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# EFFICIENCIES IN CAPACITY-BASED SCREENING OF COMPONENTS IN A SEISMIC PROBABILISTIC RISK ASSESSMENT

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## ABSTRACT

In performing a seismic probabilistic risk assessment (SPRA) of a nuclear plant, fragilities of hundreds or even thousands of structures, systems and components (SSCs) could be modeled in logic trees to quantify and rank important accident sequences and determine the overall risk or the annual core-damage frequency (CDF). However, it is impractical and cost prohibitive to calculate fragilities of such a large number of SSCs. Several methods are used to screen those SSCs that are either rugged, have high capacities, or are not risk-significant. These methods include insights from plant walkdowns, experience-based knowledge, and capacity-based screening. A capacity-based criterion was recently developed and endorsed by the Nuclear Regulatory Commission (NRC) to perform SPRAs for the Fukushima-related initiatives in the US. For sites with high seismic hazards, this criterion can still be burdensome based on high calculated screening levels and further refinements and efficiencies can be implemented to focus resources on those SSCs which are likely to be important to seismic risk and for which detailed fragility analyses should be performed.

The capacity-based screening criterion requires convolving the site-specific hazard curve with a single element plant fragility curve to establish a threshold in terms of high-confidence-of-a-low-probability-of-failure or HCLPF capacity. In an SPRA model, fragilities of SSCs that are judged to have capacities above the threshold value need not be calculated. The abscissa on a hazard curve can range from a low acceleration value to rather high accelerations of 8 to 10g. It is clear that the tail end of the hazard curve with high accelerations should not contribute to the seismic risk. This paper systematically evaluates the consequences of truncating a hazard curve and provides recommendations. In addition, a graded capacity-based screening approach to prioritize fragility calculations is recommended to provide efficiencies in an SPRA.

## INTRODUCTION

The seismic equipment list (SEL) in an SPRA typically consists of several hundred SSCs and it is neither practical nor cost-beneficial to attempt to perform fragility analyses for all of the SSCs on the SEL. Therefore, screening approaches that are technically sound need to be developed and used. The objective of a screening approach is to screen those SSCs that are not important in the SPRA and perform detailed fragility calculations for only those SSCs that are of significance in the logic model. The approach should be such that the calculated seismic core damage frequencies (SCDF) for various accident sequences are not appreciably affected by applying the selected screening methods. Guidance on screening has been provided in various industry documents. Section 5.2 of Electric Power Research Institute's (EPRI) Technical Report 3002000709, "SPRA Implementation Guide," contains some of the accepted methods and guidance on screening of SSCs. A capacity based screening approach is discussed in EPRI Report 1025287, "Screening Prioritization and Implementation Details (SPID)" and its basis was presented in a SMiRT-22 paper.

This paper provides the steps that can be used in the screening process in an SPRA. The primary objectives are to discuss efficiencies in the capacity-based screening approach by determining whether the hazard curve can be truncated, with justification, in the development of a capacity-based screening criterion, and to describe how a graded approach can be used for capacity-based screening.

## OVERVIEW OF SCREENING PROCESS

The steps in implementing the screening process in a nuclear plant seismic PRA are as follows:

- Screen out inherently rugged or seismically insensitive SSCs from the SPRA logic model.
- Use insights from plant walkdowns to screen out SSCs that are also considered inherently rugged by a trained and experienced walkdown team.
- Use the screening criteria from the tables in Chapter 2 of EPRI NP-6041-SL Revision 1 to establish HCLPF capacities of SSCs for functional failure modes.
- Perform screening of potentially high frequency sensitive components such as relays.
- Develop a capacity-based screening HCLPF using the SPID criterion for screening of SSCs.
- Create an initial SPRA screening model and use a graded approach for the capacity-based screening HCLPF to prioritize SSCs for fragility calculation based on their risk significance.

Once these screening steps are taken, fragility calculations are performed for SSCs that are not screened by the processes above. SSCs for which the SPID screening criterion is used or the tables from EPRI NP-6041 are used should be retained in the SPRA logic model with their fragilities corresponding to the screening HCLPF value. Inherently rugged or seismically insensitive SSCs need not be retained in the logic model.

