The Center for Risk and Reliability

Some Misconceptions About Multi-Unit PSAs

Presentation at the

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Working Group on Risk Assessment (WGRISK)

International Workshop on Status of Site Level PSA Developments

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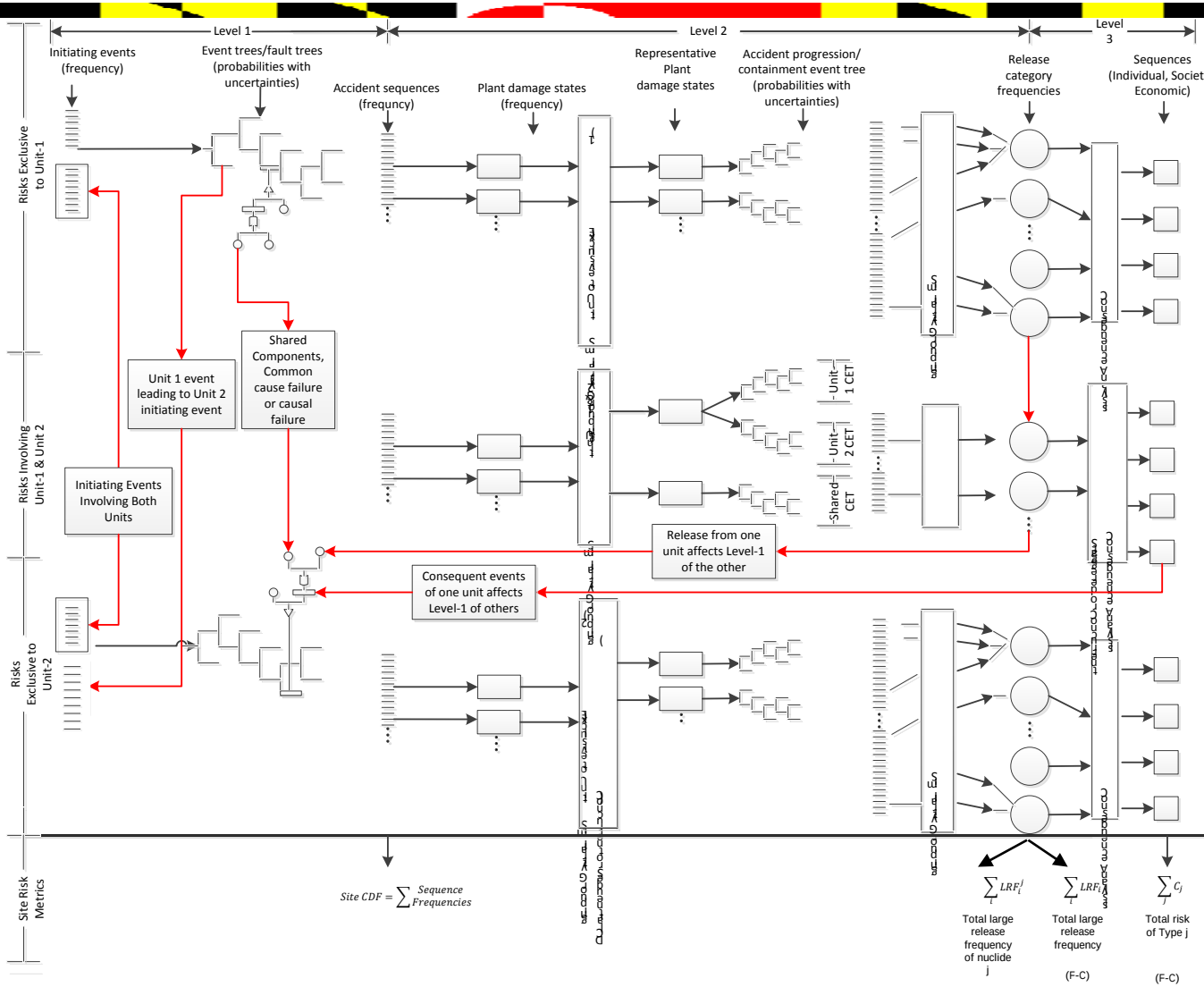
Outline

- Three Misconceptions about Calculation and Interpretation of MUPSA Risk Metrics
- Four Misconceptions about MUPSA Dependencies
- Two Misconceptions about MUPSA Consequence Analysis
- Conclusions

