RISK INFORMED APPLICATIONS IN JAPAN
REVIEW OF A SELECTED APPLICATION COMPARED AND CONTRASTED

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ABSTRACT

A review of a potential risk informed application with a Japanese partner will be discussed. A summary of the genesis and history of risk informed applications in the United States (US) using utility Probabilistic Safety Assessment (PSA) models will be reviewed along with key policies from the US Nuclear Regulatory Commission (NRC). A significant focus of this paper is a description of the methods employed to assess and implement risk-informed applications. Of specific focus is discussion of potential differences in the implementation of risk informed applications in Japan as compared to US practices. Discussion of these differences will focus on the selected potential application. Included in the discussion will be suggestions for specific actions and validation information to support implementation of the application in Japan. The paper will present insights from the selected application along with the safety and operational benefits.

Keywords: risk informed applications.

I. BACKGROUND

The intent of this paper is to present a brief history of Risk Informed Decision Making (RIDM) in the nuclear power industry in the United States of America (USA) and to discuss a potential risk informed application for implementation in Japan as a first pilot application of RIDM. Implementation of risk informed applications in the USA are presented and potential differences in implementation in Japan compared to the USA are discussed. This paper explores and provides an assessment of a potential pilot application in the Japan nuclear industry.

The USA nuclear industry has embraced and generally led the development of RIDM using Probabilistic Risk Assessment (PRA) models. The development and use of the PRA models in the context of RIDM has led to the improvement of safety at nuclear power plants and led to improved plant operations.

It has taken many decades and RIDM is fundamentally ingrained in operation of nuclear power plants in the USA and is fully part of the regulatory framework put forth by the US Nuclear Regulatory Commission (NRC) governing the design of new nuclear power plants and the safe operation of the nuclear power plant fleet.

Risk-informed decision-making in the US nuclear power industry also took decades to evolve. The evolution progressed from the first early assessment in the 1970's of safety risks at two nuclear power plants using event trees/fault trees to a need driven by improvement of plant safety, enhanced efficiency in operations, and improvements in regulatory effectiveness by a focus on those issues truly important to plant risk. The following is a brief history of the important events in the development of RIDM in nuclear power in the USA.

II. HISTORY OF IMPORTANT EVENTS IN RIDM IN THE USA

In the evolution of RIDM, it is important to note that the early regulatory framework for nuclear power plant design and operation was largely driven by deterministic methods. As mentioned earlier, it took decades of learning and experience to make the transition to include RIDM in regulations and industry initiatives. Fortunately, the learnings and experiences in the USA can be foundational and built upon to accelerate the transition to RIDM in areas outside of the USA.

Early Regulatory Framework

In the early years of commercial nuclear power, safety regulations were primarily prescriptive, focusing on specific design and operational requirements. The regulatory approach was based on deterministic safety assessments, where a set of conservative assumptions were used to evaluate the design and operation of nuclear facilities. The accident analyses in the Final Safety Assessment Reports (FSARs) were deterministic and built upon single failure assumptions, worst case system performance characteristics, and conservative assumptions, all to drive a maximum result to compare to a regulatory criterion. In short, the regulatory framework relied on the concept of deterministic design-basis accidents to ensure plant safety.

Reactor Safety Study

In the early 1970's, the Atomic Energy Commission (AEC), the predecessor agency to the USNRC, directed that a study be performed to assess the risk of nuclear power. The motivations behind the study were to understand what is the risk of nuclear power and to address anti-nuclear sentiment for public understanding of risk exposure from nuclear power plants. The study, WASH-1400 [1], "Reactor Safety Study: An Assessment of Accident Risks in US Commercial Nuclear Power Plants" was the result. WASH-1400 was the first well recognized use of PRA methods to assess the safety risk of nuclear power plants. The report provided an assessment of risk in terms of frequency (events per year) and consequences (fatalities) for two nuclear power plants with an extrapolation of the risk to the fleet of one hundred nuclear plants. While the report was met with criticisms and noted areas for additional work (e.g., treatment of uncertainties), it did identify accident sequences considered to be important and identified the importance of sequences related to loss of offsite power and station blackout (the USNRC subsequently made changes to the regulations covering the loss of all ac power). The report identified for the first time that small Loss of Coolant Accidents (LOCA) were much more important than previously thought and that some sequences are for less important to risk than previously thought such as the large LOCA, which was considered one of the most important design basis accidents for nuclear power plants.

