A Perspective on the Use of Risk Informed Safety Margin Characterization to Support Nuclear Power Plant Long Term Operation

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Abstract: In this paper we describe application of the Risk Informed Safety Margin Characterization (RISMC) approach to enhancements of nuclear power plants that are important to decisions associated with their long term operation. The RISMC approach was used to assess changes in safety margins that would occur due to hypothetical extended power uprates for a PWR loss of feedwater event and a BWR station blackout. For each of these applications, the key parameters that impact core damage probability were identified and representative probability distributions were constructed to represent the associated uncertainties. The distributions were sampled using a Latin Hypercube Sampling technique to generate sets of sample cases to simulate plant response using the EPRI MAAP accident analysis code. In each scenario, changes to the thermal-hydraulic safety margins which would occur due to the uprated power conditions were compared to those for the plant operating at its current nominal full power. Additionally, the impacts on conditional core damage probability and core damage frequency were assessed. As a result of these pilot studies, it was concluded that the RISMC framework can provide a potentially powerful approach to obtain technically robust assessments of safety margins to support critical plant operational and investment decisions.

Keywords: Risk Informed Safety Margin Characterization, Margin Management, Long Term Operation

1. INTRODUCTION

In the original design and licensing of commercial nuclear power plants (NPPs), adequate margins for parameters important to nuclear safety were ensured by the application of conservative assumptions and engineering analyses. Initially, maintenance of these margins was ensured by compliance with provisions contained in the plant Technical Specifications. Additionally, as the technology associated with probabilistic risk assessment (PRA) matured over time, insights from these studies were used to enhance NPP safety management. This has led to the development and implementation of integrated risk management programs at operating NPPs. In the United States, this capability has migrated into the regulation of NPPs; the most widely known of such risk informed regulation being the so called “Maintenance Rule” specified by 10CFR50.65 [1] where use of traditional PRA insights and formal risk management serves as a foundational principle in the compliance with this rule. In the past several years, the use of risk informed approaches has even been extended to permit use of PRA results and insights in the calculation of a configuration-specific risk informed completion time (RICT) for compliance with plant Technical Specifications (i.e. the implementation of a Risk Managed Technical Specifications (RMTS) program [2, 3, 4]).

The explicit management of NPP safety margins has served the stakeholders in the nuclear power industry exceptionally well over the four decades of commercial NPP operation. However, due to recent circumstances, a need has emerged to develop and apply a more integrated approach to evaluate and manage safety margins. The first driver for this need is a desire to extend the operational lifetimes of the currently operating fleet of NPPs. One reason for this desire to achieve NPP long term operation (LTO) is due to the low carbon footprint associated with nuclear generated electricity and the commensurate attributes of nuclear power to positively impact the effects of global climate change. A second reason for this desire is the large capital costs associated with new nuclear build – extension of the lifetime of the existing fleet can delay the need to expend the required large capital investments that are required to construct and license a new NPP. A third driver is the desire by NPP owner / operators to implement operational enhancements (such as extended power uprates (EPUs)) to achieve enhanced economic performance of the current operating fleet. The possible impacts of some of these changes on NPP safety margins are shown schematically in Figure 1 below. Finally, the accident at the Fukushima Dai-ichi plant has generated a renewed focus throughout the world on NPP safety analysis and management. The combined effect of these factors is to increase the need to more systematically and comprehensively evaluate and manage the impacts on plant safety margins over time. The net result is an increased need for an integrated and economical approach that can be applied by licensees and that can generate results that can be readily reviewed by regulatory personnel [5].

