ASSURING PSA TECHNICAL ADEQUACY FOR NEW ADVANCED LIGHT WATER REACTOR DESIGNS

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Abstract

The Probabilistic Safety Assessment (PSA) for an Advanced Light Water Reactor (ALWR) must exhibit a high level of technical adequacy, or technical quality, in order to be used as a reliable tool for making risk informed decisions concerning design and eventual operation of the plant. During the design phase, decisions on some design features may use the PSA as an input. Also, the PSA may be used as input to other operational decisions during plant design and construction including the development of procedures, development of technical specification limiting conditions for operation and scheduling of preventive maintenance activities.

For the existing fleet of light water reactors (LWRs), PSA technical adequacy can be judged from wide ranging acceptance criteria such as the PRA Standard in the United States of America that was developed jointly by the American Society of Mechanical Engineers (ASME) and the American Nuclear Society (ANS). However, the requirements for PRA technical adequacy in this PRA Standard assumes that the plant is built and has operation experience. Some of the requirements cannot be met for ALWRs in the design or construction phase and with no operational history. Key elements of a high level of technical adequacy include procedures, operator interviews, plant walkdowns and equipment reliability histories.

The ability to include these key elements into the ALWR PSA to improve technical adequacy will progress as the ALWR progresses from the design stage through the construction stage and finally to the fuel load / pre-operational stage. As the technical adequacy becomes more robust, more confidence can be placed on risk-informed decisions that are made with the PSA.

To assist in using the PSA as input to design and operational decisions in the design and construction stages of an ALWR, an addition to the ASME/ANS PRA Standard is being developed. The intent of this addition to the Standard is to provide alternative methods of addressing the requirements in the PRA Standard. This addition to the PRA Standard will provide a method of addressing PSA Technical adequacy for pre-operational ALWR plants and permit risk-informed decisions on design and operation to be made with high confidence.

Keywords: PSA, PRA, ALWR, Technical Adequacy

1. Introduction

The Probabilistic Safety Assessment (PSA) is a tool used to assess the integrated safety of nuclear power stations by identifying risk important systems structures and components as well as potential vulnerabilities. It is also an excellent tool for assessing defense in depth for low probability events. In the USA, the PSA has also become part of the fabric of plant design and operation. It is used in daily decision making regarding the alignment of systems and scheduling test and preventive maintenance to minimize potential challenges to plant safety should an upset condition occur. The PSA is also used to modify the plant design and licensing basis, such as risk-informed technical specification changes and equipment additions to support operational flexibility. To support this aggressive use of the PSA, it is imperative that the technical adequacy of the PSA is at a very high level.

For the existing fleet of light water reactors (LWRs), the technical adequacy of the PSA can be judged from wide ranging acceptance criteria such as the PRA Standard (ASME, 2009) in the United States of America that was developed jointly by the American Society of Mechanical Engineers (ASME) and the American Nuclear Society (ANS). The Standard contains hundreds of detailed requirements called Supporting Requirements (SRs) that specify the minimum set of considerations in the development of the PSA. The SRs detail what should be included in the PSA as opposed to how to accomplish it. For example, an SR requirement is “For each modeled initiating event, IDENTIFY the key safety functions that are necessary to reach a safe, stable state and prevent core damage.” However, it does not specific how to identify the safety functions.

Each SR may have varying levels of considerations that correspond to the minimum requirements for the various applications that the PSA my support. For example, conservative analyses and generic assessments may be acceptable for PSA uses that only involve risk ranking applications, but plant specific assessments would be required for use of the PSA to support plant design and operational changes.

The PRA Standard was developed for the existing fleet of plants based on experience in developing PSA studies and assumes that the plant has been built and operating for many years. The PRA Standard assumes that the plant is physically built, procedures are well developed and a significant body of previous operating experience is available to identify important elements of the PSA.

2. ALWR PSA challenges

The NRC’s 10 CFR Part 52 regulations, as further developed in Regulatory Guide 1.206, require that a PRA be developed to support the review of the Standard Plant Design Certification and to support initial operation of the plant. When this Standard is applied to the PRA for the advanced light water reactors currently being licensed and soon to be constructed, there are a number of requirements in the Standard that cannot be fully met due to the stage of plant development. Plant walkdowns to confirm modeling details, interviews with plant personnel on system operating experience (a.k.a. system health) and incorporation of operating experience are just a few of the Supporting Requirements (SRs) that cannot be met for a plant that is still in the design stages. However, as the plant design and construction progresses toward initial operation, some of these SRs can be met (e.g., plant walkdowns). Therefore the Standard needs to address alternative means if possible to address the SRs for plants still in the design stage and as it progresses toward operation.