Three Mile Island Accident

The Three Mile Island (TMI) accident in 1979 was a watershed event. TMI brought into focus that there were limitations in a prescriptive, deterministic design basis accident approach to reactor design and analysis. The accident underscored the importance of understanding and managing complex interactions among systems and components, as well as the need for a more comprehensive approach to assessing safety. The accident also brought to light the importance of understanding operator actions and human reliability analysis in assessment of accident sequences. Of course, the TMI accident may also have cemented the importance of WASH-1400 in terms of establishing a rational way of using event trees/fault trees to understand the important accident sequences (e.g., small LOCA) and provided a guide on how quantitative estimates of risks can be estimated for the accident sequences. The accident at TMI was a small LOCA which was the primary contributor to reactor risk highlighted in WASH-1400 and that sequence was previously overlooked in its importance.

Wide-Spread Use of PRA Models

In the 1980s, there were additional risk studies performed on two reactors with the goal to better understand primary containment response to accident scenarios. Other studies at a handful of nuclear plants were also performed to develop new methods, to address emergency response zones and to illustrate the risk benefit of a unique plant design with three train safety systems. The USNRC issued Generic Letter 88-20 [2] and subsequent supplements that required each nuclear plant to develop and Individual Plant Examination (IPE) and an Individual Plant Examination of External Events (IPEEE). The purpose of these studies was to build upon the growing importance of understanding the risk from <u>all</u>

accident sequences, identify any plant specific vulnerabilities to the accident sequences and make plant and procedure improvements to address the vulnerabilities. The IPE/IPEEE was the first industry wide use of PRA methods and the results have been credited with reducing overall plant risk. Some studies have shown a 40% or more decrease in industry average risk at the time of the IPE/IPEEE insights and associated plant changes.

Risk Informed Regulations and Policy

The USNRC was very active in setting regulations and agency policy for the use of risk in the regulation of nuclear power plants. Below are some of the key initiatives by the NRC; however, there are other initiatives by the NRC not listed below.

