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Blended Risk Approach in Applying PSA Models to Risk-Based Regulations

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ABSTRACT

In this paper, the authors will discuss a modern approach in applying PSA models in risk-based regulation. The Blended Risk Approach is a combination of traditional and probabilistic processes. It is receiving increased attention in different industries in the U.S. and abroad. The use of the deterministic regulations and standards provides a proven and well understood basis on which to assess and communicate the impact of change to plant design and operation. Incorporation of traditional values into risk evaluation is working very well in the blended approach. This approach is very application specific. It includes multiple risk attributes, qualitative risk analysis, and basic deterministic principles.

In blending deterministic and probabilistic principles, this approach ensures that the objectives of the traditional defense-in-depth concept are not compromised and the design basis of the plant is explicitly considered.

INTRODUCTION

Since the 1980s, when the U.S. commercial nuclear plants committed to produce plant-specific Probabilistic Safety Assessments (PSAs) in response to Nuclear Regulatory Commission Generic Letter 88-20, PSA had been used as a powerful analytical tool that provided a different means to evaluate the safety of a plant. The PSA models today are regularly used to evaluate the risk significance of different plant configurations, or to determine the risk acceptability of changes to plant design and operation. PSA methods have been applied successfully in several regulatory activities and have proven to be a valuable complement to deterministic engineering approaches.

In this paper, the authors will discuss two main approaches in using PSA models in risk-based regulations: the Quantitative PSA Approach and the Blended Risk Approach.

The Quantitative PSA Approach is the most common PSA application. This approach is the most straightforward and best when applied to the events explicitly modeled in PSA. When it is necessary to consider deterministic principles or when a costly modification of PSA logic models is required, the Quantitative PSA Approach may not be the most effective way to address the problem. In this case, a blended approach to risk evaluation is an attractive alternative.

Viewing the PSA numerical base as the only tool in evaluating risk significance of different events could lead to difficult evaluations with questionable results, especially if the analyzed events are not explicitly related to PSA parameters. In this process, it should not be forgotten that the numbers are not the real target of a PSA analysis. The most important insights come from the understanding of the PSA logic models and relative contributors to risk. The Blended Risk Approach preserves those insights and provides a way to gain sufficient risk insights with less costly, and less uncertain, methods. The Blended Risk Approach also preserves basic deterministic principles and ensures they are not jeopardized.

First, the paper will discuss the quantitative approach and problems associated with its application. Second, more attention will be given to the new blended approach to risk evaluation. This approach will be illustrated using an application in risk-based regulation.

QUANTITATIVE PSA APPROACH

Today PSA models are most commonly used to provide a quantitative risk measure of the change in plant design and operational practices. They can also provide an importance rank of the different equipment and configurations. In order to provide a consistent approach in selecting important processes and equipment, the "PSA Application Guide," (Reference 1) provides quantitative criteria for decision making.

Quantitative acceptability criteria for changes impacting CDF are illustrated in Figure 1, taken from Figure 4-1 of Reference 1. The acceptable change in CDF is based on the plant's existing baseline mean CDF: if the baseline CDF is above 1E-4/year, no increase in CDF is acceptable without further evaluation; if the baseline CDF is below 1E-4/year, the maximum acceptable change in CDF can be expressed as a function of the baseline CDF.

