Transactions, **SMiRT-25**
Charlotte, NC, USA, August 4-9, 2019
Division VII

INVESTIGATION ON THE FEASIBILITY OF CONDUCTING MANAGED SCOPE SEISMIC PROBABILISTIC RISK ASSESSMENTS

Samer El-Bahey[1], PhD., P.E, Chris Hendrix[2], Paul Amico [3], John Richards [4]

[1] Senior Engineer, JENSEN HUGHES, Phoenix, AZ, USA
[2] Principal Engineer, JENSEN HUGHES, Boston, MA, USA
[3] Senior Consultant, JENSEN HUGHES, Rockville, MD, USA
[4] Principal Technical Leader, EPRI, Charlotte, NC, USA

ABSTRACT

A significant amount of effort continues to be expended on Seismic Probabilistic Risk Assessments (SPRAs). In the US, the need for SPRAs has arisen in connection with response to Near Term Task Force (NTTF) Recommendation 2.1 but also with a variety of risk-informed regulatory applications such as the ongoing industrywide coordinated implementation of 10 CFR 50.69. As these SPRAs become more sophisticated and expectations rise, experience indicates that their costs escalate significantly. These escalating costs are often the result of the perceived need for the development and exercise of detailed building-response models and plant-specific fragility calculations for Structures, Systems, and Components (SSCs) with minimal contribution to plant risk. The costs have risen to the point at which some utilities may choose not to pursue certain risk-informed applications, or may derive limited benefit (e.g., from risk-informed categorization under 50.69).

Experience in performing SPRAs has led to a preliminary conclusion that it is possible to conduct a seismic risk assessment and gain useful insights into important risk contributors with a more informed set of analyses of building response, fragility, and plant response. This conclusion is supported by anecdotal evidence for several stations that Probabilistic Risk Assessment (PRA) analysts have been able to derive risk results and insights from preliminary SPRAs that employ appropriate adaptations of risk-informed logic to generate a managed scope, thus smaller model, from which risk insignificant structures, systems and components have been pruned (screened out).

The conclusion is particularly the case for plants sites for which the current seismic hazard is not substantially higher than the seismic design basis. From which, the feasibility of developing a methodology for a quantitatively-based, risk-informed screening of components for SPRAs is investigated herein. The development of this methodology shall be designed explicitly to address expedited use for evaluating seismic hazard risk for risk-informed applications, including the 10 CFR 50.69 categorization process in accordance with NEI 00-04. This study is intended to develop a risk informed, managed-scope SPRA and shall be designed such that, if properly implemented, the result will yield to more efficient SPRAs for use in applications such as 50.69 that meets the requirements of USNRC Regulatory Guide 1.200 and the ASME/ANS PRA Standard.

The key feature of this study is that it relies on previous experience to provide a sound basis to exclude non-contributing systems and non-contributing component fragilities from the model. If properly implemented, fragility analyses shall be developed more systematically, using risk insights to provide guidance prior to costly initial fragility calculations. Many fragilities are noncontributors to core damage frequencies (CDFs) and large early release frequencies (LERFs). The concept of the risk informed, managed-scope SPRA is to rely far more heavily on the PRA logic model to drive realistic, risk-informed screening of components prior to detailed fragility analysis. This paves the way for an overall simplified

methodology designed to produce a SPRA that meets the requirements corresponding to Capability Category (CC)-II of the ASME/ANS PRA Standard.

In summary, this ongoing research uses experience and knowledge in logic modelling, building analysis, and fragility development to develop a risk informed, managed-scope SPRA. Its risk informed screening shall be applied in an informed way that meets CC-II requirements in accordance with SFR-B1, -B4a & -E3 of the ASME/ANS PRA Standard. The PRA Standard provides ample opportunity to screen components and systems that will ultimately not impact the risk result. This approach is auditable and sufficiently transparent so that it can be demonstrated to be in accordance with the aforementioned CC-II tenets.

