OUTAGE RISK ASSESSMENT AND MANAGEMENT (ORAM) TECHNOLOGY TO IMPROVE OUTAGE SAFETY AND ECONOMICS

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ABSTRACT

The Electric Power Research Institute (EPRI) has undertaken an aggressive program, called ORAM (Outage Risk Assessment and Management), to provide utilities with tools and technology to assist in managing risk during the planning and conduct of outages. The ORAM program consists of the following 6 steps: i) Perform utility surveys and visits to assess the needs of various users. ii) Perform probabilistic shutdown safety assessments (PSSAs) to identify generic insights that can be incorporated into risk management guidelines and identify selected areas for the development of contingency actions. iii) Develop risk management guidelines (RMGs) that provide a systematic approach to the planning and conduct of outages from a safety perspective. iv) Develop insights from the shutdown safety assessments and other operating experience into the RMGs. v) Develop computer software that integrates all of the above capability into an easy to use tool for effective shutdown operation management for utilities. vi) Provide assistance in the transfer of this technology and the application of these tools.

This paper briefly describes the technical approach and tools developed under EPRI's ORAM program and its applications for improving outage safety and economics.

SHUTDOWN SAFETY ASSESSMENT

EPRI performed a comprehensive survey and visited various utilities to assess the needs of various users. These utility interviews were conducted with outage management, operations, safety and probabilistic risk assessment (PRA) personnel. Probabilistic Shutdown Safety Assessments (PSSAs) employ the basic principles of probabilistic risk assessments to quantify the frequency of endstates such as core boiling and core damage for various initiating events. Results include a timeline of endstate frequencies using an actual or representative outage. The information is supported by deterministic thermalhydraulic calculations, which calculates for example the time to core boiling and core uncover. The overall concept for ORAM products is explained in, and a brief description of PSSA approach and plant applications are provided in Figure 1.

PSSAs employ the techniques commonly used in the probabilistic safety assessment of plants at power to assess the frequency of incidents and accidents, and to provide insights into areas of vulnerability, while the plant is shut down. Extensive use of industry operating experience, the modeling of multiple plant states during shutdown, and equipment train modeling approaches are employed. Multiple end states have been analyzed, including: reactor and fuel pool boiling; core damage and radiological releases; and overpressurization.

The initial PSSA application review for a BWR was performed on a BWR6 (Grand Gulf refueling outages 4 and 5). In addition, the PSSA application results for refueling outage 5 were compared to an Independent Safety Evaluation Group (ISEG) review of the outage, to benchmark the assessment method. Major results from these studies include the following:

- The calculated probability of core boiling during refueling outage 4 compared favorably to industry operating experience. This provided an overall benchmark for the usefulness of these results.
- The contributors to the risk of boiling varied considerably over the course of refueling outage 4. Early in the outage, the chance of boiling was dominated by loss of shutdown cooling and isolation events. Residual heat removal (RHR) or service water pump failures dominated boiling risk during the bulk of the outage, particularly when plant (non-safety) service water was unavailable. Later in the outage, isolation events dominated the risk of boiling.
- Activities that affect the availability of the suppression pool as a water source were found to be a major factor influencing the probability of core damage.
- The PSSA results for refueling outage 5 were complementary with the ISEG review results, but the perspectives were sometimes different. For example, the PSSA approach identified evolution's involving...
suppression pool availability and main steam line plug installation, which were not identified in the ISEG review. In contrast, the ISEG review identified a Division III diesel generator outage as a contributor to risk, whereas the PSSA approach did not highlight this evolution because of its calculated small impact.

PSSA applications for PWRs included selected Zion and Diablo Canyon outages.5,6 Some of the results from these applications included the following:

- Risk of core boiling and core damage is generally concentrated in a few vulnerable time periods, with loss of RHR the dominant risk contributor. Inadvertent draindowns (loss of coolant accidents, or LOCAs) are important contributors to loss of RHR scenarios.

- There are vulnerable periods, other than when the water inventory is low, when the time-to-boiling margin is relatively short.

- Containment sump water availability is important because draining of the reactor water storage tank (RWST) was a contributor to core uncoverage.

- The risk of cold pressurization appears small compared to the risk of boiling, and is a negligible contributor to core damage.

Many insights were defined from these applications that will be factored into the development of BWR and PWR shutdown risk management guidelines from the perspectives of core damage, radiological release, and core boiling.