For the purposes of applying this Standard to ALWRs, it is proposed that four distinct stages be considered. The concept of stages is needed because the PRA should mature along with the design. Reviews or assessments of PRA adequacy should be conducted at certain stages to ensure that the PRA meets specific requirements that are commensurate with the design maturity. This will help ensure that the technical adequacy for risk informed applications developed before plant operation are properly dispositioned. It is only necessary to consider the four stages in the context of risk-informed applications that are initially developed using the PRA in any of the four stages and maintaining the validity of those applications as the design progresses. That is, if there are no risk-informed applications prepared based on the PRA at one of the four stages, then the stage becomes irrelevant for the purposes of technical adequacy of the PRA to support the application. The four stages are:

- Design Certification Stage (incorporation of insights) – In this stage, there is no construction started, procedures may be in a very rudimentary stage of development, there are no designated plant personnel, and there is no operating history. Procedures are meant to include:
    - Accident response procedures that define operator actions for the various accident scenarios identified in the PSA,

- Test and maintenance procedures that define pre-initiator operator errors that can impact equipment availability for an initiating event,

- Procedures that can be used to define equipment unavailability for test and maintenance.

An assessment (either self assessment or peer review) against the PRA Standard should be conducted at this stage to support technical adequacy for identifying design and operational insights. Some SRs must therefore be addressed by alternate means if possible.

- Construction Stage (development of risk-informed programs) – In this stage, construction has only started. Procedures have likely been developed but not validated, a plant operational staff has been identified and is being trained but there is no operating history. An assessment against the PRA Standard should be conducted at this stage to support technical adequacy for developing risk informed applications. The design is more robust at this point, but some SRs must still be addressed by alternate means.

- Pre-Operational Stage (completion of risk-informed programs) – In this stage, construction should be nearly complete, procedures have been validated, the plant operational staff has been trained but there is still no operating history. An assessment against the PRA Standard should be conducted at this stage to support technical adequacy for implementing risk informed programs when operation begins. The design and construction should be complete, but some SRs, such as operating history, must still be addressed by alternate means.

- Operational Stage (completion of risk-informed programs) – In this stage, initial plant operation has begun and operating history is beginning to be collected. Based on experience, the initial fuel cycle of operation of a new plant is not typical of later operation as issues are identified and resolved. Only after the completion of the second fuel cycle can operating history begin to be incorporated into the PRA and risk-informed programs. An assessment against the PRA Standard according to the guidance provided in Section 1-6 of the Standard should be conducted at this stage to support technical adequacy for adjusting risk informed programs as necessary after operation begins. From this point forward, no alternate means of addressing the SRs should be necessary.

Some of the requirements cannot be met for ALWRs in the design or construction phase and with no operational history. Key elements of a high level of technical adequacy include procedures, operator interviews, plant walkdowns and equipment reliability histories.

3. Use of PSA for ALWRs

In developing alternative means to address SRs, consideration needs to be given to the decisions that will be made using input from the PSA. There are two distinct regulatory decisions that rely, in part, on the PSA:

- Is the Standard Plant PSA for which a design certification is being sought technically adequate to support incorporation of PSA insights into the proposed design and operation of the plant?

- Is the plant specific PSA technically adequate to support the development of risk-informed applications that will be used to govern initial operation of the plant?

After initial startup of the plant, operating experience will be gained that can be factored into the PRA and used to adjust risk informed programs that govern the long term operation of the plant. Therefore, the technical adequacy of the PSA, as judged by the Supporting Requirements in the PRA Standard, needs to change as the plant progresses from a design stage to the pre-operational stage and finally into the post-operational stage.

During the design phase, decisions on some design features should use the PSA as an input. The adequacy of the design and proposed operation can be assessed by reviewing the PSA for vulnerabilities, defense in depth and the risk significance of key components

During the construction phase, the PSA should be used as input to development of procedures, development of technical specification surveillance intervals and limiting conditions for operation and scheduling of test and preventive maintenance activities. It can also be used for the development of in-service inspection programs that will be initially used when the plant begins operation.

