Delivering the Nuclear Promise
Top Innovative Practice

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Intersecting Vulnerabilities
2022 Top Innovative Practice Winner

Summary

PSEG Nuclear uses a deterministic screening process to risk-score individual Equipment Reliability (ER) issues by probability and consequence. The resulting issues are displayed on a matrix called the Heat Map. Consequence attributes are primarily driven by production and nuclear safety. While several of these attributes (e.g., Maintenance Rule safety significance, Mitigating System Performance Indicator or MSPI equipment) are adequate surrogates for actual Probabilistic Risk Assessment (PRA) information, none directly measure severe accident risk increases. In late 2020, the PSEG Board of Directors challenged PSEG Nuclear to apply a risk-informed method to prioritize Heat Map issues based on 'Intersecting Vulnerabilities.' An intersecting vulnerability is a situation where a higher risk results from the aggregation of related issues versus the individual risk from each of these issues. Industry benchmarking indicated that this would be a first-of-a-kind application of PRAs. A pilot project was implemented to determine the feasibility of an approach that includes mapping existing Heat Map issues into the PRA models, calculating meaningful risk estimates, determining when those estimates indicate a potential intersecting vulnerability and communicating the results to plant management. This approach, after some adjustments, is currently being used to evaluate Heat Map issues and has identified several instances of intersecting vulnerabilities.

Implementation of this approach has provided a valuable safety input that has factored into prioritizing equipment maintenance and has reduced severe accident risk for the PSEG Nuclear fleet.

Innovation

PSEG Nuclear has implemented multiple risk-informed programs that optimize plant operations. Site PRA Engineers assist with effectively incorporating PRA insights into these programs, such as the Surveillance Frequency Control Program and MOV/AOV Programs. Equipment Reliability programs at PSEG and across the industry have not fully used quantitative PRA insights to support decisions. This is in part because PRA models have a limited ability to address various levels of degradation of a system.

Often bounding calculations of CDF and LERF are used to support technical decision making. However, it is difficult to capture actionable insights from the resulting risk information because it is often conservative. PSEG's approach of identifying intersecting vulnerabilities is a first-of-a-kind method of generating PRA insights for degraded equipment that highlights both the quantitative risk increase potential as well as the inter-system vulnerabilities.

The intersecting vulnerability process has several inherent limitations that must be addressed during

application. First, simple quantification of risk metrics is not adequate for decision making. Risk metrics point to issues that may have intersecting vulnerabilities, but the equipment reliability and PRA assumptions that drive these metrics must be understood as part of the decision making. Second, current programs do not capture the changes in risk insights as plant status changes. The static PRA approach is valid for the average plant risk model but may not completely describe any short-term mitigating actions that would be appropriate for specific plant conditions.

EPRI risk management software is leveraged to calculate thousands of PRA cases, representing combinations of equipment failures. The resulting dataset is processed in a relational database, allowing for flexible inputs and outputs, and different methods of reviewing results. The key output from this data is a list of screened intersecting vulnerabilities and associated plant components, and mapping of current Heat Map issues to these plant components. This allows for an engineer to easily review intersecting vulnerabilities for a given equipment reliability issue and determine whether any current Heat Map issues need to be considered when developing the elimination or mitigation strategy. Potential resulting actions include an accelerated issue resolution schedule or additional bridging actions implemented to reduce the risk until the issue can be eliminated or permanently mitigated. For further refinement of failure mode and accident sequences, Engineering can consult with site PRA engineers. This process simplifies the PRA model down to insights that can be dynamically applied to a Heat Map issue by Engineering without requiring intimate knowledge of the PRA model.

Safety

Items on the Heat Map represent degraded conditions on both safety-related and non-safety-related systems. A detailed risk analysis of each issue using station PRA models is not practical. There are deterministic screening criteria in the issue ranking process that account for relative risk significance, such as when the issue could cause a loss of safety function. However, CDF/LERF results are not explicitly analyzed. This could potentially result in top accident sequences not being considered when developing mitigation plans. With the incorporation of Intersecting Vulnerabilities risk insights, CDF and LERF can now be reviewed to determine the bounding risk impact of equipment issues. Priorities for eliminating Heat Map issues can be changed, and/or alternative or temporary mitigation strategies can then be implemented to reduce this risk to the plant.

As an example, consider a recent issue with Hope Creek's Turbine Digital Electronic-Hydraulic Control (EHC) Pump. First, we determined the risk increase factor of the EHC pump. Mapping the failure of this component into the PRA model increases the core damage risk by a factor of 2.6, which is significant but not extremely high. Similarly, the risk increase factors for a Control Rod drive pump issue, a Control Equipment Room ventilation issue and a High Pressure Safety Injection system issue were 2.02, 1.00 and 4.27 respectively. The next step was to calculate the dual component or intersecting vulnerability risk increase for the component pairs. The intersecting vulnerability risk increase factor was calculated for the EHC pump paired with each of the other 3 issues. The intersecting vulnerability risk increase ratio was 2.67 for the combined impact of the EHC issue and the Control Rod Drive issue, which is unusually high. No significant intersecting vulnerability risk increase was noted for the other issue pairs. By resolving the EHC vulnerability during the first available refueling outage, this risk to the station was eliminated in an expedited manner. Figure 1 shows this relationship.

