Multi-Unit PSA Made Simple

Ensuring scalability of multi-unit nuclear power sites PSA calculations is a challenge. The complexity of the analysis grows exponentially with the number of units and events.

RiskSpectrum AB has developed a multi-unit PSA modelling approach that is based on separate PSA models for single units but combining them so that sequences of events can include several units.

Use Your Existing Models

RiskSpectrum Multi-Unit PSA (RSMU) fully employ and utilize existing PSA models and their analyses of individual nuclear power plant units. In RSMU the multi-unit scenarios are defined separately, by specifying initiating events affecting multiple units, failures of shared equipment, shared parts of safety systems, common cause failures of components across units, and possible human failure events with consequences exceeding a single unit.

One Multi-Unit Event Tree for All

The multi-unit events are arranged in a so-called multi-unit event tree, where the failure and success of the multi-unit events form sequences. At the end of each sequence, RSMU pass the information from the multi-unit event tree to the individual unit´s PSA models and quantify their conditional consequence probabilities, e.g., core damage, for each unit separately. Finally, RSMU compose the quantification results of the multi-unit sequences and individual units to the overall multi-unit failure frequency.

The approach has two main advantages:

- Use of the existing “standard” models
- Use of generated MCS lists

The use of the standard one-unit´s PSA models means that you can continue to maintain your single unit PSA model and there is no need to create a specific, separate PSA model to perform the multi-unit calculations. This is time saving when the model is set up – but, more importantly, it will reduce the effort to maintain the required PSA models.

Use the MCS-Lists

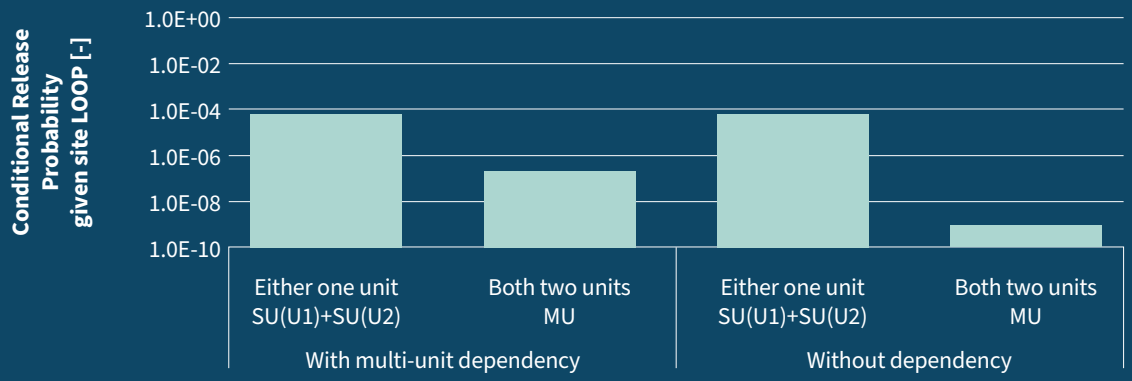
In general, you can assume that MCS lists for quantifying the impact of a multi-unit event shouldn’t be higher than the risk of a single unit failure. This means that a MCS list which is considered sufficient to represent a single unit failure must also be sufficient to represent a multi-unit failure.

This is assuming that a Core Damage Frequency (CDF), including two or more units are still relevant (and not negligible compared to the single unit CDF). If the concurrent CDF were much lower than the single unit CDF, such that the cutoff for the single unit MCS should be much lower to represent it relevantly, then the concurrent CDF will surely not be of interest (it would be negligible).

The use of existing MCS lists will also provide a sound basis for scalability of the approach. As the complexity of solving a fault tree increases with the number of events and operators, it is clear that a combination of two or more-unit PSA models will rapidly increase the complexity of the problem to be solved. Using pre-calculated MCS lists will not only provide fast means for calculation, but also that relevant cutoff levels (on a single unit basis) can be used and thereby provide high precision of the results within a reasonable calculation time.

What is the Impact?

In the figure below the conditional release probability given a loss of off-site power event is shown. Two large size PSA model were used simulating multi-unit CCFs and multi-unit human error dependencies. As expected, an increase in the multi-unit release probability can be seen when multi-unit dependency is considered. The only inputs necessary for the quantification were the MCS of the single units and a list of the multi-unit CCF events and human error dependencies.

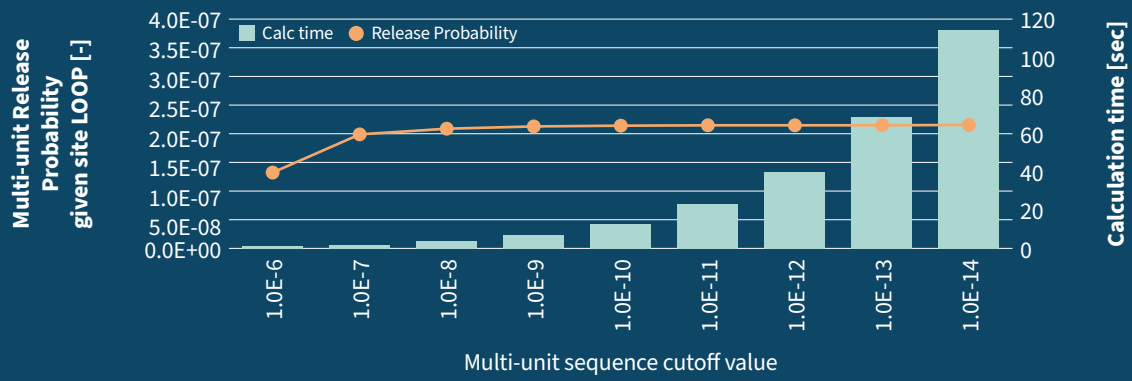


Managing Cut-Off and Calculation Time

Calculation time is always an issue when it comes to quantification of core damage or release frequencies using a PSA model. In the figure below the results of quantification of multi-unit release probability using a two-unit model with 30 multi-unit events given a loss of off-site power event.

Without cutoff, the number of multi-unit sequences generated by the multi-unit event tree would in the range of billions and calculation time will exceed days even if each sequence is calculated within fractions of seconds.

With multi-unit sequence cutoff, the quantification of trivial sequences that do not affect the overall results are prevented, and the calculation time is significantly reduced without degrading accuracy. The graph shows that the quantification results converging at cutoff values that can be handled within a minute. Achievement of short calculation times implies that more detailed MCS list as an input can used and an increase in accuracy as if we were using the original model instead of MCSs as inputs.



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