In addition to reducing the effort required to perform an SPRA suitable for use in risk-informed applications in general, it is anticipated that the outcome of this research will support a more meaningful approach to the risk-informed categorization of SSCs under 10 CFR 50.69 for many plants. Plants that do not have an up-to-date SPRA or SMA have limited options for assessing the risk significance of SSCs relative to seismic challenges under the existing 10 CFR 50.69 guidance.

METHODOLOGY

Capacity based screening is the typical approach that is used for determining the SSCs for which fragility analysis should be conducted. The standard practice for SPRAs is that certain SSCs are inherently seismically rugged and consequently have a very low probability of failing as a result of a seismic event, seismic failure of such SSCs need not be included in the PRA logic models. Exclusion of such SSCs from the logic models does not affect the seismic Core-Damage Frequency (CDF) or the insights derived from the SPRA. Other SSCs may be less rugged but would still have sufficient capacity such that their failures would be unlikely to contribute significantly to the CDF in a SPRA. Screening criteria per EPRI NP-6041 are developed for these SSCs.

Detailed fragility calculations are not warranted for SSCs that meet these criteria. Fragility calculations are conducted for all other SSCs. Figure 1 below shows the typical capacity-based screening approach.

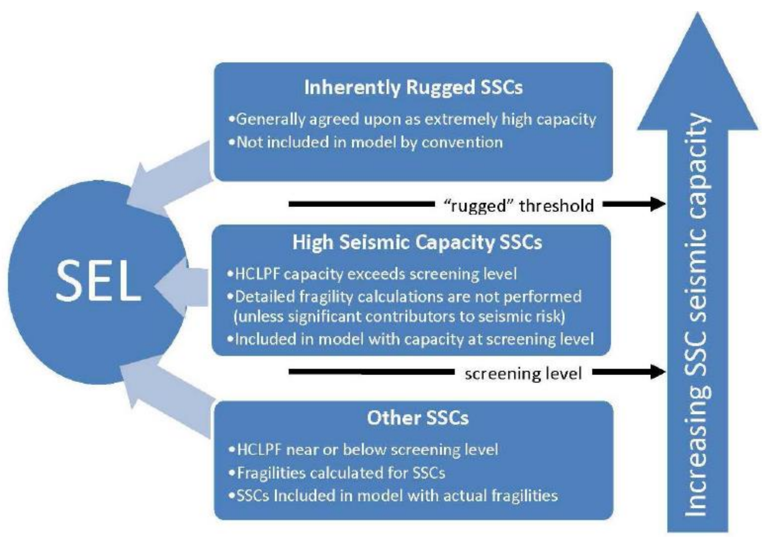

Figure 1. Capacity-Based SSC Screening Approach (Excerpt from EPRI-1025287).

The above capacity-based screening approach does not consider PRA importance factors and results in a walkdown SEL as shown in Figure 2 that mostly requires fragility evaluations and many of those fragilities are noncontributors to core damage and large early release frequencies which is time consuming and unnecessarily costly. The proposed methodology is an enhanced screening process based on a combination of capacity-based screening and risk importance-based screening based on insights of previous SPRAs resulting in a smaller walkdown list and a smaller group of required fragilities as shown in Figure 3 below.

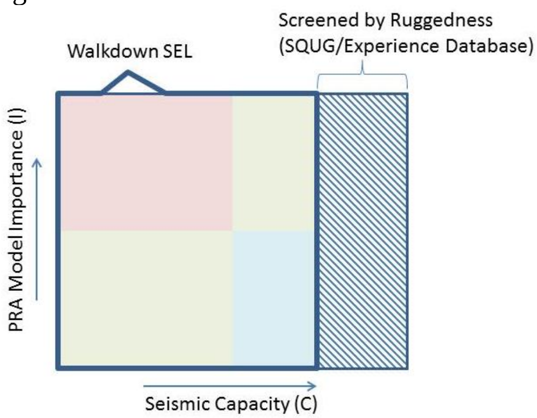

Figure 2. Typical Walkdown SEL resulting from Capacity-Based Screening.