a. *10 CFR 50.62,* Anticipated Transients without SCRAM (ATWS) [3] and 10 CFR 50.63, Station Blackout [4] – these rules in 1981 and 1986 were issued in response to the insights from WASH-1400 that documented the higher risk of the sequences than previously thought.
b. *NRC Safety Goals* – the USNRC established Qualitative Safety Goals, Quantitative Health Objectives (QHOs) and Subsidiary Goals – NRC established qualitative safety goals in 1986, quantitative safety goals for prompt fatality and cancer fatality in terms of probability per year, and subsidiary goals for use in risk informed regulations and applications in terms of Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) [5].
c. *USNRC Generic Letter 88-20* – as discussed above, the generic letter issued in 1988 has each licensee to assess vulnerabilities to risk from severe accident sequences.
d. *10 CFR 50.65, Maintenance Rule* – the rule in 1991 established that before performing maintenance activities and corrective and preventive maintenance, the licensee shall assess and manage the increase in risk that may result from the proposed maintenance activities [6].
e. *NRC PRA Policy Statement* – the policy statement in 1995 [7] made the use of PRA a bedrock in regulatory activities. The policy statement included, "The use of PRA should be increased to the extent supported by the state of the art and data and in a manner that complements the defense-in-depth philosophy," and "PRA and associated analyses (e.g., sensitivity studies, uncertainty analyses, and importance measures) should be used in regulatory matters, where practical within the bounds of the state-of-the-art, to reduce unnecessary conservatisms associated with current regulatory requirements, regulatory guides, license commitments, and staff practices."
f. *Reactor Oversight Process (ROP)* – in 1999, the NRC pursued changes to the program for oversight of nuclear plant operations by a licensee. The changes transitioned the oversight process from being somewhat subjective and not predictable to a process that was objective and with quantitative measures of plant performance. The ROP inspection program now uses risk information in inspections, monitoring of plant performance and in determination of event or issue importance.
g. *10 CFR 50.69, Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors* - the rule uses a risk-informed process to evaluate the safety significance of Structures, Systems and Components (SSCs) and establishes the appropriate level of special treatment requirements for SSCs [8]. It is important to note that this rule is a voluntary rule; it is not imposed on licensees. The rule ensures that the scope of special treatment requirements imposed on SSCs is risk informed. For SSCs that do not significantly contribute to plant safety, this approach in the rule maintains SSC functionality at a reduced level of assurance.
h. *USNRC Regulatory Guides* – as part of implementation of the 1995 policy statement on the use of PRA, the NRC developed regulatory guidance to support implementation of risk informed applications. These guides include Regulatory Guide (RG) 1.174 "An Approach for using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis" [9], RG 1.175 "Risk-informed Inservice Testing" [10], RG 1.176 "Graded Quality Assurance" [11], RG 1.177 "Risk-informed Technical Specifications" [12], RG 1.178 "Risk-informed Inservice Inspection" [13] and RG 1.201, "Guidelines for Categorizing Structures, Systems, and Components in Nuclear Power Plants According to Their Safety Significance" [14]. Also, the NRC issued RG 1.200, "Acceptability of Probabilistic Risk Assessment Results for Risk-Informed Activities" [15] which endorses industry guidance and consensus standards such as ASME/ANS RA-Sa-2009, Addenda to ASME/ANS RA-S-2008, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment of Nuclear Power Plant Applications" [16].

III. Risk Informed Applications

Risk informed applications can be categorized as involuntary and voluntary applications. Involuntary applications are those that are mandated or imposed by the regulator such as 10 CFR 50.65, Maintenance Rule. Voluntary applications are those that a licensee can choose to implement or not to implement. Voluntary applications usually provide an alternative to a prescriptive deterministic requirement, are usually pursued because of a beneficial economic analysis and are typically risk neutral or risk beneficial although an insignificant increase in risk may be acceptable in accordance with USNRC regulatory guidance. Below is a summary of the major voluntary risk applications pursued in the USA. The applications reviewed below vary in complexity of the analyses and in complexity of implementation. Some applications can be justified and implemented in a simple manner because they are based upon generic analyses applicable to a fleet or type of plant which has received regulatory approval. Other applications require implementing complex risk analyses, supporting administrative and technical programs and comprehensive implementation among disciplines across the nuclear plant organization. The below descriptions endeavor to describe the required analyses. When available from industry literature, the benefits associated with the application are described.