### *Inherently Rugged SSCs, Walkdown Insights, EPRI Experience-based Screening, and Relays*

Certain SSCs are inherently seismically rugged and consequently have a very low probability of failing as a result of a seismic event. Unless some abnormality is identified during walkbys, seismic failure of such SSCs need not be included in the SPRA logic models since the exclusion of such SSCs does not affect the seismic CDF or the insights derived from the seismic PRA. Table 1 lists some of the SSCs that can be considered as inherently rugged.

In addition to the SSCs in Table 1, pressure, temperature, level and flow transmitters with 10g peak GERS, strainers, dampers and some exhaust fans may also be considered rugged with further review by a seismic walkdown team. Guidance is also available in industry documents such as the EPRI report on Generic Seismic Technical Evaluation of Replacement items (G-STERI), to get insights on screening of those SSCs that are classified as seismically rugged or insensitive.

A trained and experienced seismic walkdown team can assess whether a component being walked down has high seismic capacity. For example, junction boxes or small wall-mounted panels with robust anchorage can be judged by the walkdown team to have very high capacities such that their inclusion in the PRA logic will have a negligible impact. The basis of such judgments by the walkdown team should be well-documented and explicit fragility calculations for these components can be avoided.

Table 1 – Inherently Rugged SSCs

| SSC | Comment |
|---|---|
| Manual valves | Compact manual valves are considered to be of sufficiently high seismic capacity and can be screened from the SEL. |
| Motor-Operated Valves (MOVs) and Air-Operated Valves (AOVs) | Non-active MOVs and AOVs that do not change state (e. g., normally open and desired position is to stay open) are considered inherently rugged but a walkby should still be performed if they are on small lines (1" and smaller) to confirm that the valve / operator support is adequate for large operators. For non-active MOVs / AOVs on larger size lines, general area walkdowns, piping walkdowns or a sampling walkby is sufficient. Active MOVs / AOVs that change state are included for seismic evaluation. MOVs / AOVs are also included in the relay chatter evaluation for possible spurious operation due to relay chatter. |
| Check valves, solenoid-operated valves with Generic Equipment Ruggedness Spectrum (GERS) up to 9g, and small safety and relief valves | These types of valves are considered to be of sufficiently high seismic capacity and can be screened from the SEL. |
| Compact Pumps | Compact pumps are typically rugged. The anchorage or mounting would be expected to have high capacity but this should be validated by an experienced seismic walkdown team. |
| Temperature Elements | Seismic inertial loads for pipe-mounted temperature elements may be inconsequential; a walkdown team can further review the screening. |

Tables 2-3 and 2-4 in EPRI NP-6041 can be used to estimate functional HCLPF capacities of SSCs. For NP-6041 Table 2-4, an updated approach has been recommended in EPRI Report 1019200 to compare 1.5 times the screening spectral acceleration to the in-structure response spectrum (ISRS) peak. Thus, the functional HCLPF capacity based on Table 2-4 can be estimated using the ratio between the 1.5 times the Table 2-4 spectral acceleration and the ISRS peak. When using this table, the anchorage capacity must be assessed separately. For structures, assigning a HCLPF value equal to the screening level in Table 2-3 of EPRI NP-6041 may be conservative and SPRAs require use of realistic fragilities to the extent possible to properly rank accident sequences and to get accurate risk insights. However, Table 2-3 screening values can be used initially and the need to calculate explicit fragility parameters for structures can be determined via sensitivity analyses at a later stage based on the importance of the structure and the relative fragilities of equipment and components housed within the structure.

The methods for relay screening are well known – circuit analysis to determine whether functionality during a seismic event is needed and whether or not contact chatter is acceptable, operator actions, and then, if needed, performing a fragility calculation. In some cases, relays are tested to the limits that can be reached by a shake-table, and plants that have ground motions with a significant high frequency content, the combination of in-structure and in-cabinet amplifications at high frequencies can be large such that the demand far exceeds the capacity even at the shake-table limits. In such cases, judgment by the fragility analyst is needed whether performing an explicit fragility calculation will add value to the SPRA. Sensitivity analyses using the SPRA logic model can be performed to determine the need for fragility calculations of relays.