In the pre-operational stage, the risk-informed applications that were developed during earlier stages need to be validated using the updated PSA. Risk important components need to be identified and included in relevant operational programs such as the Maintenance Rule in the U.S. Also, a final search for vulnerabilities should be conducted using the pre-operational PSA.

Once operation has begun, data collection becomes very important so that the PSA can be updated to reflect actual operating history including component reliability and availability and initiating event frequencies.

The ability to include these key elements into the ALWR PSA to improve technical adequacy will progress as the ALWR progresses from the design stage through the construction stage and finally to the fuel load / pre-operational stage. As the technical adequacy becomes more robust, more confidence can be placed on risk-informed decisions that are made with the PSA.

4. A modified PSA standard for ALWRs

Alternative actions for ALWRs to satisfy the RA-Sa-2009 Supporting Requirements that cannot be satisfied for a pre-operational plant could be developed as described below. Rather than describe alternative actions for each individual SR that cannot be satisfied, the alternative actions could be developed for topical areas. For example, alternative actions for any SR that requires a walkdown to confirm equipment placement, spatial effects, etc. are described under the topic of walkdowns. These alternative actions would be applicable at each stage of plant development. The alternative actions are a guide; assessors of the technical adequacy of the PRA at any stage need to consider the state of plant development in determining the appropriate alternative actions.

Only one full peer review of the PRA model, as described in this Standard, should be performed and that could occur at any stage of the PRA model development. After the initial peer review, self assessments may be sufficient at succeeding stages of model development for those changes that can be categorized as model updates as defined in Section 1-6 of the Standard. Focused peer reviews may be required for model upgrades as discussed in Non-Mandatory Appendix 1-A of the Standard. A single peer review of the PRA is considered to be sufficient because the peer review examines the methods used to build and quantify the PRA and updates are permitted without additional peer review. For example, during the design stage of a new plant, spatial effects would be addressed from 3-D models, layout drawings, etc. A peer review at this stage would ensure that all spatial effects are addressed. Subsequently, as the plant construction progresses, the spatial effects identified from the 3-D models and layout drawings would be validated and the PRA model updated to reflect any discrepancies identified. However, this should not be considered an upgrade because the same spatial effects are being assessed – only by different methods as the plant goes from design to finish of construction.

- **Walkdowns -** Confirmation of design features using walkdowns will not be possible until construction is completed for the relevant design features. ALWR Alternative Actions include:
    - Design Certification Stage: USE drawings (e.g., layout and isometric) and/or 3-D digital simulations to CONFIRM design features prior to placement of all equipment.
    - Construction Stage: USE drawings (e.g., layout and isometric) and/or 3-D digital simulations to CONFIRM design features prior to construction and placement of all equipment. Initial cable routings should also be reviewed at this stage to minimize risk of multiple spurious shorts.
    - Pre-Operational Stage: PERFORM walkdowns to confirm design features, component layout and cable routings after placement of all equipment and before fuel load.
    - Post-Operational Stage: SRs satisfied at Pre-Operational Stage; No additional actions required. Periodic review to ensure any design changes are properly implemented consistent with the intent of the initial design. Confirm integrity of seals, penetrations and barriers credited or assumed available in the PRA.

- **Interviews -** Interviews with plant personnel to obtain relevant operating experience will not be possible until plant operation has begun. ALWR Alternative Actions include:
    - Design Certification Stage: USE interviews with system designers and procedure developers.
    - Construction Stage: USE interviews with plant personnel from existing plants who have knowledge of the ALWR design and proposed operation. Review LERs or manuafacturers reports for operating experience on similar key components at other plants
    - Pre-Operational Stage: USE interviews with plant personnel who will be operating the plant. If this is not the first plant, consider experience of similar units.
    - Post-Operational Stage: CONFIRM model assumptions are consistent with operating experience after two cycles of operation are completed.

- **Procedures, Operating Philosophy and Talk-Through**s **-** Final plant specific operating, emergency, abnormal, test and maintenance procedures may not be available. Procedure users may not have been trained on the procedure usage. ALWR Alternative Actions include:
    - Design Certification Stage: USE draft procedures supplemented by REVIEW of safety analysis for operator actions.
    - Construction Stage: USE procedures that have been developed at that time, including interviews with operators and simulator trainers.
    - Pre-Operational Stage: USE procedures that have been validated through trial usage, including operator training exercises.