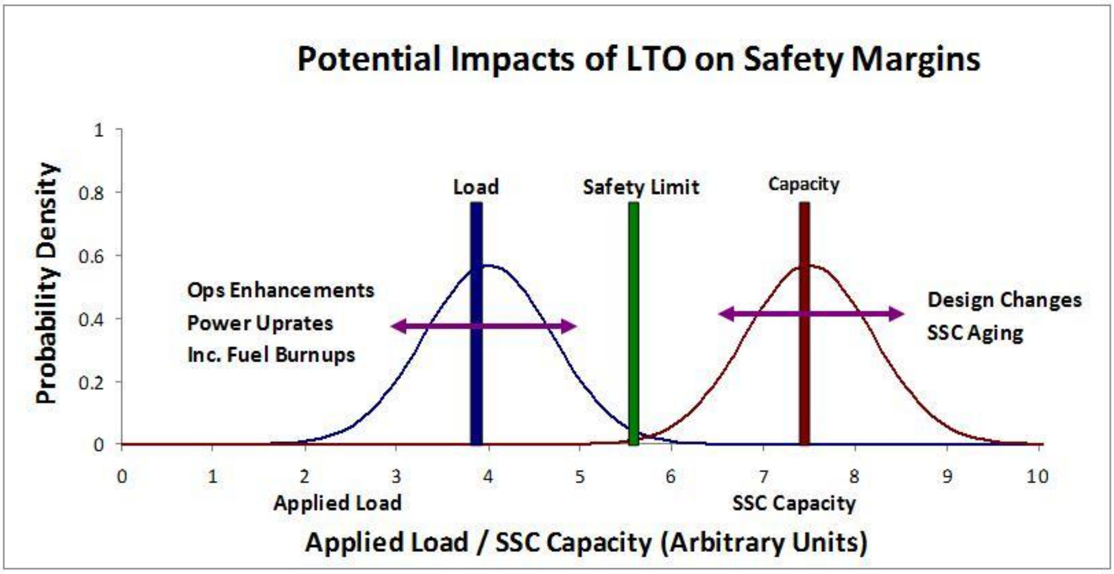


Figure 1: Potential impacts of NPP LTO on safety margins.

To address this need, ongoing research has been conducted to develop and demonstrate a risk-informed approach to evaluate and characterize NPP safety margins. The basic framework is represented conceptually by the relationship $P(C>L)$ which depicts the evaluation of a parameter (represented by a load L) versus an acceptance criterion (represented by a capacity C). In the current operational and regulatory framework this assessment is simplified to consist of a comparison of point estimates (with the limiting load often represented as a "safety limit"). In the context of operational and regulatory decision making within this paradigm, uncertainties are addressed by use of conservative assumptions and engineering analysis methods. However, in reality the relevant parameters are more accurately represented as distributions that account for the uncertainties associated with prediction of both the load and the capacity. The risk informed safety margin characterization (RISMC) approach described in this paper modifies this paradigm so that the concept of "margin" is transformed from a simple "distance" between the point estimates of the load and capacity to that of a probability that the load experienced will exceed the capacity to handle it.

Research into the RISMC approach was initially undertaken by the Nuclear Energy Agency Committee on the Safety of Nuclear Installations (NEA/CSNI) to identify a technically robust approach to allow regulatory agencies to assess the impact of extended plant operation on NPP safety margins [6]. For operational and economic reasons both the United States Department of Energy (US DoE) and the Electric Power Research Institute (EPRI) also initiated research efforts in the RISMC approach as part of their efforts to evaluate the feasibility and technical needs associated with NPP LTO [5, 7]. Since the initiation of this work a large body of material has been published in the literature on results and insights from this research. The intent of this paper is to provide a summary of the application of the approach to issues of importance from a NPP LTO perspective. A discussion of the history of the RISMC approach is not provided here as it is available elsewhere (for a brief history and status (as of 2011) the reader is referred to reference [8]).

2. APPLICATION TO LOSS OF FEEDWATER EVENT

In the initial EPRI research into the RISMC approach, a fundamental concern was to what extent RISMC would be capable of being applied in a manner that was economical; i.e. one that was capable of being implemented within a reasonable timeframe with application of a reasonable amount of resources. In short, a fundamental question that needed to be answered was, is RISMC capable of being applied as a practical tool that could support real-world decision making? Due to this concern (which was initially identified during the original NEA/CSNI research) it was determined that the initial EPRI work should focus on determining how the approach could be applied to a realistic NPP issue in a manner which addressed these potential impediments. Thus, the objective of this initial application of RISMC was structured to apply current generation tools on a relatively well understood pilot application. A focus of this pilot application was to assess the utility of the approach to support effective and efficient decision making. As a result, the initial EPRI sponsored application of RISMC was to evaluate safety margins associated with a Loss of Feedwater (LOFW) event in which initiation of feed and bleed cooling would be required. In this work, prior analyses of LOFW events were reviewed to identify the most important parameters that would be likely to influence whether core damage would occur. From this review, appropriate probability density functions were developed for each of the identified parameters. Using these parameter distributions, the RISMC methodology was applied to generate the system load vs. capacity probability distribution functions using the EPRI MAAP computer code. These distribution functions were assessed to identify the probability that the system load could exceed the system capacity and the conditions under which this situation could occur. Detailed results from this research are reported in references [9, 10] so they will not be reproduced here.