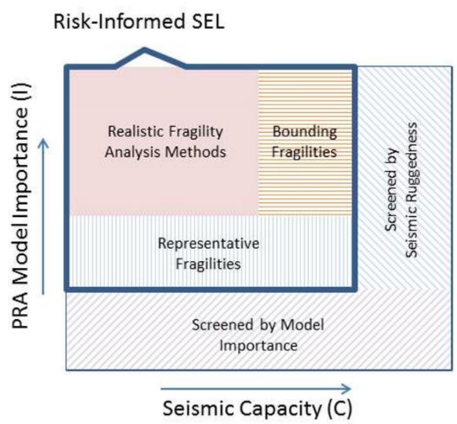

Figure 3. Risk-Informed SEL resulting from Capacity/Importance Screening.

Taking a closer look at the proposed enhanced screening methodology in Figure 4, capacity thresholds are defined and depicted on the horizontal axis as a "Rugged Threshold" and a "Screening Level" threshold, these capacity-based screening levels are in EPRI-6041, and EPRI-1025287. The newly introduced importance thresholds are depicted on the vertical axis as "Importance Threshold", and "High Importance Level."

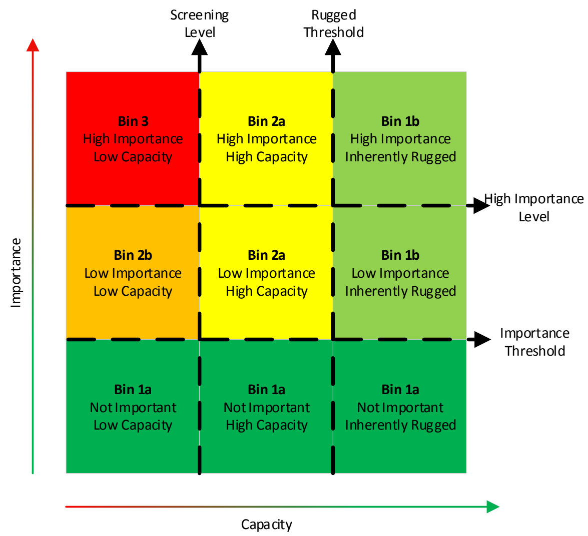

Figure 4. Proposed Capacity/Importance Screening Methodology.

For the purpose of this study, the importance thresholds shall be set to 0% for the "Importance Threshold" and 2% for the "High Importance Level" based on the Fussell-Vesely Importance (FVI). The FVI is a factor used to quantify the risk importance of a component as recommended by EPRI 3002000709 to rank components based on their importance to the SPRA model.

Fussell-Vesely Importance (FVI) of a modeled plant feature (usually a component, train, or system) is defined as the fractional decrease in total risk level when the plant feature is assumed perfectly reliable. The FVI for plant feature, i, may be calculated as follows:

$$\mathrm{FVI}_i = \frac{\mathrm{CDF}_{p_{fi}=0}}{\mathrm{CDF}_{\mathrm{nom}}} \tag{1}$$

Where $\mathrm{CDF}_{p_{fi}=0}$ is the Core-Damage Frequency when the plant feature is assumed perfectly reliable and $\mathrm{CDF}_{\mathrm{nom}}$ is the calculated Core-Damage Frequency. If all the sequences comprising the total risk level (e.g. CDF) are minimal, the F-V also equals the fractional contribution to the total risk level of all sequences containing the (failed) feature of interest.

Note that a component's seismic fragility (i.e. HCLPF) is used as input in the determination of its actual probability of failure (p_{fi}). Additional investigation is pertinent for a more realistic threshold values as additional sensitivity studies are required. For the purpose of this feasibility study, components are classified based on their FVI as follows:

- Components having FVI=0% shall be placed in Bin 1a
- Components having 0% < FVI< 2% shall be placed in Bins 2a, 2b, and 1b depending on their capacity-screening criteria.
- Components having FVI>2% shall be placed in Bins 1b, 2a, and 3 depending on their capacity-screening criteria.