  - Post-Operational Stage: CONFIRM model assumptions are consistent with operating experience after two cycles of operation are completed.

- **Generic Data -** Generic data may not be applicable for the ALWR design features. Generic data may not be available if equipment has not previously been used in nuclear plant applications. ALWR Alternative Actions include:

  - Design Certification Stage: EVALUATE the applicability of generic data to the ALWR design, operational features and environment. Where applicable, USE generic data from nuclear applications when possible. USE generic data from other applicable data sources and testing data if available.

  - Construction Stage: EVALUATE the applicability of generic data to the ALWR design, operational features and environment. Where applicable, USE generic data from nuclear applications. Otherwise, USE generic data from other applicable data sources.

  - Pre-Operational Stage: EVALUATE the applicability of generic data to the ALWR design,

  - operational features and environment. Where applicable, USE generic data based on components being used for nuclear applications. Otherwise, USE generic data from other applicable data sources.

  - Post-Operational Stage: SRs satisfied at Pre-Operational Stage; No additional actions required.

- **Similar Plants -** For ALWR PRAs for a reference plant design, there may not be similar plants available for comparison. ALWR Alternative Actions include:

  - Design Certification Stage: EVALUATE the applicability of data and results from existing plants taking into account differences in design, operational features and environment.

  - Construction Stage: EVALUATE the applicability of data and results from existing plants, including sister plants, taking into account differences in design, operational features and environment.

  - Pre-Operational Stage: EVALUATE the applicability of data and results from existing plants, including sister plants, site specific PRAs taking into account differences in site specific factors that impact the PRA.

  - Post-Operational Stage: COMPARE data and results from operating plants taking into account differences in site specific factors that impact the PRA.

- **Plant- Specific Operating Experience and Data -** Plant-specific operating experience and data may not be available. ALWR Alternative Actions include:

  - Design Certification Stage: USE generic data when plant specific data does not exist. ENSURE that data is applicable to the application in the ALWR (environment and functional requirements).

    - Construction Stage: INCORPORATE applicable utility operating experience as appropriate to the ALWR.

    - Pre-Operational Stage: INCORPORATE applicable utility operating experience as appropriate to the ALWR. USE plant specific operating experience from existing plants, including sister plants.

    - Post-Operational Stage: USE plant operating experience from the first two fuel cycles of operation and sister plants. Early operating experience may be screened based on expected future operation.

- **Assumptions and Uncertainty -** For PRAs performed prior to initial plant operation, there are assumptions that are made to develop the PRA because design and operational information are preliminary. There are uncertainties in the details of the as-built and as-operated plants. ALWR Alternative Actions include:

    - Design Certification Stage: USE best available information. IDENTIFY unverified assumptions based on the stage of design. IDENTIFY unique uncertainties related to the stage of the plant design. CHARACTERIZE uncertainty with regard to their use in the PRA model and potential impacts. Pay particular attention to risk significant assumptions.

    - Construction Stage: USE best available information. VALIDATE unverified assumptions as information becomes available.

    - Pre-Operational Stage: USE final design information. VALIDATE unverified assumptions to the extent possible.

    - Post-Operational Stage: USE as-built information. VALIDATE all remaining unverified assumptions.

To assist in using the PSA as input to design and operational decisions in the design and construction stages of an ALWR, an addition to the ASME/ANS PRA Standard is being developed. The intent of this addition to the Standard is to provide alternative methods of addressing the requirements in the PRA Standard. This addition to the PRA Standard will provide a method of addressing PSA Technical adequacy for pre-operational ALWR plants and permit risk-informed decisions on design and operation to be made with high confidence.

5. Conclusions

The use of the PRA for ALWRs must consider the stage of completion of the design and construction of the plant and should include steps to validate the earlier PRA models and assumptions as plant design and construction moves toward operation. The proposed modification to the ASME/ANS PRA Standard is a step in this direction.

6. References

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Background

- Probabilistic Safety Assessment (PSA) is an integral part of the design and regulatory licensing of the new and advanced reactors
- Traditional PSA analyses are done for operating plants where equipment and procedures are well known and an operating history is available.
- For new advanced reactors, this information may not be available, depending on the stage of design, construction and early operation.