As a result of the successful outcomes of this initial application of the RISMC approach, the decision was made to expand the effort to apply the approach to an issue relevant to NPP LTO that has actively been pursued by a number of NPP owner / operators – implementation of an extended power uprate (EPU). In this research, the analysis of the LOFW event was extended to evaluate the potential change in safety margins that would occur for various different power uprate levels (up to a maximum uprate of 20%) referenced to a generic Westinghouse 4 loop PWR with Model D5 steam generators (SGs) and both motor driven and turbine driven auxiliary feedwater (AFW) systems. We note that the reference plant design used in these studies also included high head centrifugal charging pumps (CCPs) and intermediate high head safety injection systems (HPI). In these analyses, the key output parameter was identified to be core damage and the critical event determining whether core damage would occur was whether feed and bleed cooling was initiated within a timeframe where the combination of available injection systems (i.e. trains of safety injection) and number of opened Power Operated Relief Valves (PORVs) could successfully cool the core and prevent the occurrence of core damage. Again, technical details of this analysis have been reported elsewhere [11, 12] so only the key outcomes and insights will be summarized here.

To obtain an understanding of the impact of an EPU on NPP safety margins (in this case peak fuel cladding temperature as a surrogate measure of the onset of core damage) analyses were performed at five levels of increased plant output ranging from the current licensed full power level up to 120% of the current full power level in increments of 5% power increases. Thus, the analyses were performed at 100% (considered as the reference case), 105%, 110%, 115% and 120% of the NPPs current authorized full power output. The analyses encompassed increases up to the current limit permitted in the United States (and include those increases commonly referred to as extended power uprates – EPUs). As would be expected, as plant power output was increased the amount of margin decreased as measured by an increase in the probability of core damage. In most of the cases evaluated, the amount of the decrease experienced was small. A representative example is shown in Figure 2. The observed increases in core damage probabilities and reductions in margin that occur with increasing power levels are a consequence of:

- The initial plant power level
- Increased decay heat levels leading to additional cooling and pressure relief requirements on the safety injection systems and relief valves

- The concomitant reduction in the time for completion of necessary operator actions (such as initiation of safety injection for feed and bleed cooling) that would be needed to mitigate the effects of this event

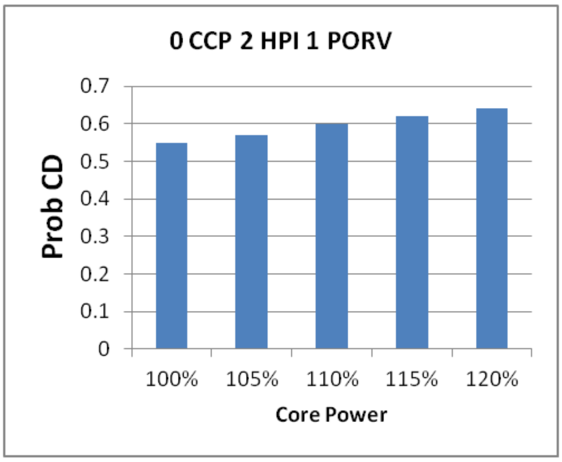


Figure 2: Example results for RISMC analysis of LOFW event showing the increase in core damage probability (representative of a decrease in safety margin) with increase in plant output as the result of a power uprate. These results are for the plant configuration of 0 high head centrifugal charging pumps (CCP), 2 intermediate high head safety injection systems (HPI), and 1 power operated relief valve (PORV) available.

Although these analyses generally indicated rather small decreases in safety margin as a result of a plant uprate, the RISMC method identified several cases where this was not the case. One such example is shown in Figure 3. This (and other similar instances of this type of) behavior is significant in that it suggests that, above a certain power output (starting somewhere between 110% and 115% power in this case), the potential for core damage exists for certain plant configurations which at lower power levels have negligible probability. These results suggest that there is a threshold for core damage in this power range for this specific plant configuration. Thus, these cases suggest that the RISMC methodology has the capability to identify potential “cliff edge” effects with respect to NPP safety margins. In light of the lessons learned in the aftermath of the Fukushima Dai-ichi accident, this clearly is an important capability inherent in the approach.