For the capacity-based screening, the Ground Motion Response Spectrum (GMRS) is used to identify the capacity-based screening threshold. The GMRS represents a consistent level of hazard between plants and is generally similar in shape and magnitude to the Review Level Earthquake (RLE). In fact, a number of the plants use the GMRS as the RLE. Based on this, HCLPF values can be normalized by dividing by the plant-specific GMRS PGA to yield a ratio that is indicative of general risk to nuclear power plants. Component types with HCLPFs that generally fall above ~1.5 x GMRS PGA are viewed as being less likely to be significant to risk and may often be considered for reduced scrutiny in terms of fragility calculation, and component types with HCLPFs that generally fall above 2.5 x GMRS PGA are viewed as being very unlikely to be risk-significant and can generally be considered for reduced scrutiny in terms of fragility calculation. This is based on SPID, Section 6.4.3, where 2.5 x GMRS is given as an acceptable screening level beyond which detailed fragility calculations are not performed. From which, the Capacity-based screening thresholds are set to the following:

- Components having HCLPFs > 2.5 GMRS shall be placed in Bins 1a, and 1b
- Components having 1.5 GMRS < HCLPFs < 2.5 GMRS shall be placed in Bins 1a, and 2a
- Components having HCLPFs < 1.5 GMRS shall be placed in Bins 1a, 2b, and 3

These conclusions based on component type will not be universal as they do not consider the components relationships to plant systems. However, for components that generally have higher fragilities, it may be reasonable to use a high generic or representative fragility early in the SPRA process and only consider further scrutiny in calculating fragility if the component is deemed significant from the PRA model using a conservative threshold.

These values are generally ignored in evaluating the fragility of component types as they are not calculated values. If a 0.1g value has been successfully used in the SPRA, it implies that the significance of a component is low based on its system and relationship to safe shutdown.

A summary of the overall proposed SPRA process using the enhanced screening criteria is presented in Figure 5. The proposed methodology shows that items that are screened in Bins 1a and 1b should not be included in the SPRA quantification. Items falling in Bin 2a shall be assigned fragilities based in EPRI-6041 screening criteria or design-based scaling methodologies, and items falling in Bin 2b shall be assigned fragilities based on Conservative Deterministic Failure Margin (CDFM) methodology. Finally, items falling in Bin 3 shall be assigned realistic detailed fragilities. Figure 6 shows the different fragility calculation methods based on the above bins from least to most refined method.

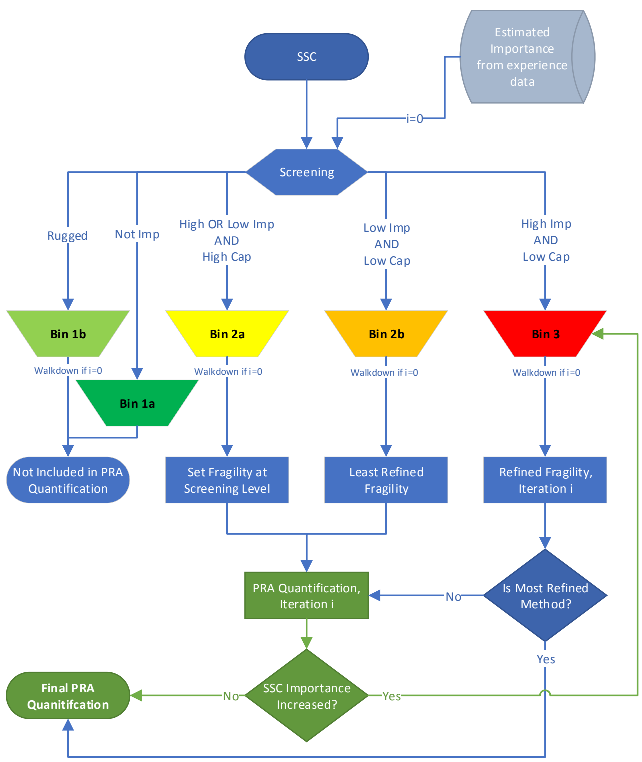

Figure 5. Overall proposed Process.