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The Challenge

- How to assure that the decisions being made that are based on the PSA related to the design and operation of the plant are based on a robust PSA
  - *From a regulatory perspective, consider*
    - Regulatory approvals for the design certification
    - Regulatory approvals for risk informed applications prior to plant operation
    - Regulatory approvals for approval of plant operation
  - *From a designer perspective, consider*
    - Choices between design alternatives
    - Development of test and maintenance schedules and procedures
    - Development of emergency procedures

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General Adequacy Basis

- The ASME/ANS PRA Standard, RA-Sa-2009, provides requirements for judging the technical adequacy of the PSA
  - This is used by the U.S. NRC for determining the capability of the PSA to support various risk-informed decisions
  - European regulators may have similar country specific standard or guidance on a country specific basis
- The ASME/ANS PRA Standard is a consensus standard approved by all stakeholders in the US, including the NRC (with limited clarifications and exceptions)
  - It has evolved through several editions based on trial usage at operating plants

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Applying the PRA Standard to Advanced Plants

- Some SRs in the PRA Standard cannot be addressed for ALWRs prior to operation
  - **Walkdowns** for consequential damage, fire, flooding, etc.
  - **Interviews** with plant personnel to validate design and operational assumptions
  - **Procedures** to characterize operator actions and error likely situations
  - **Generic Data** to model component reliability and initiating events
  - **Comparison** to similar plants for reasonableness of results
  - **Plant Specific Data** to reflect the actual plant operating philosophy
  - **Assumptions and Uncertainty** to assess the confidence in risk decisions

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Progression of the Advanced Plants

- As the plant progresses from a paper design to an operating plant these SRs can be fully addressed
  - Prior to operation, an alternate means of considering the requirements needs to be identified
- There are four distinct stages of plant progression that can be used to identify
  - The degree to which requirements can be met
  - The possible risk informed decisions

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Stages of the Advanced Plants

- Design Stage
  - This is the paper plant stage
- Construction Stage
  - This is the stage where actual construction and placement of equipment is taking place
- Pre-Operational Stage
  - This is the complete plant just prior to operation
- Early Operation Stage
  - This is the early operation stage where design issues are being addressed.

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Risk-Informed Decisions

- Design Stage
  - PSA is used to assess vulnerabilities and determine whether the basic design represents a high level of safety; later details should not alter these basic decisions
- Construction Stage
  - PSA is used to for equipment procurement, procedure development, technical specification development and initial training of plant personnel; later details should only result in refinements to these activities

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Risk-Informed Decisions (2)

- Pre-Operational Stage
  - PSA is used to develop regulatory oversight programs such as reliability assurance, configuration risk management etc. Plant operation should only result in refinements to these programs
- Early Operation Stage
  - PSA is used to validate the design assumptions. Subsequent plant operation will continue to refine the PSA model and risk-informed decisions.

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Alternative Methods for PSA Adequacy

- Alternative methods for addressing SRs can be effective in assuring PSA technical adequacy prior to operation
  - **Walkdowns** – Use of drawing and 3-D models
  - **Interviews** – Use designers and procedure writers
  - **Procedures** – Use safety analyses
  - **Generic Data** - Use applicable data from other sources
  - **Comparison** – Use existing plants with engineering judgments
  - **Plant Specific Data** – Use similar plants if applicable
  - **Assumptions and Uncertainty** – Identify and document assumptions and uncertainties
- Validate the PSA as the plant progresses from design to operation

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Peer Review and Self Assessments

- Peer reviews and self assessments are an integral part of judging technical adequacy
  - The PSA is a massive effort that cannot be easily verified by independent reviews of the entire model
  - Self Assessments and peer reviews have been shown to be an effective means of identifying systemic deficiencies that could impact risk-informed decisions
    - Experience has shown that they can be successfully performed at the design stage using surrogates for some requirements
  - Using the PRA Standard philosophy, a full peer review might only be required once during the plant development
    - Focused peer reviews and self assessments can be used for PSA model upgrades

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Conclusion

- The ALWR PRA Standard currently being developed provides an effective means to assess the technical adequacy of the PSA for risk informed decision-making during plant design, construction and early operation.
  - The ALWR PRA Standard provides a consistent method for judging PSA technical adequacy across the different ALWR designs

- The ALWR PRA Standard is currently in the writing stage
  - Subsequent approvals through established ANS and ASME processes will be required before it can be issued as a Standard

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