There is no order or importance ranking to these misconceptions. I chose them intuitively from two dozens or so misconceptions that I have compiled. Some have acknowledge them and may consider them as “assumptions” in their analysis

Recall Quick Overview of MUPSA



Misconceptions about Calculation and Interpretation of MUPSA Risk Metrics

Misconception 1

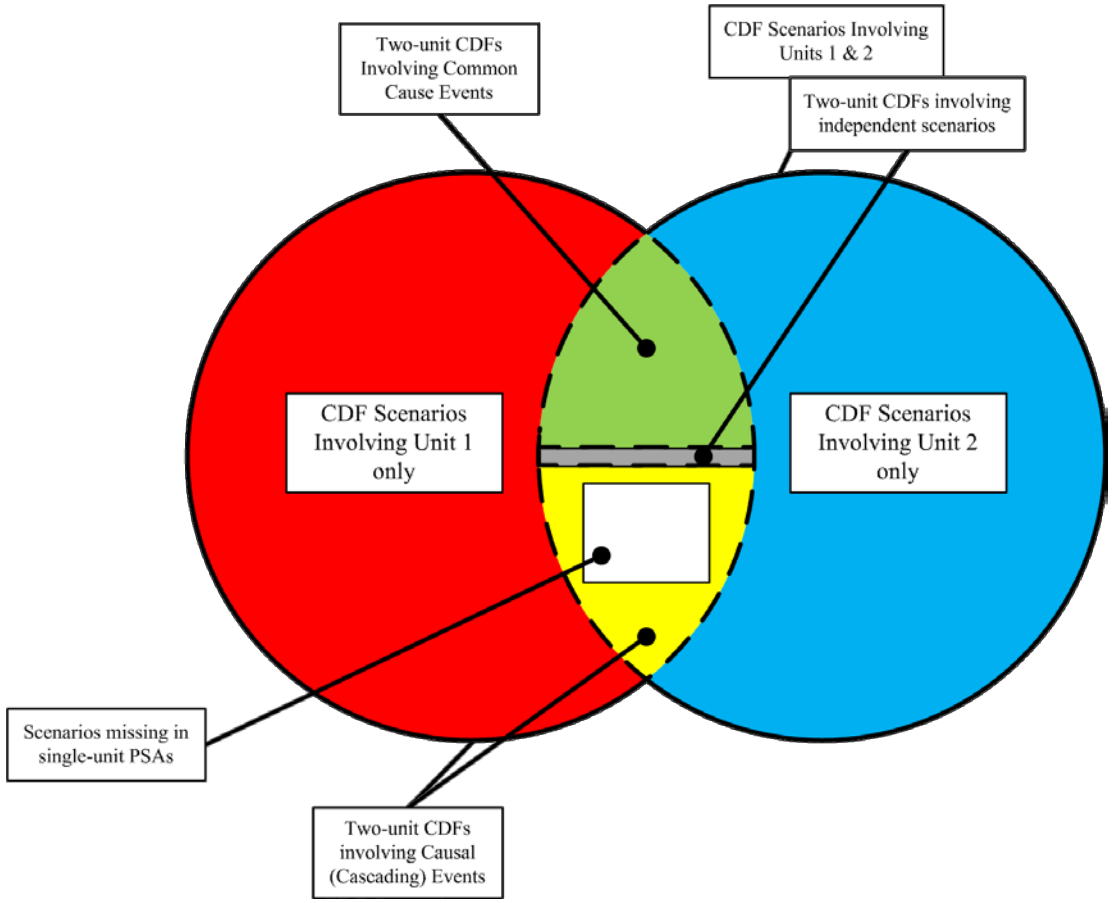
The upper bound of the site risk metric is the sum of individual unit risk metrics

- This belief apparently comes from the notion that probability of the union of multiple non-mutually exclusive random events is:

  $\Pr(E_1 \cup E_2 \cup \cdots \cup E_n) < \Pr(E_1) + \Pr(E_2) + \cdots + \Pr(En).$

- This is true only if these are marginal probabilities of events E_i
- Most if not all single-unit PSAs don't find the "marginal" CDF
- Single-unit PSAs often lack causal scenarios initiated from one unit (due to say, room flooding or missiles generated) and migrated to another unit
- Traditional we don't model causal events in the single-unit PSAs, so that it can be considered a "marginal" risk metric (unless if you add them later)
- Only "forward" sequence of events are considered!
- So, the true multi-unit risk could be larger than the sum of unit risk metrics

Misconception 1 (Cont.)