## EFFICIENCIES IN CAPACITY BASED SCREENING

A SMiRT-22 paper (Bhargava, et al) discusses the development of a capacity-based screening criterion which was included in the NRC endorsed EPRI - SPID guidance and in an NRC Interim Staff Guidance on seismic margin assessment, for the resolution of NRC's Fukushima Near-Term Task Force (NTTF) recommendation 2.1. A screening HCLPF capacity was established as follows:

- A screening HCLPF capacity is calculated by convolving the fragility of a single element with the site-specific hazard curve such that the seismic CDF is about 5E-7 per year.
- Alternatively, as an equivalent to the above criterion, a screening HCLPF capacity is calculated as about 2.5 times the peak ground acceleration (PGA) of the ground motion response spectrum (GMRS).

For SSCs above this HCLPF capacity, fragility calculations are generally not required. This screening HCLPF capacity is used when reviewing previous design or other calculations of SSCs and the fragility analyst can judge, by inspection, that a previous calculation shows margins above the screening HCLPF capacity. In that case, an explicit HCLPF or fragility calculation need not be performed and the SSCs are retained in the SPRA logic model with their HCLPF capacity equal to the screening HCLPF capacity.

It was recognized during the development of the above capacity-based criterion, that the screening HCLPF value is likely to be high for sites with high seismic hazards and fragility analyses may be needed for a larger number of SSCs than required, some of which many be non-contributors to risk. Therefore, the process needs to be improved. One suggestion in the SMiRT-22 screening paper and in the SPID is to refine the above screening methodology by convolving the initial plant logic equation with the hazard curve, rather than using a single element, to calculate the screening HCLPF. This will likely reduce the screening HCLPF capacity, but the fragilities of all required SSCs can at best be preliminary in the initial phase of quantifying the plant logic equation. While iterations can be done to improve the screening HCLPF with updated fragilities as the SPRA progresses, this can cause difficulties in efficiently performing the screening.

A second approach that is discussed here is whether a hazard curve can be truncated to determine a lower capacity-based screening HCLPF value. For two representative sites, a rock site and a soil site in the Central and Eastern United States (CEUS), for which the mean PGA hazard curves are plotted in Figure 1; Tables 2 and 3 show the results of convolving a single element with the full hazard and with the hazard curve truncated at varying levels. These tables list the screening HCLPF values developed using the SPID approach.

As shown in Figure 1, the full mean rock hazard curve was defined up to an acceleration of 7.3g. In Table 2, the results for screening HCLPF values corresponding to a CDF of 5E-7 per year, calculated for the entire hazard curve, for a truncated curve that excludes accelerations above 3g, and for a truncated curve at 1g, are 1.76g, 1.388g, and 0.731g, respectively. In this example, the alternate SPID criterion of 2.5 x GMRS PGA gives a screening HCLPF of about 1.4g, which is about the same as convolving the single element with the hazard curve truncated to exclude accelerations above 3g. Obviously, with a higher screening level, more explicit fragility calculations will need to be performed.

The full mean soil hazard curve (Figure 1) was defined up to 7.5g. The screening HCLPF values, shown in Table 3, calculated using the entire hazard curve and truncated curves to exclude accelerations above 1g and then above 0.5g corresponding to a CDF of 5E-7 per year; are 0.329g, 0.299g, and 0.239g, respectively. In this example, the alternate criterion of 2.5 x GMRS PGA gives a screening HCLPF of about 0.28g, which is slightly lower than the screening HCLPF based on convolution of a single element with the hazard curve truncated to exclude accelerations above 1g.