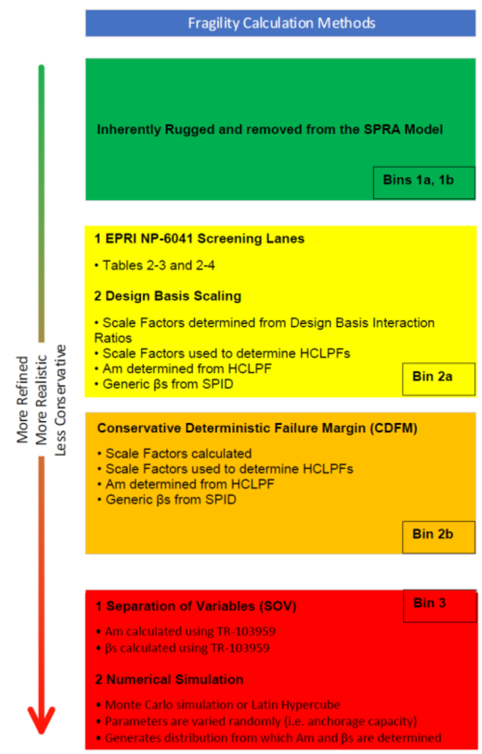

Figure 6. Fragility Calculation Methods based on Proposed Bins.

IMPORTANCE-BASED SCREENING DATA PROCESSING

The initial phase of the study was compiling data for SEL components from 9 Units at 7 nuclear power plants. Of the 7 plants, 5 are of the Pressurized Water Reactor (PWR) type and 2 are of the Boiling Water Reactor (BWR) type. The database included information pertinent to the feasibility study as the Reactor Type, Component Class, GMRS Peak Ground Acceleration (PGA), Functional HCLPF, Structural HCLPF, Failure Mode, and FVI Importance. The database was initially grouped by component class and sorted by Importance percentage (Imp%; Percent of SSCs where F-V Importance is greater than 0.00%) as shown in Table 1 below.

Table 1. SSC counts by class.

Component Class	Tot.	Imp%
11 Chiller	16	0.0%
13 Motor Generator	12	0.0%
19 Temperature Sensor	117	0.0%
07 FOV/AOV	945	4.1%
18 Instrument Rack	319	6.3%
09 Fan	134	9.0%
02 LVSG	48	10.4%
10 Air Handler	161	10.6%
08 MOV/SOV	1349	10.7%
15 Battery Rack	90	13.3%
05 Horizontal Pump	256	14.1%
20 Control Panel/Cabinet	1081	14.7%

Component Class	Tot.	Imp%
00 Other	3534	14.7%
14 Distribution Panel	290	18.3%
21 Tank	393	19.3%
17 Engine Generator	36	19.4%
01 MCC	234	22.2%
12 Air Compressor	13	23.1%
04 Transformer	151	26.5%
22 Cable Tray/Conduit Raceway	63	34.9%
16 Battery Charger/Inverter	124	36.3%
06 Vertical Pump	136	38.2%
03 MVSG	28	42.9%

It is observed that component classes 11 Chillers, 13 Motor Generators, and 19 Temperature Sensors never contributed to the risk in the logic model for all 7 plants. And therefore, could be placed in Bin 1a and readily excluded from the PRA model.

Further data processing was conducted per equipment class to observe trends in importance and to investigate if entire equipment classes have FVI less than a 2% of contribution to risk from which could be placed in Bins 2a, 2b, and 1b.

A plot depicting FVI importance versus Count percentage (number of components having FVI less than the X axis value to the total number of components in the corresponding component class) is presented in Figure 7 below. It is observed that these component classes never contributed to the risk for all seven plants with an FVI greater than 2%. It is concluded that these classes could be placed in Bins 2a, 2b, and 1b using importance as a basis.

Figure 8 presents the rest of the component classes where an FVI importance factor above 2% was observed. For example, it can be seen that about 50% of vertical tanks in previous SPRA's had an FVI above 2%. Transformers, fans, and battery racks were other classes that are also seen as highly important classes with FVI values for 35% of the total transformers analyzed having an FVI of more than 2%. About 25% of tanks and horizontal pumps have FVI above 2%. It is concluded that these classes could be placed in Bins 1b, 2a, and 3 using importance as a basis.