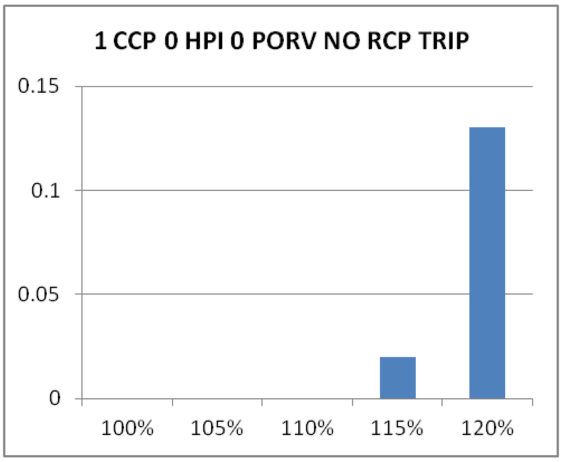


Figure 3: Example results for RISMC analysis of LOFW event showing a possible instance of a ”cliff edge” effect due to the EPU. These results are for the plant configuration of 1 CCP, 0 HPI, and 0 PORV available in a scenario where the reactor coolant pumps (RCP) are not tripped.

From a decision making perspective, the capability of the RISMC approach to evaluate the impact of potential operational enhancements is a valuable outcome of the method. However, the evaluation of these impacts is only one element that is of importance to NPP decision makers. A second, and equally important, aspect is the capability to evaluate alternative enhancements (either procedural or physical) that may be needed to recover margin if necessary. To address this aspect of decision support, a limited study was conducted to assess the margin recovery provided by several postulated enhancements to plant design or operational strategies to address a LOFW event. The intent of this exercise was to assess the degree to which such enhancements could be evaluated using the RISMC framework and the relative difficulty of conducting such an analysis. From the perspective of NPP LTO, there is a strong economic incentive to maximize asset performance and value. Application of EPUs and extended plant operating lifetimes are two such methods that have been employed by NPP owner / operators to achieve these business objectives. Thus, it would be very beneficial to have a methodology that can evaluate the impact on safety margins of such economically driven enhancements and also the expected safety margin benefits that could be obtained by different alternative margin recovery strategies.

In this research, five potential strategies for recovering margins impacted by the EPU for a LOFW event were postulated.

1. Early Initiation of Feed and Bleed
2. Early Feed and Bleed with Steam Generator Depressurization
3. Increased HPI Pump Flow
4. Extra PORV Capacity
5. Manual Reactor Trip on Occurrence of a LOFW Event

These margin recovery simulations were run using the plant configuration of 0 CCPs, 2 HPIs, 2 PORVs opened and No RCP Trip for the 120% EPU. This case was chosen due to the relatively large reduction in safety margins associated with the increased plant power output for this plant configuration.

Due to space limitations, in this paper the results of analysis for only one of these enhancements will be discussed. More complete descriptions of each enhancement and results obtained from its analysis are available in references [11, 12]. Figure 4 displays the impact of early initiation of the feed & bleed mode of cooling (compared to the current cue given in the plant emergency operating procedures based on wide range level indication) for cases where no charging pumps are available. The scenario evaluated is the case with 2 HPI trains and 2 PORVs available and with no RCP trip. As can be seen the early initiation of feed & bleed cooling substantially reduces the probability of core damage for all levels of increased plant power output. However, there still remains a significant probability of core damage even with early feed & bleed initiation. From the analytical results shown below, one can conclude that this approach does not recover substantial margin. Nonetheless, this approach is relatively easy and inexpensive to implement (certainly in comparison with implementation of mitigation strategies that would require physical plant modifications such as installing higher capacity HPI pumps or larger PORVs). From a decision making perspective this approach thus has both positive and negative attributes which would need to be considered.

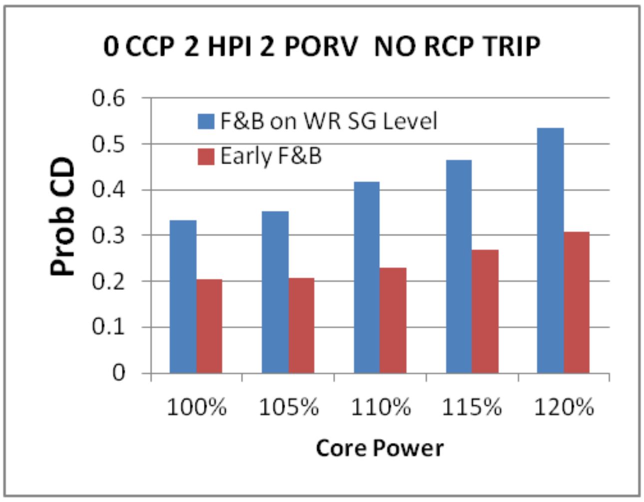


Figure 4: Comparison of Feed &Bleed initiation times for the plant configuration of 0 CCP, 2 HPI, and 2 PORV available in the case of the RCPs not tripped.