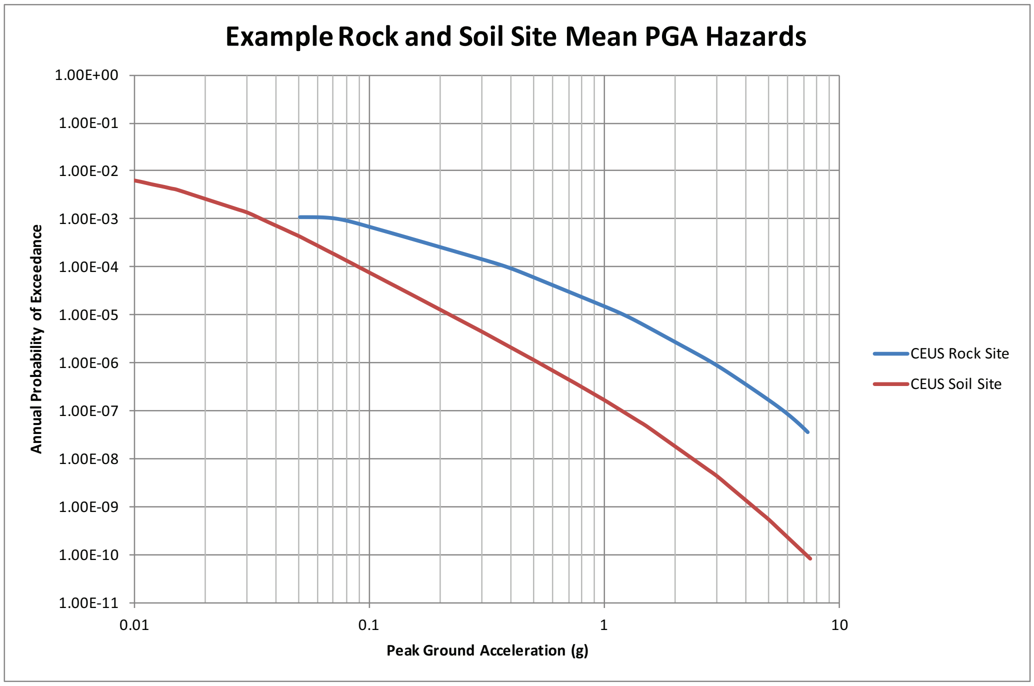


Figure 1 – Representative Rock Site and Soil Site Hazard Curves

Table 2 – Screening HCLPFs with a Rock-Site Hazard Curve

| Screening HCLPF (g) | SCDF Resulting from the Convolution of a GMRS with a Single Element (per year) | | |
|---|---|---|---|
| | Full Hazard Curve (up to 7.3g) | Hazard Curve Truncated at 3g | Hazard Curve Truncated at 1g |
| 0.700 | 5.73E-06 | 4.97E-06 | 6.45E-07 |
| 0.731 | 5.17E-06 | 4.41E-06 | **5.00E-07** |
| 0.800 | 4.17E-06 | 3.43E-06 | 2.88E-07 |
| 0.900 | 3.12E-06 | 2.41E-06 | 1.32E-07 |
| 1.000 | 2.39E-06 | 1.72E-06 | 6.22E-08 |
| 1.100 | 1.86E-06 | 1.24E-06 | 2.99E-08 |
| 1.200 | 1.48E-06 | 8.96E-07 | 1.48E-08 |
| 1.300 | 1.19E-06 | 6.55E-07 | 7.43E-09 |
| 1.388 | 9.92E-07 | **5.00E-07** | 4.14E-09 |
| 1.400 | 9.68E-07 | 4.81E-07 | 3.82E-09 |
| 1.500 | 7.96E-07 | 3.56E-07 | 2.00E-09 |
| 1.600 | 6.62E-07 | 2.64E-07 | 1.07E-09 |
| 1.700 | 5.54E-07 | 1.97E-07 | 5.80E-10 |
| 1.760 | **5.00E-07** | 1.84E-07 | 5.02E-10 |
| 1.800 | 4.67E-07 | 1.48E-07 | 3.20E-10 |

Table 3 – Screening HCLPFs with a Soil-Site Hazard Curve

| Screening HCLPF (g) | SCDF Resulting from the Convolution of a GMRS with a Single Element (per year) | | |
|---|---|---|---|
| | Full Hazard Curve (up to 7.5g) | Hazard Curve Truncated at 1g | Hazard to 0.5g |
| 0.200 | 1.91E-06 | 1.74E-06 | 1.07E-06 |
| 0.239 | 1.18E-06 | 1.02E-06 | **5.00E-07** |
| 0.250 | 1.05E-06 | 8.93E-07 | 4.09E-07 |
| 0.299 | 6.46E-07 | **5.00E-07** | 1.67E-07 |
| 0.300 | 6.40E-07 | 4.94E-07 | 1.64E-07 |
| 0.329 | **5.00E-07** | 3.61E-07 | 9.91E-08 |
| 0.350 | 4.20E-07 | 2.86E-07 | 6.84E-08 |
| 0.400 | 2.90E-07 | 1.71E-07 | 2.95E-08 |