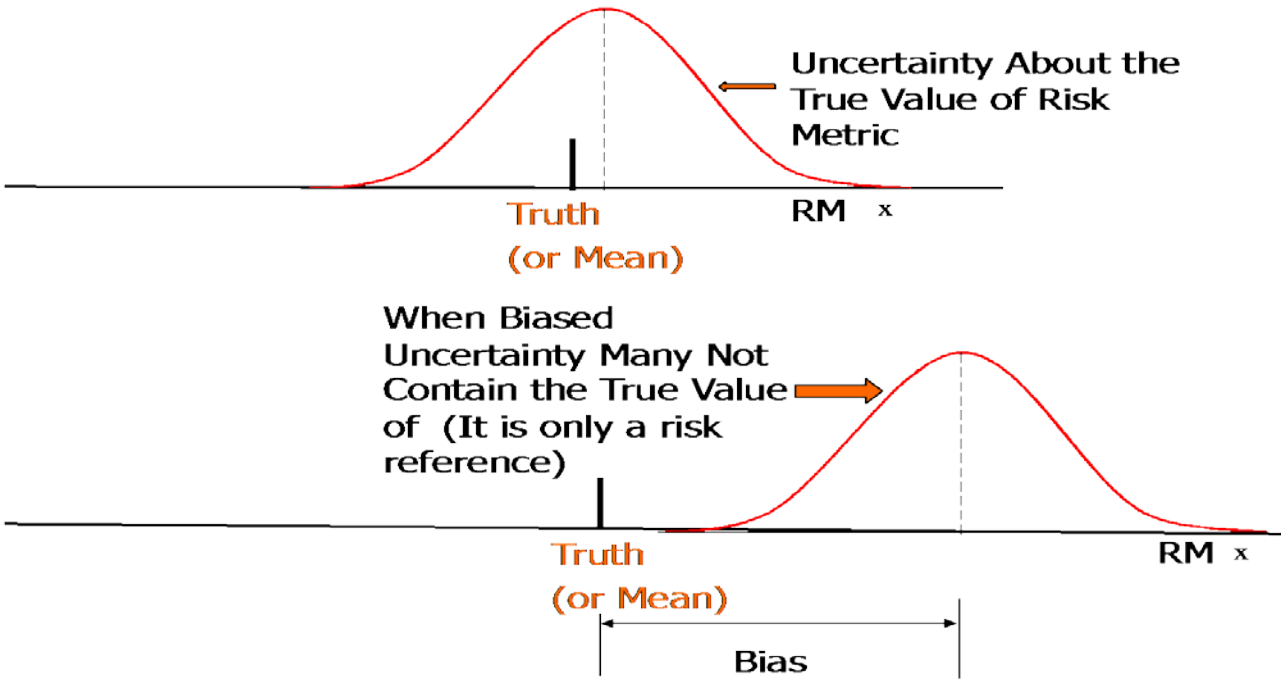


Misconception 2

Bias in risk metrics is captured by the uncertainty estimation and has no implications on risk information

- Bias is not uncertainty, only the amount (or degree) of bias in PSA results is uncertain
- Bias is a deliberate skewness in the risk event or results, whereas uncertainty is lack of knowledge or information about the event
- Bias exists in all PSA results (not just MUPSAs) and rooted in:
  - Conservatism
  - Approximation
  - Scope
  - Simplification
  - Quality

Misconception 2 (Cont.)