Finally, we show the comparative impact of each of the postulated margin recovery strategies in Figure 5. The leftmost bar in Figure 5 shows the conditional core damage probability (CCDP) for the 120% power uprate case without any of the mitigation strategies being utilized. The next bar (120% EPF) shows the results of analysis of implementation of a modification to provide enhanced HPI pump flow. The third bar (120% EPORV) shows the results for implementation of enhanced PORV capacity. The fourth bar (120% EPF EPORV) represents the effects of the combination of enhanced HPI pump flow and enhanced PORV relief capacity (i.e. implementation of both postulated plant modifications). The last bar (120% ERx) represents the results for a case where reactor trip always occurs shortly after the LOFW event occurs. As seen in Figure 5, either the enhanced HPI pump flow or enhanced PORV capacity strategy can restore the safety margin for a 120% power uprate to its level prior to the uprate and the combination of these two strategies will yield a larger margin at 120% than existed prior to the uprate (and the postulated enhancements).

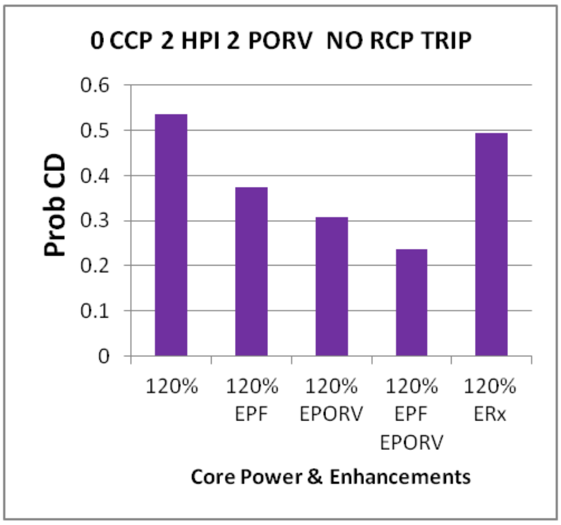


Figure 5: Comparison of postulated enhancement strategies for LOFW margin recovery for the plant configuration of 0 CCP, 2 HPI, and 2 PORV available in the case of the RCPs not tripped.

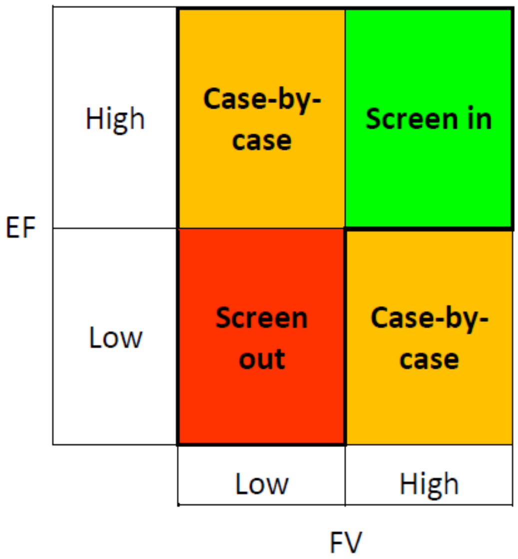
3. APPLICATION TO BWR EXTENDED STATION BLACKOUT

As a more substantive application of RISMC a second pilot evaluation applicable to LTO decisions was conducted. This study built upon, and expanded, the methodology previously applied in the analysis described in the previous section by consideration of the impact of hypothetical power uprates at a large BWR/4 NPP with Mark I containment. This case study was chosen because it is anticipated that power uprates will continue to have important implications for the long-term economic operation of the current fleet of NPPs. The case study specifically focused on events involving a total loss of AC power station blackout (SBO) event. Similar to the analyses performed for the PWR LOFW event, the most important parameters that are likely to influence whether core damage would occur were identified and probability distribution functions were developed for each identified parameter. To enhance the utility of the approach to LTO decision making, several additional figures of merit (FOMs) other than those which are representative of NPP safety (i.e. core damage frequency, conditional core damage probability, etc.) but are important in the LTO decision-making context (e.g. FOMs associated with potential regulatory or economic impact on the NPP) were also developed. Using these parameter characterizations, the RISMC methodology was applied to generate system load vs. capacity curves for the BWR SBO event for several different enhanced plant power levels using the MAAP computer code. Again, due to space limitations, in this paper we will only describe some key improvements that were developed and demonstrated during this pilot application. More complete descriptions and results are contained in references [13, 14].