Utilities are also implementing new, innovative uses of the PSSA methodology. Currently they are using the methodology to help respond to increased outage related regulatory requirements being proposed by the Nuclear Regulatory Commission (SECY 93-190). It is expected that this analysis will help refute the need for these new requirements and thus diminish any impact they would have on utility outage costs.

RISK MANAGEMENT GUIDELINES

Risk Management Guidelines (RMG) provide a framework for systematic and consistent reviews of outages from a safety perspective.7,8,9,10 Each outage is divided into discrete plant states and assessed relative to the amount of defense-in-depth for each key safety function. Based on this assessment, one of four color codes are assigned. Risk management guidelines exist for each combination of plant state and safety function. Guidelines exist that provide important information to be considered for the conditions under review. This process is shown and briefly described in Figure 2:

The logical Shutdown Safety Function Assessment Trees (SSFATs) were developed to analyze defense-in-depth for each plant state and the following safety functions:

- Reactivity Control and Monitoring
- Shutdown Cooling (Fuel in Vessel)
- Inventory Control (Fuel in Vessel)
- Fuel Pool Cooling (Fuel in Pool)
- Electrical Power Control (AC and DC)
- Vital Support System Control
- Containment Integrity and Cooling

Each plant state is reviewed relative to the seven key safety functions. The relative reliability of each safety function is determined by a decision logic contained in a SSFAT. A “color” is assigned to the safety function indicating the relative degree of defense-in-depth to which the safety function is supported. “Green” indicates that the function is fully supported to the full design and operational capability of the plant. “Red” indicates that the function is minimally supported. “Yellow” and “Orange” represent intermediate levels of support.

For the combinations of plant state and available systems, guidance is being developed for each safety function in order to make risk based decisions for conducting safe and efficient outages. This guidance in the form of recommendations should help identify possible
Assessing "Defense in Depth" of Outages

- Plant states
- System availabilities
- Insights

Plant Status
- Green
- Yellow
- Orange
- Red

Guidelines
- NUMARC Guidelines
- INPO Guidelines
- Operating experience reviews
- Technical specifications
- Administrative controls

Other Input
- Do's
- Don'ts
- Mitigating actions
- Contingency actions
- Rescheduling options

Figure 2 - How the EPRI Shutdown Risk Management Guidelines are Being Developed

The key accident scenarios that pose a risk to the safety functions are included as part of the insights for utility use. Scenarios include initiating events and potential subsequent failures which have been observed in industry experience or were found to be significant in the Probabilistic Shutdown Safety Assessments. Scenarios leading to several undesirable endstates are considered including bulk boiling, core damage, fuel bundle uncovery, fuel pool boiling or draindown, and cold overpressurization of the vessel.

The guidelines also contain a bulleted list of cautions, concerns, recommendations and considerations pertinent to the conditions under review. Each item is supported by a description of the technical basis or other reason for the guideline element. Guidelines include insights on potential initiating events, on improving safety function reliability and availability, on detection of adverse conditions, and on appropriate response actions. In addition, guidelines will include consideration related to the safety function under review that might adversely affect other safety functions.

ORAM SOFTWARE AND RESULTS

EPRI has generated a software package to implement the various tools (shown in Figure 1) that EPRI has created to address outage management need for risk management. This ORAM software contains various modules and is PC based. These tools consist of Probabilistic Shutdown Safety Assessments, Risk Management Guidelines, Effectiveness Monitoring, and Contingency Planning. In addition an enhancement to link procedure compliance, outage effectiveness monitoring, etc., with component level details using Dial CAFTA is in progress. These tools use information obtained from potentially automatic links to the outage scheduling software, the plant's IPE model, and the plants tagging program.
The various modules of the ORAM software and their development and improvement of these tools, EPRI's effort is now directed towards implementation and transferring this technology to utilities.

A number of both BWR and PWR plants are currently using ORAM technology, this has resulted in enhanced safety (factor 4 to 10) and improved economics (e.g. estimated \( \pm \$100M \) benefits for BWR and PWR plants).

REFERENCES


CONCLUSIONS

EPRI has developed the ORAM tools for utility use during the planning, conduct, and post-outage critiquing of outages. These tools have already resulted in measurable improvement in outages from both a safety and an economic perspective. In addition to continued
### Tabel 1 - Examples of ORAM Application

<table>
<thead>
<tr>
<th>Plant</th>
<th>Safety Assessment</th>
<th>Risk Management</th>
<th>Contingency Planning</th>
<th>ORAM Software Application</th>
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