Cost Savings

Risk-informed equipment reliability actions will reduce the potential for plant issues to result in significant operational events and associated regulatory response. Long term unreliability and unavailability of equipment important to safety could leave PSEG plants vulnerable to Reactor Oversite Program violations, and poor performance as measured by NRC and INPO indicators. Regulatory inspections following these events are large resource and cost expenditures for the fleet.

Prioritization of equipment repair can result in optimized work planning. This would allow for fewer emergent and out-of-cycle repair windows, allowing for less re-allocation of resources. This could also reduce outage scope.

Productivity/Efficiency

One of the major issues impacting engineering teams is knowledge transfer. Creating a framework for new engineers to be quickly onboarded improves the overall productivity of an engineering organization. There is often an initial barrier of complexity with PRA and risk-informed insights. This results in a less effective use of PRA insights to supplement engineering work products and decision-making.

With the intersecting vulnerabilities process, PRA insights are condensed down to simple system dependencies that are much easier to initially review. This allows for self-sufficiency in the engineering organization and opens the door to collaboration between Engineering, PRA, and Operations. This collaboration is vital to generating effective equipment reliability strategies.

Transferability

The intersecting vulnerabilities process can be used across the industry. Most plants have a process for equipment reliability issue prioritization that is analogous in function to the PSEG Heat Map. In addition, all U.S. nuclear plants maintain plant-specific PRA models. Nuclear plant designs, especially support systems, vary across the industry. While risk significance is largely consistent for key safety systems, system design and operational differences result in corresponding risk insight differences. This makes PRA the ideal tool to use for this application. The industry can exercise these PRA models in the same way and develop a list of intersecting vulnerabilities. Beyond internal events, stations with other hazard PRAs can utilize those in a similar manner to develop additional insights. At PSEG Nuclear, the same approach was used with success at both Salem and Hope Creek. The databases and processes developed are universal and would be simple for other utilities to configure.

There are further collaboration efforts planned with EPRI to incorporate lessons learned in communicating risk insights to station leadership. EPRI has a project to look at risk-informed decision making in general. That project is currently focused on Enterprise Risk, which is the direction provided by member utilities, and EPRI Technical Report 3002023855, "Enterprise Risk Management and Risk-Informed Decision-Making," has been published based on research to date. EPRI PRA tools are adequate for this activity, but if many utilities implement a similar project, there may be opportunities to streamline the information processing.

Team Members

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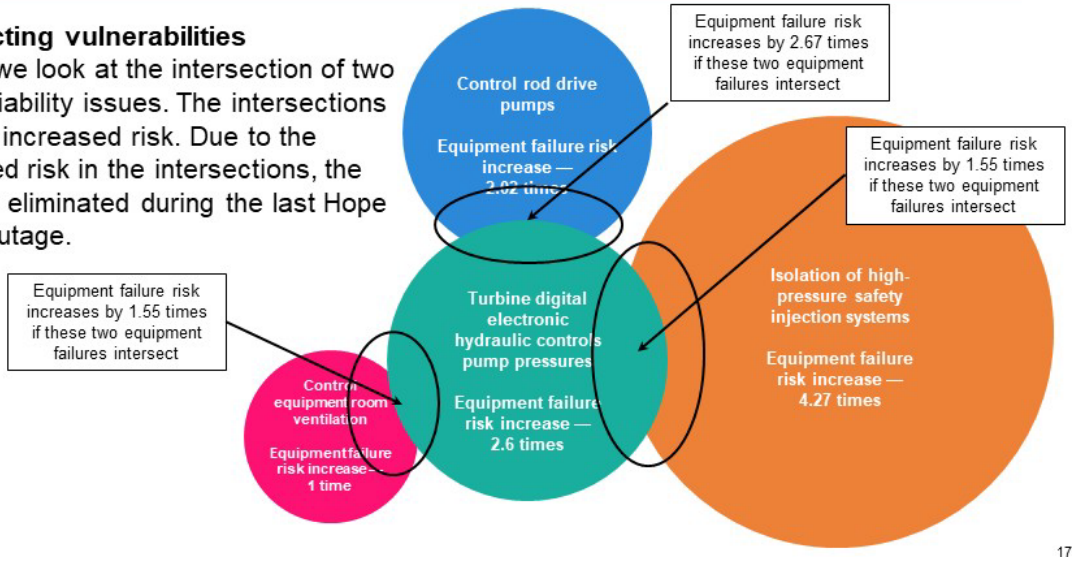
Figure 1 — Intersecting Vulnerabilities Example

Intersecting vulnerabilities

Finally, we look at the intersection of two plant reliability issues. The intersections indicate increased risk. Due to the increased risk in the intersections, the risk was eliminated during the last Hope Creek outage.



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