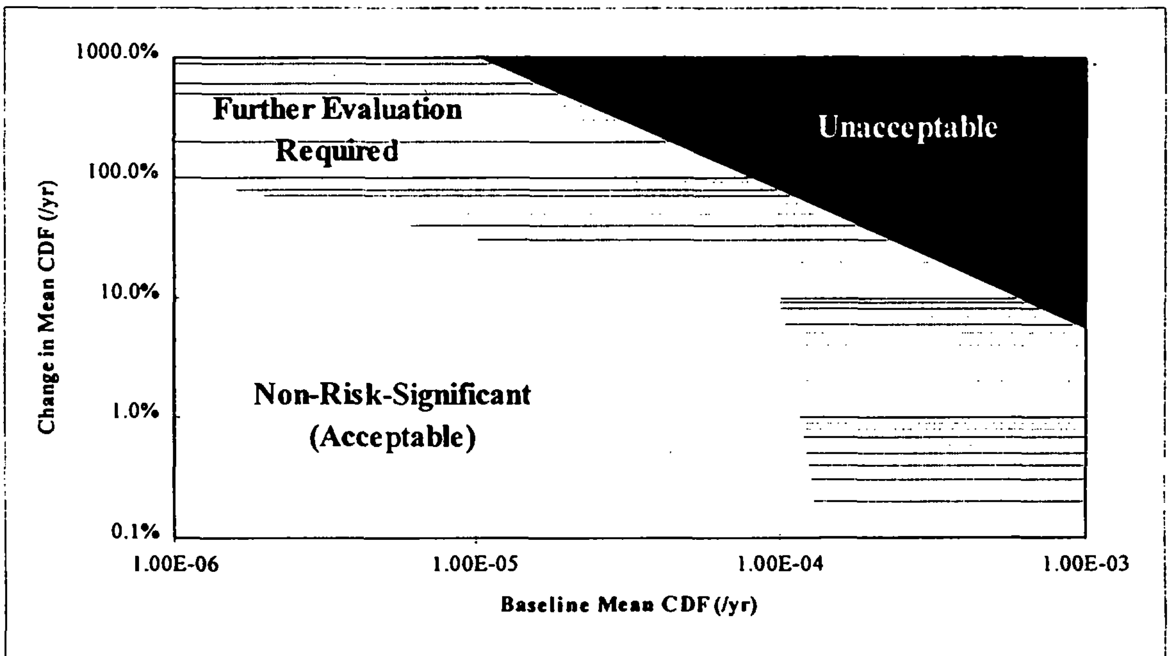

Figure 1: Quantitative Acceptability Criteria for Change in Plant Design and Operational Practices
(from Reference 1)

The problem with this quantitative approach is that, in decision making, it makes a comparison between different plants' CDFs and, therefore, PSAs. This comparison is very questionable because PSAs are not performed based on strict and predefined conditions and criteria. Different utilities use different methodologies, different logical structures, different databases, different human factors, etc. Examples of uncertainties in PSA models are given in Table 1. Because of these uncertainties, comparing two CDFs without a detailed PSA evaluation is not possible, and a quantitative criteria based on the CDF absolute value is difficult to accept.

Table 1: Examples of Uncertainties in PSA Models

Uncertainties Based on Qualitative and Quantitative Information

1 Completeness
- What was not modeled, such as spatial events.
- What is not considered , such as the possibility of design deficiencies
- What was limited in scope, such as data analysis and Failure Modes and Effects Analysis

2 Logic Modeling
- Key assumptions
- Level of detail
- Recovery Actions
- Limits of the selected model

3 Quantification
- Failure rate model approximations, such as standby, demand, and operating characterizations.
- Applicability of data, either plant-specific or generic.
- Human error probability
- Processing simplifications or truncations.

A relative risk significance can quantitatively be measured by the risk importance measures. The problems and limitations of this approach are discussed by the same authors in Reference 14.

BLENDED RISK APPROACH

The Blended Risk Approach, as a combination of traditional and quantitative processes, is defined below:

1. It uses design basis and other deterministic regulations and standards to provide a proven and well-understood basis on which to assess and communicate the impact of potential change.

2. It is more based on the logic structure of PSA, than on the numbers. This logic structure includes the failure combinations causing undesired events or success paths preventing undesired events. In other words, this logic structure is based on the information contained in the fault trees and event trees. The quantitative insights can be used, but are not essential for this approach.

3. In combining deterministic and probabilistic insights, this approach ensures that the objectives of the traditional defense-in-depth concept are not compromised and that the design basis of the plant is explicitly considered.

This approach also introduces the qualitative risk approach to the area of risk-based regulation. Qualitative risk approaches are well known in non-nuclear industries and are receiving increased attention in the U.S. and abroad. They will be discussed in the next section.

The basis for the current, mostly deterministic regulations, lies in a fundamental philosophy: defense-in-depth. Two primary forms of defense-in-depth are barriers and redundancy. In Table 2, a few simple rules are defined which, when applied, provide assurance that the defense-in-depth principles are maintained for any PSA application.

Table 2: Rules Used to Incorporate Deterministic Principles

RULE	DETERMINISTIC EVALUATION	PSA EVALUATION
Preserve Barrier Defense-in-Depth	A change should not increase the chance of systematic coupling of RCS & containment performance (coincident failure of both RCS and containment, or the bypass of one of those barriers)	Both Core Damage Frequency and Large Early Release Frequency should be considered. The qualitative approach should confirm that performance of both barriers is not effected.
Preserve Frequency versus Redundancy Relationship	The loss of redundancy due to change should be considered in combination with the frequency of challenge	The PSA sequences already include frequency of challenge and redundancy. A qualitative approach should be based on a different redundancy level for a different frequency of challenge. Single failure criteria should be preserved.
Preserve Low Potential for Dependent Failures	Dependent Failures include common cause failures, support system failures, certain human actions, and spatial effects. In order to avoid undermining redundancy, a change should not significantly increase the potential for dependent failures.	New dependent failure mechanisms, introduced by the change, and change effects on support systems and human actions should be evaluated on a case-by-case basis.
Preserve Deterministic Margins	The impact of change on component reliability, should include explicit consideration of component performance margins. A deterministic margin includes thermal margin, flow rate margin, test performance compared to acceptance criteria, etc.	PSA evaluations are not explicitly applicable. Past performance of the component should be evaluated.