It is recognized that truncating a hazard curve to establish a lower screening criterion is rigorously not appropriate because the risk contribution associated with the tail end of the hazard curve is not accounted for. However, if in the final SPRA, the SCDFs of important accident sequences and the entire plant are unaffected whether fragilities are convolved with a truncated hazard curve or with a full hazard curve, then it would also be appropriate to use the truncated hazard curve to develop the screening criterion. For instance, if the truncation for the example rock site hazard curve is done at 3.0g, it implies that the probability of failure ($P_F$) from the annual frequency of ground motions exceeding 3.0g should be negligible in the final logic model and this $P_F$ need not be added to the final calculated plant SCDF. To examine this, a parametric analysis was performed for a single simplified SPRA logic equation representing a nuclear plant that was based on the top 50 cutsets and contained 21 SSCs. For each – rock and soil hazard curve of Figure 1 - the model was quantified with the full curve and two truncated curves in three ways – the HCLPF capacities of ten risk-significant SSCs were assigned to be equal to the capacity-based HCLPF screening value successively for the two truncated hazard and the full hazard curves, and the capacities of other SSCs were kept low. Tables 4 and 5 show the SCDF results for the rock site and soil site hazard curves respectively.

Table 4 – Parametric Study Results for a Rock Site Hazard Curve

| **Table 4 – Parametric Study Results for Rock Site Hazard Curve**Case | Rock Site Hazard Curve | | |
|---|---|---|---|
| | Truncation Level | | |
| | 1.0g | 3.0g | Not Truncated (Full) |
| 10 SSCs at 0.731g HCLPF (1g Trunc.)<br>Other SSCs Low @ 0.35g HCLPF | 3.606E-05 | 7.718E-05 | 7.937E-05 |
| 10 SSCs at 1.388g HCLPF (3g Trunc.)<br>Other SSCs Low @ 0.35g HCLPF | 3.484E-05 | 6.212E-05 | 6.556E-05 |
| 10 SSCs at 1.760g HCLPF (Full)<br>Other SSCs Low @ 0.35g HCLPF | 3.481E-05 | 6.1250E-05 | 6.390E-05 |

Table 5 – Parametric Study Results for a Soil Site Hazard Curve

| Case | Soil Site Hazard Curve | | |
|---|---|---|---|
| | Truncation Level | | |
| | 0.5g | 1.0g | Not Truncated (Full) |
| 10 SSCs at 0.239g HCLPF (0.5g Trunc.)<br>Other SSCs Low @ 0.15g HCLPF | 7.145E-06 | 1.121E-05 | 1.181E-05 |
| 10 SSCs at 0.299g HCLPF (1g Trunc.)<br>Other SSCs Low @ 0.15g HCLPF | 6.372E-06 | 9.614E-06 | 1.025E-05 |
| 10 SSCs at 0.329g HCLPF (Full)<br>Other SSCs Low @ 0.15g HCLPF | 6.116E-06 | 9.0720E-06 | 9.841E-06 |

To get meaningful insights, an assumption made in this parametric study is that ten risk-significant SSCs could be screened; therefore, their capacities were assigned to be equal to the screening level HCLPF. Parametric studies with other assumptions were also made (such as assigning the HCLPF screening level to only 5 SSCs instead of 10) that indicated similar trends; therefore, they are not presented here. From Tables 4 and 5, the "correct" plant SCDFs from this example plant model are obtained when the screening level was derived with the full hazard curve and this full hazard curve was also used in the final quantification. Thus the correct SCDFs for the rock hazard curve from Table 4 and for the soil hazard curve from Table 5 are 6.39E-5 and 9.841E-6 per year respectively. From Table 4, it can be seen that a truncating the hazard curve at 3.0g gives about the same SCDF, but truncation at 1.0g reduces the SCDF by about 50%; therefore, truncation of the hazard curve at 3.0g is considered acceptable to obtain a capacity based screening criterion, but not at 1.0g. Similarly, for the soil hazard curve in Table 5, it can be seen that truncating the hazard curve at 1.0g is acceptable, and even if the screening HCLPF for the ten significant SSCs was used as 0.5g, the final SCDF remains about the same.