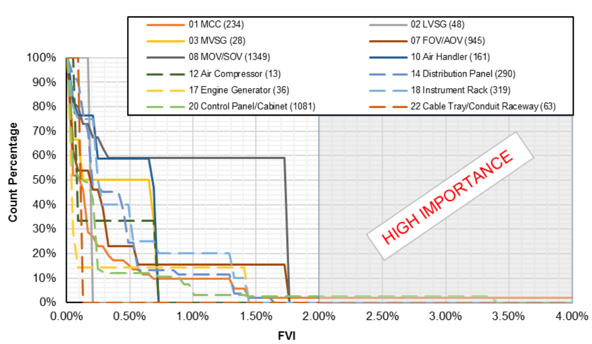

Figure 7. FVI Importance vs Count Percentage for Component Classes below 2%.

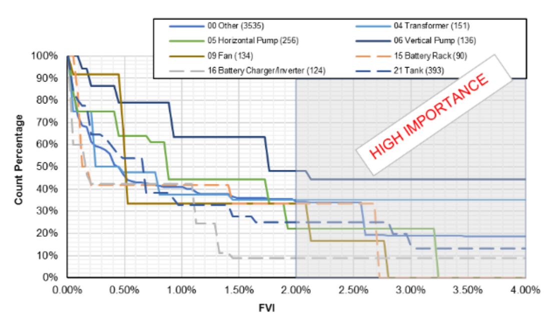

Figure 8. FVI Importance vs Count Percentage for Component Classes above 2%.

CAPACITY-BASED SCREENING DATA PROCESSING

The GMRS PGA for the 7 plants included in the compiled data ranges from 0.24g to 0.436g with an average of 0.33g and a standard deviation of 0.075g. Figure 9 depicts component classes where only 5% of the components experienced HCLPFs below 1.5 x GMRS and about 12% of the components experienced HCLPFs below 2.5 x GMRS. These classes may be candidates for reduced scrutiny in terms of fragility calculation, but care should be taken to identify situations that may lead to reduced functional or structural capacity. From which, it is suggested that these classes be placed in Bins 1a and 2a (components having 1.5 x GMRS < HCLPFs < 2.5 x GMRS).

Figure 10 depicts component classes where these components experienced significant HCLPF values below 1.5 x GMRS. These classes may be candidates for additional scrutiny in terms of fragility calculation. From which, it is suggested that these classes be placed in Bins 1a, 2b, and 3 (Components having HCLPFs < 1.5 GMRS). Figure 11 depicts component classes where these components experienced HCLPF values above 2.5*GMRS in the majority of cases (only 5% of items had HCLPFs below 2.5g and none below 1.5g). These classes may be candidates for exclusion from the PRA model by designating them as inherently rugged and placed in Bins 1a, and 1b (Components having HCLPFs > 2.5 x GMRS).

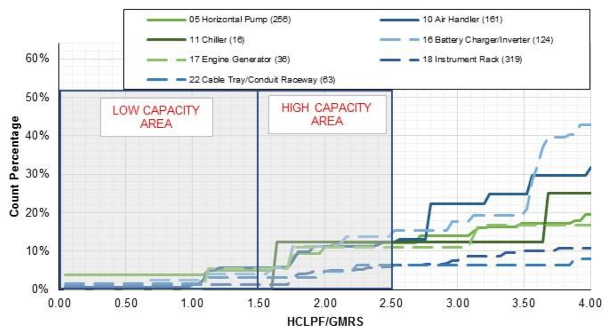

Figure 9. HCLPF/GMRS vs Count Percentage for Component Classes with High Capacity.

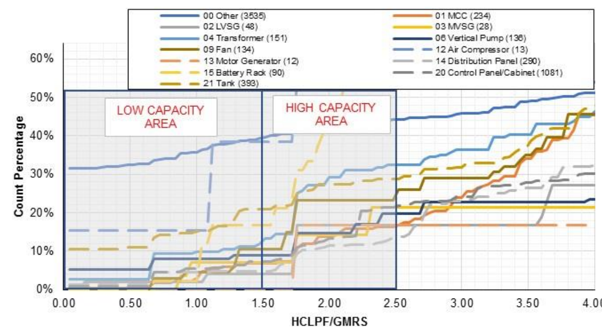

Figure 10. HCLPF/GMRS vs Count Percentage for Component Classes with Low Capacity.