Risk Informed Technical Specifications

a. Required Action End States – This application (also known as Safe Mode End States) justifies the preferred end state for technical specification actions from Mode 5 to Mode 4 and/or Mode 3 (usually hot shutdown). Given particular equipment failures, this application permits a plant to remain in a mode where steam is available thus providing two diverse motive force drivers for safety systems (electric and steam). Previously the technical specification action statement had the end state in a non-steaming mode thus inherently relying solely on electric power. Benefits beyond the risk reduction due to diversity in motive power include less time to shutdown a plant to the required mode, a quicker return to power and a risk reduction since switchover to residual heat removal is not required. Economic benefits have been estimated at $250K to $500K per use.
b. Mode Changes – This application allows mode changes with inoperable equipment and modifies the restrictions on mode changes in the technical specification. This applies to certain equipment for which the target operating mode results in entering an action statement, providing the time specified in the technical specification to put the equipment in service. The benefits from changing the mode restraint logic allow greater flexibility based upon a risk assessment for the inoperable equipment in the plant configuration showing a negligible impact. Economic benefits have been estimated at $300K to $500K per use.
c. Missed Surveillance - This application supports an increase in the time allowed to delay entering a technical specification required action when a surveillance is missed based upon a risk assessment showing a negligible impact. Economic benefits have been estimated at $250K to $500K per use dependent upon if a shutdown is avoided.
d. Completion Times – This application supports determination of technical specification completion times using a configuration risk management program to manage plant risk. This application provides the plant with the ability to extend completion times to complete activities for inoperable equipment while remaining at-power. The allowable extension is dependent on the configuration risk management program assessment of risk and can potentially extend the completion time up to 30 days. The benefits include support for on-line maintenance activities potentially removing scope from plant outages, longer completion times for low risk maintenance configurations, flexibility in maintaining the plant at power. Economic benefits have been estimated at $250K to $1M per year.
e. Surveillance Test Intervals – This application provides an approach to extend technical specification surveillance test intervals based upon a risk informed assessment of the test interval and review of component history, corrective actions and licensing commitments among other deterministic considerations. Benefits include reduced cost for testing, reduced component actuations, and reduced outage scope and complexity. Economic benefits have been estimated at $250K to $1M per year.

Containment Integrated Leakage Rate Test Interval – This application extends the containment integrated leak rate test frequency to once every 15 years on a permanent basis based upon a risk assessment considering containment release scenarios and acceptable performance history. Benefits include reduction in outage time by 1 to 3 days by eliminating this complicated test and reduced costs for testing over plant life. Economic benefits have been estimated at $1M- $3M over plant life.

Risk Informed Inservice Inspection for Piping – This application allows for weld inspections to be established based upon risk significance of the specific weld or piping segment. The process uses operating experience and risk insights to target the pipe segments that present the greatest risk looking at likelihood and consequences of failure. Benefits include safety improvement by focusing on risk significant inspections, fewer inspection activities, reduced radiation exposure and shorter outages. Estimated economic benefits are $10M+ over plant lifetime.

Risk Informed Inservice Testing for Pumps and Valves – This application provides for risk informed changes to pump and valve testing frequency and methods using deterministic and PRA methods under a RIDM process. Components are risk ranked and changes to low ranked components are assessed for overall impact on plant risk. Consensus Standards (e.g., ASME Code for Operation and Maintenance of Nuclear Power Plants [17]) have approved Code Cases that have been accepted by the regulator that support RI-IST. The benefits include increased time between tests, reduced costs for specialized test equipment/services, and reduced radiation exposure. Economic benefits have been estimated at $1M over plant life.

SSC Categorization – This application supports using risk information to categorize safety related and non-safety related systems, structures and components as high safety significant components and low safety significant components. The categorization allows for alternative treatment requirements for safety related components ranked as low safety significant. Alternative treatment covers procurement, quality assurance, testing frequency and methods, maintenance, and environment qualification as examples. Benefits include reduction of procurement costs, maintenance time and radiological exposure along with removal of components from regulated programs such as Maintenance Rule and Quality Assurance program requirements. Economic benefits have been estimated at $10M or more over plant life.

IV. Potential First Risk Application – Suggestion for Japan Nuclear Industry

There are three decades of PRA model development and associated risk applications in the USA that can be leveraged to implement those technologies in Japan and in other countries. The experience and learnings accumulated over the three decades can be used to effectively implement risk applications in a timely and methodological manner. The concept has been described before as using global experience on a local level.

Potential first risk applications in Japan can build upon the experience in the USA and can include various considerations that can be important to stakeholders. Stakeholders may have different considerations and priorities; however, some may be common. For example, improved safety is considered a common consideration among the stakeholders while low cost may be a consideration of the nuclear plant owner/operator but not necessarily for a regulatory agency. A comprehensive assessment of considerations across stakeholders should be made. The assessment could be used to funnel down and identify a potential first risk application in Japan for future pilot plant implementation.