Therefore, as seen from Tables 4 and 5, lower capacity-based screening levels derived by truncating a hazard curve in an SPRA are acceptable for this example logic model. However, the validity of this approach must be verified at a later stage in the SPRA effort when the logic model is essentially complete and the screening HCLPF or fragility parameters have been included in the logic model quantification.

## GRADED APPROACH WHEN USING CAPACITY-BASED SCREENING

In a nuclear plant SPRA, calculating fragilities of a large number of SSCs because of a high capacity-based screening criterion may lead to significant resources being spent on fragility analyses only to find out later that many calculations were not needed or some SSCs had a negligible impact on the SCDF. To avoid spending resources on fragility calculations of SSCs that are not safety-significant, a graded or iterative approach is suggested. The steps in this iterative approach, which are outlined in Figure 2, are as follows:

1. Develop an initial SPRA logic model and assign either generic fragilities or rough fragilities estimated or judged from the existing plant calculations to the SSCs in this model. Perform an initial quantification of this model with the entire site-specific hazard curve and develop a list of say 50 SSCs that are top contributors to the seismic risk. This is an initial list of SSCs that are candidates for performing fragility analyses.

2. Develop a screening level HCLPF capacity using the 5E-7 per year criterion of the SPID using: (a) a hazard curve truncated to an appropriate level, based on the judgment of the SPRA analyst, convolved with a single element and (b) the truncated curve convolved with the initial plant logic equation. Use

the lower of these two values, or even a slightly lower HCLPF capacity, as the initial screening value.

3. From the list of top 50 SSCs, screen those SSCs that meet the capacity criterion developed in step 2, and perform initial fragility calculations for the remaining SSCs in that list. It is noted that the initial fragility calculations need not be very detailed; and the seismic margin method per EPRI NP-6041 SL can be used with past guidance (e.g. SPID) to assign reasonable variabilities.

4. Enter these fragilities in the SPRA model and quantify it again. Develop a list of say top 100 contributors to risk. Screen those SSCs that meet the capacity criterion of step 2, and perform initial fragility calculations for the remaining SSCs in this list.

5. Repeat the above process as often as needed until the initial fragility calculations of all non-screened SSCs that need to be entered in the SPRA model are prepared.

6. Enter these initial fragilities of SSCs and quantify the SPRA model. It is noted that for the SSCs that were screened, their fragility parameters that are entered in the logic model will be equivalent to the screening HCLPF capacity.

7. Quantify the model with the truncated hazard curve (same as step 2) and the full hazard curve and see if the results are about the same. If so, the iteration process is nearly complete and the fragility calculations of the most risk-significant SSCs should be improved and finalized using the separation of variable or the fragility method, as recommended by the SPID, and entered in the logic model for final quantification. If not, the screening criteria should be updated by increasing the truncation value of acceleration in the hazard curve. In this case, fragility calculations may be required for a few more SSCs. The process should continue until satisfactory results are obtained.

In the above steps, as the feedback from walkdowns and calculations is provided, the fragilities of SSCs that exceed the screening HCLPFs will be assigned the screening HCLPFs. For the SSCs that do not have HCLPFs greater than the screening HCLPF, the seismic review team will calculate a HCLPF based on the design and installation of the SSCs. These HCLPFs will be used to update the approximate fragilities used in the initial SPRA quantification.

Another improvement in developing the screening criterion can be made if the final plant SCDF is expected to be high, e.g., 1E-5 per year or higher. In this case, the 5E-7 CDF per year criterion of the SPID can be relaxed to a higher CDF value and the screening HCLPF value calculated using the same method as the SPID would be lower, thereby screening out more SSCs from explicit fragility calculation.

## CONCLUSIONS

A plant performing an SPRA should use all possible methods that are technically justified in performing the screening of SSCs. This will provide focus on performing fragility analyses of those SSCs that are potentially important to seismic risk. Calculation of fragilities of SSCs in a seismic PRA is perhaps the most resource intensive task in an SPRA and this paper provides efficiencies in screening of SSCs and discusses a graded approach for performing fragility calculations. The purpose is to reduce conservatisms in the capacity-based screening method and the approach described herein is to truncate the plant seismic hazard curve and validate that the truncation is appropriate. The broader goal is to conduct an SPRA that is realistic and avoids conservatisms in methods, criteria, and calculations. It is hoped that research and improvements in some of the concepts discussed here will continue with the objective of achieving seismic safety of nuclear power plants from SPRAs in a systematic and efficient manner.