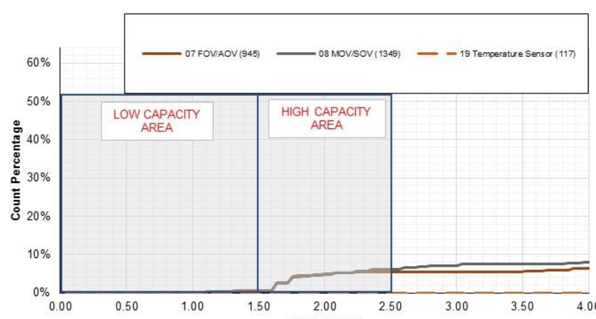

Figure 11. HCLPF/GMRS vs Count Percentage for Component Classes with Very High Capacity.

CONCLUSION

The objective of this study is to demonstrate a proof of concept for a risk informed, managed scope SPRA that can reduce the number of structures, systems, and components (SSCs) needed to perform a complete and thorough SPRA. The scope of work outlined herein relies on a compilation of information from recently completed SPRAs to derive insights into the risk significance of various SSCs. This information was used to develop guidance that could significantly reduce the effort required to complete a SPRA capable of supporting a variety of risk-informed applications.

Data has been compiled from SPRAs that have been completed in the recent past or nearing completion from 9 Units at 7 nuclear power plants. Of the 7 plants, 5 are of the Pressurized Water Reactor (PWR) type and 2 are of the Boiling Water Reactor (BWR) type, with a focus on those that have undergone peer reviews in accordance with the expectations of the ASME/ANS PRA Standard (or that are currently awaiting such a peer review). Patterns and trends were identified among plants of similar design relative to the risk importance measures, and particularly Fussell-Vesely; and the seismic capacities and fragility characterizations.

An importance-based screening concept is proposed in addition to the traditionally used capacity-based screening in order to quantify component classes that are candidates for reduced scrutiny and a classification of components based on proposed bins relevant to the fragility refinement method is concluded and shown in Figure 12 below.

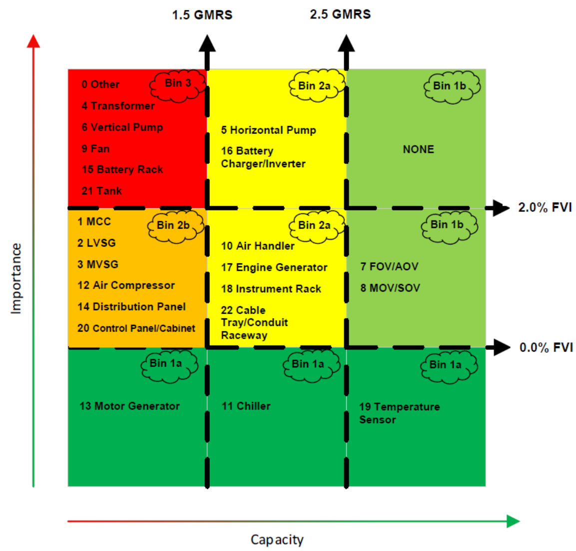

Figure 12. Proposed Classification of Component Classes for Importance-Capacity based Screening.

REFERENCES

NEI 00-04, Rev 0. (2005). *10 CFR 50.69 SSC Categorization Guidelines*.

NRC Regulatory Guide 1.200, Rev 2. (2009). *An approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities.*

ASME/ANS RA-Sa–2009. (2009). *Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications*.

NEI 16-09. (2017). *Risk Informed Engineering Programs (50.69) Implementation Guidance*.

EPRI NP-6041-SL Rev 1. (1991). *A Methodology for Assessment of Nuclear Power Plant Seismic Margin*.

EPRI 1025287. (2013). *Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic*.

EPRI 2002000709 (2013). *Seismic Probabilistic Risk Assessment Implementation Guide*.

EPRI 3002002997 (2014). *High Frequency Testing Program: Seismic Testing Summary and Application Guidance*.