The first significant process enhancement implemented in this study was to develop a systematic approach that could be applied to identify the most significant parameters for which the treatment of uncertainty would be important. Application of the RISMC process uses information from the reference plant PRA as well thermal-hydraulic (T-H) simulations (in the studies reported upon here these consist of MAAP code calculations). As illustrated in Figure 1 above, it is the uncertainties in both the load and capacity distributions that impact the available safety margin. If there were no uncertainty in the key parameters and physical phenomena, the load distribution function basically could be represented by a Dirac delta function. In application of the RISMC method a basic event that contributes little to the FoMs would be a likely candidate to screen out of the selection process. This condition suggests two possible criteria for the screening and selection of probabilistic input parameters in this study:

- High risk importance, e.g. as measured by a metric such as Fussell-Vesely (FV) importance
- High variance, e.g., as measured by a metric such as error factor (EF).

Figure 6 conceptually shows the selection criteria of the key probabilistic-based parameters for the safety margin analysis that was used in this research to select applicable BWR SBO sequences.



EF		
High	Case-by-case	Screen in
Low	Screen out	Case-by-case
FV	Low	High

Figure 6: Parameter screening criteria used for BWR SBO study.

In this study basic event parameter data were used to identify useful numerical criteria for the high / low cut-offs for FV and uncertainty. As an initial screening the following cut-offs were chosen:

- High FV ≥ 0.005
- High EF ≥ 3

The FV cut-off of 0.005 is consistent with one of the generally accepted criteria for determining risk significant structures, systems and components (SSCs) in regulatory applications in the United States (e.g. it is used in implementation guidance for the Maintenance Rule). The selection of an EF of 3 allows for screening out a large number of basic events with relatively low uncertainties (e.g., those due to independent failures), while capturing most common-cause and key human error basic events. Several insights from application of these criteria were immediately apparent [13]. First, common-cause type failures of key SBO mitigation equipment tend to have large FV values and large uncertainties and therefore they were included in the analyses. Likewise, critical operator actions such as aligning alternate AC power supplies and 4 kV electrical cross-ties also were included. On the other hand, given significant amounts of plant-specific operational performance data, independent event failure probabilities for pumps, diesel generators and valves could be expected to have relatively low uncertainties and would be good candidates to be screened out of the analysis. The various loss of offsite power (LOOP) initiators, and their closely coupled offsite power non-recovery probabilities (i.e., event duration), are significant contributors to core damage frequency and have large uncertainties, and were also included in the analysis.

The second major enhancement identified and applied to this analysis was the recognition that many of the key events and mitigation measures that could be taken in an SBO situation (such as emergency depressurization, alternate RPV injection or the occurrence of the SBO event itself) can have different impacts on public safety, the regulatory environment (both locally and nationally), as well as direct and indirect economic consequences (both to the NPP owner / operator and other stakeholders such as the local populace). As a result of this understanding, it was hypothesized that the RISMC approach could, with only minor adaptations, be applied to provide decision makers with information on the margins (and potential impacts of postulated plant enhancements on them) associated with these conditions. In this approach, key sequences are grouped into plant impact states which characterize the effect of the event on the plant. For example, a plant owner / operator also would be concerned with any additional costs / burdens that would result from such an event. For example, in evaluating LTO investments a plant owner / operator would be interested in the possible likelihood of the need to use alternate injection paths that use untreated sources of water and could result in significant costs due to the need to discharge relatively fresh fuel due to corrosion induced by the untreated water. Table 1 tabulates the impacts of the key events that were identified as significant to BWR SBO sequences that could be of concern to NPP decision makers and could be evaluated as part of the RISMC evaluation.

