism required. Non-mandatory Appendix 2.A includes a discussion of this LPSD evolution selection process.

2.1.3 The Concept of Plant Operating States

A POS is formally defined in Section 1.2, and this definition is repeated here for convenience.

plant operating state (POS): a standard arrangement of the plant during which the plant conditions are relatively constant, are modeled as constant, and are distinct from other configurations in ways that impact risk. POS is a basic modeling device used for a phased-mission risk assessment that discretizes the plant conditions for specific phases of an LPSD evolution. Examples of such plant conditions include core decay heat level, primary water level, primary temperature, primary vent status, containment status, and decay heat removal mechanisms. Examples of risk impacts that are dependent on POS definition include the selection of initiating events, initiating event frequencies, definition of accident sequences, success criteria, and accident sequence quantification.

A set of exclusive POSs is identified for each LPSD evolution selected for analysis. The complete set of POSs cover all time periods represented in each selected LPSD evolution. A POS can be a quasi-steady state set of plant conditions or involve a transition of one or more plant conditions between steady state POSs. For example, multiple POSs may be defined to model the LPSD evolution from nominal full power to cold shutdown with residual heat removal cooling. Specifically, a hot standby POS that covers a transition temperature range of 350°F to 200°F may be modeled as one POS with an assumed constant temperature of 350°F. The complete set of exclusive POSs for a specific LPSD evolution represents a discretization of the LPSD evolution time line.

Each identified POS represents the plant initial conditions in a time interval where they are relatively constant, are modeled as constant, and are distinct from other POSs that make up the LPSD evolution in ways that impact risk. Quantification of sequence frequencies for time-averaged CDF is performed separately for each POS. CDF and LERF are thereby calculated and reported naturally at the POS level for each POS. All the important aspects of plant operation and configuration that affect the quantification of CDF and LERF must generally be assumed constant within a POS.

Several different plant conditions could be used to define a POS, but model understanding and configuration control are facilitated when the set of plant conditions chosen is consistent with those used by plant personnel to govern LPSD operations (i.e., plant operating modes or operating conditions as defined in plant technical specifications). The process of identifying the exclusive set of POSs and their associated plant conditions modeled as constant within the POS interval is referred to as POS analysis. POS analysis is facilitated when the list of plant conditions used to identify and define the POSs is kept to the minimum required to distinguish the differences in risk.

In addition to making quantification of an LPSD evolution practical, POS analysis serves another very important purpose. POSs form the basis for the LPSD PRA model development. The selection of initiating events, development of initiating event frequencies, definition of accident sequences, justification of success criteria, and accident sequence quantification are performed separately for each POS or groups of POSs that are not otherwise screened out. Subsequent peer reviews of these other PRA elements are then performed using the POS discretization. Therefore, the set of plant conditions used to define each POS is also chosen to achieve these additional functions.

An example set of plant conditions that could be used to define POSs is provided in Supporting Requirement LPOS-A3. The Grand Gulf [5] and Surry [6] LPSD PRAs developed by the USNRC contain

examples of POSs selected to model different LPSD evolutions including refueling outages for a BWR and PWR, respectively. Further description of POS analysis is provided in non-mandatory Appendix 2.A.

2.2 High Level and Supporting Requirements for the POS Analysis

Objectives: The objective of the POS analysis is to define multiple sets of unique reactor and plant conditions (i.e., POSs) for the purpose of identifying and evaluating the plant response to off-normal conditions with potential to lead to core damage and/or large early release. Each POS is also used to separately evaluate the selection of applicable initiating events, definition of accident sequences, establishment of system success criteria, and for accident sequence quantification. Together, the sets of POSs cover the entire spectrum of low power and non-power operation within the scope of the LPSD PRA. Once defined, the POSs have the following characteristics:

- (a) Low power and shutdown sets of reactor and plant conditions affecting the PRA are divided into POSs based on their unique impacts on plant response.
- (b) Each low power and shutdown POS so identified is to be defined in terms of important plant conditions that may affect the delineation and evaluation of core damage and large early release.
- (c) Low power and shutdown POSs that are grouped together are shown to be represented by the relevant characteristics of the combined group.
- (d) POS frequencies, durations, and decay heat levels are characterized and quantified.
- (e) For each POS, the relationship between decay heat level, reactor level, and pressure and the systems available for decay heat removal are well characterized.