EXAMPLE OF BLENDED RISK APPROACH APPLICATION

The difference between a traditional quantitative PSA approach and a blended PSA approach will be illustrated using one of the ongoing applications in the risk-based regulatory framework. Inservice inspection (ISI) is an especially difficult problem to address as a risk-based application. Proposed changes to ISI require a change in the ASME Code Section XI inspections performed on Class 1 and Class 2 piping. The new proposed inspections are to be distributed only to risk-important locations. The new distribution is expected to lead to a significant reduction in the number of inspections required. The change is expected to affect pressure boundary failure (PBF) likelihood, but it is not clear how and to what degree. The difficulties in applying the PSA approach are summarized as three basic problems:

Problem No. 1:	There is a large uncertainty in values for pressure boundary failure probabilities.
Problem No. 2:	There is limited knowledge from which to understand the ISI impact on pressure boundary failures.
Problem No. 3:	There is limited, or no explicit modeling of pressure boundary failures in PSA.

Problems 1 and 2 involve the ability to establish a connection between evaluated change and PBF. The affected risk variable is PBF probability, which is very low, with a large uncertainty range. The PBF probability is the function of various stochastic factors, such as stress or flaw distribution. The existence of flaws and the probability of ISI detecting them are both concerns of uncertainty. A negligible number of "defects" have been detected in the current Section XI Program.

Also, connecting the risk variable to CDF or LERF is difficult because PBFs are not explicitly included in the PSA. PBFs are implicitly included in some initiating event frequencies. The basic problem is in defining real consequences of PBFs on different piping locations. Those consequences are unique for this type of failure, because of the spatial effects and failure-specific recovery actions.

There are two different approaches being developed in the U.S. in an effort to define risk important piping locations for the redesign of the ISI program. One of them uses a PSA quantitative approach (Reference 6), and attempts to quantitatively address all difficulties described above. The other approach uses the blended approach described here (Reference 3, 4, and 5).

The blended approach to ISI evaluation includes relative rankings of PBF likelihoods and consequences, organized in a risk matrix, which is an essential tool in qualitative risk analysis. The PBF likelihoods are grouped into three PBF categories, consequences are grouped into four consequence categories. Based on these, the risk matrix shown in Figure 2 is constructed. Different risk regions are defined on the matrix. They correspond to the different inspection policies to be defined.

The categories for PBF likelihood are selected based on the presence and type of degradation mechanisms the piping is susceptible to. This factor is considered not only to have a preeminent effect on PBF likelihood, but also to be one that actual inspections could be aimed at.

Pressure Boundary Failure Category	Consequence Category			
	None	Low	Medium	High
Large				
Small				
None				

High Risk Region

Medium Risk Region

Low Risk Region

Figure 2: Risk Matrix

The PBF likelihood categories are as follows:

"None": No degradation mechanism is present

"Small": One or more degradation mechanisms are present which are likely to result in a small leak (for example, thermal fatigue, corrosion cracking, cavitation...)

"Large": One or more degradation mechanisms are present which are likely to result in a large leak (for example, erosion-corrosion, or any other mechanism in combination with water hammer)

Consequence evaluation is based both on PSA evaluation and deterministic rules from Table 2. Pipe break can result in various consequences: initiating event, loss of system or train, degradation of containment integrity. Deterministic and Probabilistic "importance measures" used in this evaluation are given in Table 3. This approach makes it possible to establish importance measures for initiating event or containment performance, which is not possible with the traditional PSA approach. The categories for consequences are as follows:

"None": The PBFs which do not affect safety functions

"Low": The PBFs which do not significantly effect the plants' defense-in-depth, and result in a conditional core damage probability lower than 1E-6.

"Medium": The PBFs between "low" and "high" category

"High": The PBFs which significantly jeopardize the plant's defense-in-depth, and result in a conditional core damage probability higher than 1E-4.

A similar risk matrix is being used in Sweden for ISI Evaluation. However, their consequence categories are very different and are based on the pipe size and plant systems. Also, PSA was not applied.

Table 3: Consequence Importance Measures

CONSEQUENCE OF PRESSURE BOUNDARY FAILURE	DETERMINISTIC "IMPORTANCE MEASURE"	PROBABILISTIC "IMPORTANCE MEASURE"
INITIATING EVENT	Redundancy of Unaffected Mitigating Systems	Conditional Core Damage Frequency, Including Both Direct and Indirect Effects of the Failures
LOSS OF TRAINS/SYSTEMS	Frequency of Challenge versus Redundancy of Unaffected Mitigating Systems. Exposure Time to Challenge is also a Factor	Core Damage Probability, with a Loss of the Trains/Systems for a Given Exposure Time.
EFFECT ON CONTAINMENT INTEGRITY	Number of Containment Barriers	Conditional LERF

CONCLUSION

Abraham Maslow once said, "If your only tool is a hammer, you may view every problem as a nail." In the present world of risk-based regulation, we must not view any of the complex applications as "a nail"; we must, instead, search for new tools. The Blended PSA Approach offers an alternative to standard PSA applications. It blends the principles of deterministic and probabilistic evaluation, in order to provide an enhanced quality and robustness to the risk-based applications.

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