Key Event	**Public Safety Impact**	**Regulatory Impact**	**Economic Loss**	**Plant Impact State**
Station blackout occurs		X	X	PI1
ECCS suction from suppression pool		X	X	PI2
RPV level below TAF and short duration fuel temperature excursion		X	X	PI3
Emergency depressurization occurs		X	X	PI4
Alternate injection with external water source (e.g., HPSW)		X	X	PI5
PCPL is reached, containment venting	X	X	X	PI6
RPV injection after containment failure	X	X	X	PI7
Core damage	X	X	X	CD
Large (early or late) radiological release	X	X	X	LR

Table 1: Impact of key events and associated plant impact states.

It is important to note that the plant impact states are not necessarily mutually exclusive. For example, emergency procedures would require emergency depressurization (ED) at or shortly after reactor level reaches the top of active fuel (TAF). There would be only a short window to avoid ED once TAF is reached. Thus, for the purpose of evaluating strategies to mitigate these cases, it would likely be prudent for NPP decision makers to use the worst plant impact state in such assessments.

4. NEXT STEPS – RISK INFORMED MARGIN MANAGEMENT

One outcome of the RISMC method could be its use in a more comprehensive "performance-based" approach to management of plant safety margins. Such an approach would focus on the development and implementation of risk informed strategies that focus on desired and measurable outcomes, rather than on prescriptive processes, techniques, or procedures. From the perspective of ensuring adequate NPP safety over the course of the extended operating lifetimes envisioned within LTO, the ultimate objective of such an approach would be to develop an integrated suite of performance measures that would ensure adequate safety margins are maintained over the NPP lifecycle.

In support of such an approach, research conducted under the US DoE funded Light Water Reactor Sustainability (LWRS) program has conceptually developed an approach that would meet these objectives [15]. This approach is characterized by the eight steps shown in Figure 7.

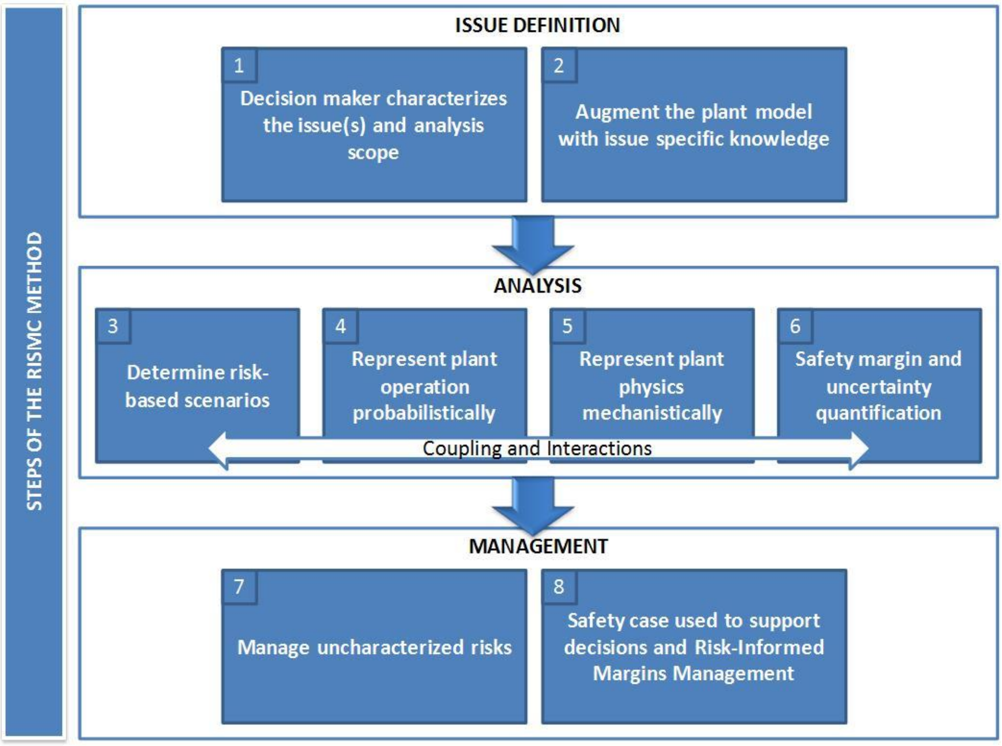


Figure 7: Depiction of the high-level steps required in Risk-Informed Margin Management.

Following are basic descriptions of each of these steps (excerpted from [15]) which characterize an integrated Risk Informed Margin Management (RIMM) approach.