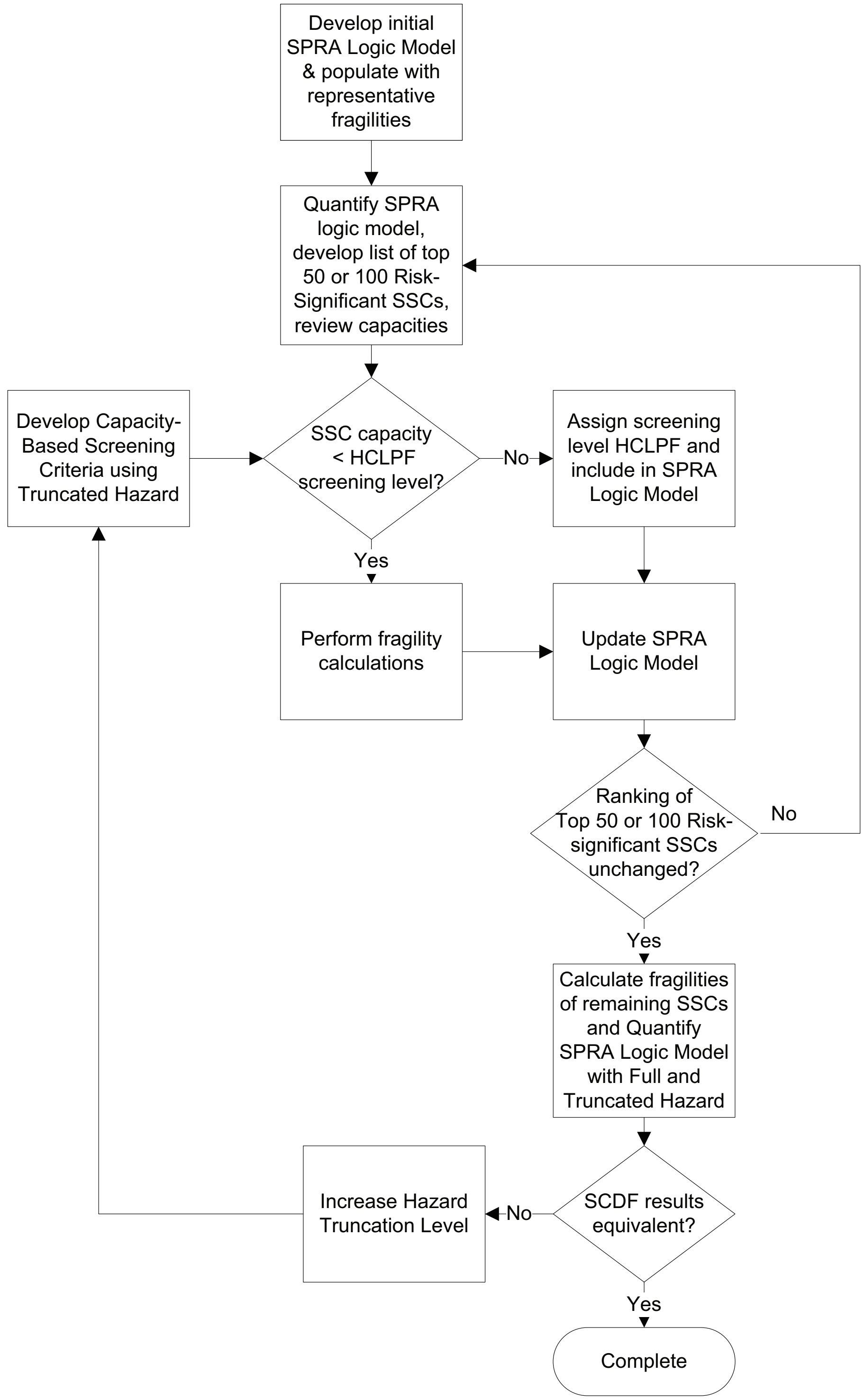


Figure 2 – Efficient Application of Capacity-Based Screening

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