Various considerations for a potential first risk application were identified for review. The considerations are viewed primarily from a qualitative perspective in the assessment. The considerations in the assessment are as follows.

a. Analysis complexity – analysis to support a first application should be as simple as possible. Complex analyses may depend on models or analyses that are not mature enough to support an analysis and may need significant review and approval. Complex analyses would likely require a long schedule time to complete.
b. Generic analysis – a generic analytical basis for the risk application is considered beneficial. For example, generic analysis previously approved by the regulator which is applicable to a group of plants (e.g., Boiling Water Reactors, Pressurized Water Reactors) would make the analysis simple and likely only to require a confirmation that the generic analysis is applicable to a specific plant confirming that there are no plant specific design or operation differences that would make the generic analysis invalid.
c. Ease of implementation – ease of implementation of the risk application is seen as beneficial. The risk application should not impact a multitude of the plant programs and procedures nor cut across the nuclear power plant organization work processes.
d. Cost of implementation – cost of implementation should not be a burden. Risk applications seen as having lower costs of implementation are seen as beneficial.
e. Clear to the public – the risk application should be easy and clear for the public to understand. More complex or advanced risk applications may be difficult to understand and impact public support.

f. Risk beneficial - the risk application should be risk beneficial or at least risk neutral. Risk applications in the USA are allowed to have an insignificant increase in plant risk in accordance with the regulatory guidance, but risk insignificant increases should be avoided for a first application.
g. Regulation changes – risk applications that do not require changes to regulations are seen as beneficial. For this consideration, a perspective from regulations in the USA is used as the basis.
h. PRA models – risk applications which rely primarily on at power internal events models are seen as beneficial. In the USA, risk applications need to consider internal events, external events and low power/shutdown risk. There are risk applications that only need at power internal events PRA models and other hazards can be considered in a simple and qualitative manner.

The above considerations have been placed in matrix form. The matrix form is provided as a visual aid to help funnel down and identify a potential first risk application. The matrix is shown in Figure 1.

Figure 1

	RI TS Completion Times	RI Engineering Programs (10CFR50.69)	RI – In-Service Testing / Inspection	Integrated Leakage Rate Test Extension	Surveillance Test Extension	Safe Mode End States & Mode Changes	Missed Surveillance	MR / MSPI / SDP
Internal Events PRA	✓	✓	✓	✓	✓	✓	✓	✓
Internal Flooding PRA	✓	✓	✓	✓	✓	✓*	✓*	✓#
Internal Fire PRA	✓	✓*		✓*	✓*	✓*	✓*	✓#
Seismic PRA	✓	✓*		✓*	✓*			✓#
High Winds & Other External Events PRA	✓	✓*		✓*	✓*			✓#
Low Power / Shutdown PRA	✓*	✓*		✓*	✓*			
Generic Analysis			✓a	✓a	✓a	✓	✓	
Regulatory Change Needed	N	Y	N	N	N	N	N	Y
Risk Beneficial (B), Neutral (N), Small increase (I)	N/I	N/I	B	N/I	N/I	B	N/I	B/N/I
Simple (S) or Complex (C)	C	C	C	C	S	S	S	C
Ease of Implementation Yes (Y) or No (N)	N	N	N	Y	N	Y	Y	N
Clear for public	N	N	N	N	N	Y	N	N
Cost High (H), Medium (M), Low (L)	H	H	H	M	M	L	L	H

* = Can be implemented without this model scope, but the benefits will be limited by the requirement to apply bounding assumptions.
\# = Dependent upon the application and the scope of the issue.
a = Methodology only