1. Characterize the issue to be resolved in a way that explicitly defines the modelling and analysis which needs to be performed. Formulate an "issue space" that describes the FoMs to be analyzed and develop proposed decision criteria which would be employed. (Note that in [15] these FoMs are specifically identified as FoMs that address NPP safety; however, as indicated above in the discussion of plant impact states, such FoMs need not be limited in this manner and the approach could be expanded to include a broader range of criteria important to the decision making process.)

2. Quantify the state-of-knowledge associated with the key variables and models (i.e. the uncertainty inherent in them) which are relevant to the issue of interest. As an example, if the analysis is focused on NPP LTO decisions and aging mechanisms are present that may degrade components critical to the decision, then these mechanisms should be characterized and included in the models used to support the decision.
3. Determine issue specific scenarios and event timelines that are necessary to evaluate the risks associated with the issue of interest. These scenarios need to be able to capture any timing considerations (e.g. operator initiation of feed and bleed cooling in the LOFW scenario described in section 2 above) that may affect the relevant physical phenomena and the impacts on safety margins, as described in steps 4 and 5 below. It should be noted that there are anticipated to be numerous interactions that occur during analysis steps 3 – 5 of the RIMM process and these steps likely will be iterated in a feedback loop. We also note that since the RISMC process used to conduct the analysis is statistical in nature, to obtain the load and capacity distributions that provide a representation of the safety margins which are evaluated in step 6, the approach will require evaluation of a large number of scenarios. It is for this reason that the RIMM approach fits very well into a modelling and simulation paradigm for its execution.
4. Provide a probabilistic representation of plant operation using the scenarios identified previously in step 3. For example, plant operational rules (e.g., requirements from plant operating procedures and Technical Specifications, constraints imposed by maintenance schedules, etc.) will need to be incorporated into the models to provide realism to the scenarios modelled and analytical results that are obtained.
5. Provide a mechanistic representation of the relevant plant physics. To support the RISMC approach, distributions for the key plant process variables (i.e., loads) and the capacity to withstand those loads for the scenarios identified in step 4 will need to be developed. Again, because of the probabilistic nature of the approach, a modelling and simulation paradigm is best suited for implementation of these steps in the RIMM process.
6. Construct and quantify probabilistic load and capacity distributions relating to the FoMs that will be analyzed to determine the probabilistic safety margins.
7. Determine appropriate strategies to manage uncharacterized risk. Because no model is ever a completely accurate representation of the phenomena it is intended to represent, the responsible decision makers need to be aware of any limitations in the analysis and adhere to protocols of “good engineering practices” to augment the analysis as needed. This step relies on effective communication of the assumptions and limitations in each of the analysis steps in order to understand the risks that were characterized. It also is appropriate at this point in the RIMM analysis to review the decision criteria proposed in Step 1 and modify any element of the evaluation (i.e. the decision criteria, the technical analysis or both) as appropriate. From this perspective the RIMM process can best be characterized as an approach that is risk informed rather than one that is risk based.
8. Identify and characterize the factors and controls that determine the relevant safety margins within the issue being evaluated to develop appropriate implementation strategies. Determine whether additional work to reduce uncertainty would be worthwhile or if additional (or relaxed) safety controls are justified.

At this time the RIMM approach outlined above is at a conceptual level. However, many of its necessary elements are in place (at least to some degree) at all operating NPPs. The challenge is to further develop RIMM as an integrated process and to demonstrate that it can be executed within a NPP’s current operating structure (e.g. organization, access to necessary computational capabilities, etc.).

5. CONCLUSION

Maintaining plant safety margins will be an important element in enabling the LTO of the current fleet of commercial NPPs. To achieve this objective, the development and application of a robust method to perform plant safety margin evaluations is essential. To be successfully adopted by industry and regulatory bodies, these new methods must be developed in a manner that is technically accurate and economically efficient. The research activities and results summarized in this paper have provided successful demonstrations that the RISMC framework can be applied in such a manner to analyze and obtain important insights into significant issues associated with NPP risk management and LTO decision making. In particular, this research has demonstrated that the RISMC approach can be performed using a reasonable level of resources and within a timeframe that supports effective NPP decision making. Thus, the RISMC framework can provide a powerful approach to obtain technically robust assessments of safety margins in the support of critical NPP operational and investment decisions. Based on the successful pilot demonstrations of RISMC to applications important to NPP risk management described in this paper, further work is warranted to develop an integrated approach for Risk Informed Margin Management that can be implemented to ensure the economic and safe long term operation of the current fleet of NPPs for decades to come.

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