Table 2-1 High Level Requirements for Plant Operating State Analysis (HLR-LPOS)

Designator	Requirement
HLR-LPOS-A	The POS analysis shall use a structured, systematic process to identify and define a complete set of plant operating states to be analyzed in the LPSD PRA.
HLR-LPOS-B	The POS analysis shall justify all screening and grouping of POSs or LPSD evolutions to facilitate an efficient but realistic estimation of CDF and LERF and to support subsequent requirements to be evaluated by a POS or group of POSs.
HLR-LPOS-C	The POS analysis shall determine the POS frequencies and durations along with the representative decay heat levels associated with each POS.
HLR-LPOS-D	The POS analysis shall be documented consistent with the applicable supporting requirements.

The supporting requirements for POS analysis that follow apply to the full scope LPSD PRA for internal events. Specific applications may require only a subset of the hazard groups, LPSD evolutions, and associated POSs that would make up a full scope LPSD PRA. The supporting requirements for POS analyses of the internal events hazard group may have to be supplemented when other hazard groups are included in the model scope. The requirements for hazard groups in Parts 4 through 9 include revisiting the POS analysis for internal events to ensure that they remain applicable when considering changing plant conditions within a specific hazard group, e.g., changing fire boundaries, flood barriers, etc. (see Supporting Requirement LPOS-A7).

**Table 2-2(a) Supporting Requirements for Plant Operating State Analysis –
High Level Requirement A**

The POS analysis shall use a structured, systematic process to identify and define a complete set of POSs to be analyzed in the LPSD PRA (HLR-LPOS-A).

	Capability Category I	Capability Category II	Capability Category III
LPOS-A1	IDENTIFY a representative set of LPSD evolutions (e.g., refueling outages) to be analyzed.	IDENTIFY a representative set of LPSD evolutions to be analyzed, including refueling outages, other controlled shutdowns, and observed forced outages (e.g., refueling outages, drained-down maintenance outages, non-drained maintenance outages, hot shutdowns).	IDENTIFY a representative set of LPSD evolutions to be analyzed, including refueling outages, other controlled shutdowns, and observed forced outages (e.g., refueling outages, drained-down maintenance outages, non-drained maintenance outages, hot shutdowns). In addition, IDENTIFY unique LPSD evolutions including forced outages from nominal full power conditions that involve relatively low-frequency safe stable states (e.g., feed and bleed conditions, high pressure recirculation states, and low pressure recirculation states).
LPOS-A2	For each identified LPSD evolution, REVIEW plant-specific documentation (such as Technical Specifications and normal shutdown, refueling, and startup procedures) and records (such as recent outage plans and records, maintenance plans and records, operations data, trip history, control room logbooks, and thermal-hydraulic data such as refueling outage time to boil and time to core damage calculations) for the following: (a) operating modes or operational conditions as defined in plant Technical Specifications (b) RCS configurations such as vented or not vented, and whether temporary RCS penetrations are installed and their differential pressure capability along with the presence of vessel internals, which in some plants limits natural circulation cooling, and decay heat removal mechanisms such as steaming or residual heat removal (c) range of RCS parameters, e.g., power level or decay heat level, average reactor coolant temperatures, pressures, and water level (d) available RCS level instrumentation (e) mode switch position (for BWRs) (f) activities that may lead to changes in the above parameters, e.g., drain down, filling and venting, dilution, fuel movement, and/or cooldown (g) containment status (e.g., deinerted, intact, open)		