The left-hand y-axis of the matrix identifies PRA models and the above stakeholder considerations. The top x-axis identifies major risk applications. Red text in the matrix is used to identify attributes that are less optimal for a first risk application and green text is used to identify attributes seen as beneficial for a first risk application. Note that these determinations are subjective and based in large part on US experience. As mentioned above, an at-power internal events PRA model is seen as a necessary quantitative model for a risk application and is therefore associated with a green check mark. Other quantitative PRA models are viewed as adding PRA modelling complexity and are shown as red check marks. Note that some of the PRA models have asterisks indicating that they may be handled using qualitative assessments. Regarding the generic analysis consideration, there are two types of generic analysis. One is an analysis methodology approved by the regulator in which the analyst follows a detailed methodology to arrive at a result. Only the methodology is approved. The other is an analysis approved by the regulator in which the results can directly be applied to a group of plants. Regarding the mandatory risk applications of such as Maintenance Rule (MR), Mitigating System Performance Indicator (MSPI) and Significance Determination Process (SDP), those USNRC required applications may or may not need quantitative risk assessments. The type of model, quantitative or qualitative, is driven by the specific issue for resolution and level of detail to meet the needs of the regulator and nuclear plant operator.

Review of Figure 1 shows a shaded column. The column is shaded because it has the smallest number of less optimal attributes (red text) and the largest number of beneficial attributes (green text). The shaded column is for the Safe Mode End States & Mode Changes risk applications. The safe mode end states application is a recommended first pilot application. As mentioned earlier, the application allows a plant to remain in a higher mode of operation while in a Technical Specification action statement. The higher mode is hot and generating steam and therefore steam is available as a motive force for powering equipment. The safe mode end states application is recommended for the following reasons.

a. Risk Beneficial

   i. Always better to have diverse means of motive power for safety functions, electricity and steam.
   ii. Only relying on electric power equipment for decay heat removal leaves reliance on offsite power and/or emergency diesel generator capability and associated vulnerabilities.

b. Easy to Understand

   i. Other risk applications such as extending test frequencies or eliminating tests may be difficult for the public to understand why less testing is better.

c. Easy to Implement

   i. The application references a generic analysis with the results approved by the USNRC for implementation by boiling water reactors and pressurized water reactors. This results in ease of approval and little to no plant specific analyses.
   ii. Simple to implement as it only changes the end state listed for the selected Technical Specifications approved in the generic analysis.

V. Considerations for a Pilot Application

The above qualitative assessment provides a starting point for a first pilot risk application in Japan. There are other considerations recognizing differences in Japan and USA implementation. Some of the considerations are as follows.

a. Involvement of industry stakeholders – the risk applications in the USA were developed with coordination and input from stakeholders across the industry. These stakeholders included the nuclear utilities, nuclear vendors, Owners Groups, Electric Power Research Institute (EPRI), Nuclear Energy Institute (NEI), USNRC and the public. The roles and responsibilities for stakeholders in Japan for the candidate application need to be defined for the candidate application.

b. Maturity of PRA and risk applications in Japan – Japan can build upon the experience and lessons learned from PRA and risk applications in the USA. As Japan continues the journey of PRA modeling and risk applications, it can be recognized that PRA models are under continual development. Searching for a perfect PRA model can hinder and delay risk applications. PRA models will never be perfect, and they should provide a good representation of the as built as operated plant.
c. Nuclear plant licensing – it is expected that there will be differences between Japan and the USA in how to meet licensing requirements when implementing risk applications. For example, the requirements for how to change and obtain regulatory approval for Technical Specification modifications need to be understood.
d. Confirmation of generic analyses – the generic analyses supporting the candidate risk application were based upon boiling water reactor and pressurized water reactor designs in the USA. The generic analyses will need to be confirmed for applicability to reactors in Japan.
e. Risk management culture and communications – as more complex risk applications are pursued, the nuclear power plant organization across functions and across all levels needs to have a basic understanding of PRA and risk applications and how they are used to support safe plant operations. This risk informed safety culture is foundational.

VI. Conclusions

This paper provides an assessment to help define a candidate risk application for first pilot use in Japan. As discussed, the safe mode end states risk application is seen as risk beneficial, easy to understand and easy to implement. Differences in maturity of PRA modeling and risk applications between Japan and USA should be considered when implementing the candidate application. Stakeholders in the Japan nuclear industry should be involved to ensure a common approach and understanding of the candidate risk application which can drive a successful implementation.

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