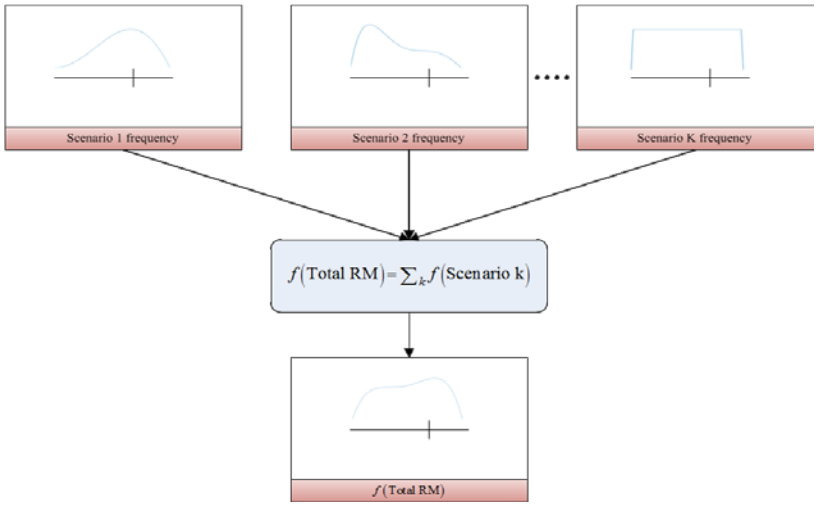


- When biased, the risk metric should be corrected to show the range and distribution within which the true metric resides
- Corrections needed if multiple risk metrics are to be aggregated
- Biased risk metric in risk-informed applications could mask and thus distort important risk contributors!

Misconception 3

Risk metrics from multiple hazards, reactor units, and radiological sources should not be aggregated

- Evidently this view is because of implicitly recognizing bias in the results of various risk metrics
- If no biases are involved in the scenarios leading to the same outcome, mean risks can simply summed up



Misconception 3 (Cont.)

- If risk metrics are biased due to sources in "Misconception 2," presently we lack methods for unbiasing and then aggregating
- One method is to elicit *k* experts for the amount of bias in metric *i* :

$$\frac{f_i^{ub}}{f_i^b} = F_i$$

$$F_i = \left(\prod_{k=1}^{n} F_i^k\right)^{1/n} \Rightarrow \quad f_i^{ub} = F_i \times f_i^b$$

$$L(F_i|m_i, s_i) = \prod_{k=1}^{n} \frac{1}{\sqrt{2\pi}} \frac{1}{F_i^k s_i} e^{-\frac{\left[\ln\left(F_i^k\right) - m_i\right]^2}{2s_i^2}}$$ For equally qualified experts

$$L(F_i|m_i, s_i) = \frac{1}{\tau} \prod_{k=1}^{n} \frac{1}{\sqrt{2\pi}} \frac{1}{F_i^k s_i} e^{-\frac{\left[\left(ln\left(F_i^k\right)\right)^{w_k} - m_i\right]^2}{2s_i^2}}, where, \sum_{k=1}^{n} w_k = 1$$ For unequal experts

$$\pi_1\left(m_i, s_i | \text{ all } F_i^k\right) = \frac{L(F_i|m_i, s_i)\pi_0(m_i, s_i)}{\iint_{m_i, s_i} L(F_i|m_i, s_i)\pi_0(m_i, s_i) dm_i ds_i} \Rightarrow \quad f_i^{ub} = F_i \times f_i^b$$

Misconceptions about MUPSA Dependencies

Misconception 4

Single-unit parametric values for CCF models are applicable to multi-unit common cause events

- Inter-unit dependencies are weaker than intra-unit dependencies because of less proximity and tighter coupling factors
- Our earlier works using the U.S. Licensee Event Reports (LERs) show inter-unit hardware dependencies have a mean conditional failure probability of 0.028.
- Whereas β factor intra-unit dependencies for hardware units reported in NUREG/CR-6268 are in the range of 0.03-0.22
- Use of intra-unit common cause parametric estimates adds bias into the results with possible masking effect
- Other countries (Korea and Japan) have done work in inter-unit common cause analysis, but more data analysis would be needed in this direction

Misconception 5

Human errors are independent across multiple units/radiological sources

- This is driven by the view that operating teams of units are different
- Pre-initiator actions and post-initiator recovery actions rely on similarly developed procedures, training and sometimes shared personnel
- Control rooms at times use different corners of a shared contiguous area
- Our analysis of the U.S. LER data shows that the mean conditional probability that an operator will make a similar pre-initiator error in a second unit is 0.032 (slighter larger than hardware inter-unit dependencies!)
- Human interactions and the prevailing common socio-economic, political and safety culture also affect human dependencies
- Common cause human errors should be considered in MUPSAs

Misconception 6.

Only common cause dependencies among similar or identical equipment across multiple units are important

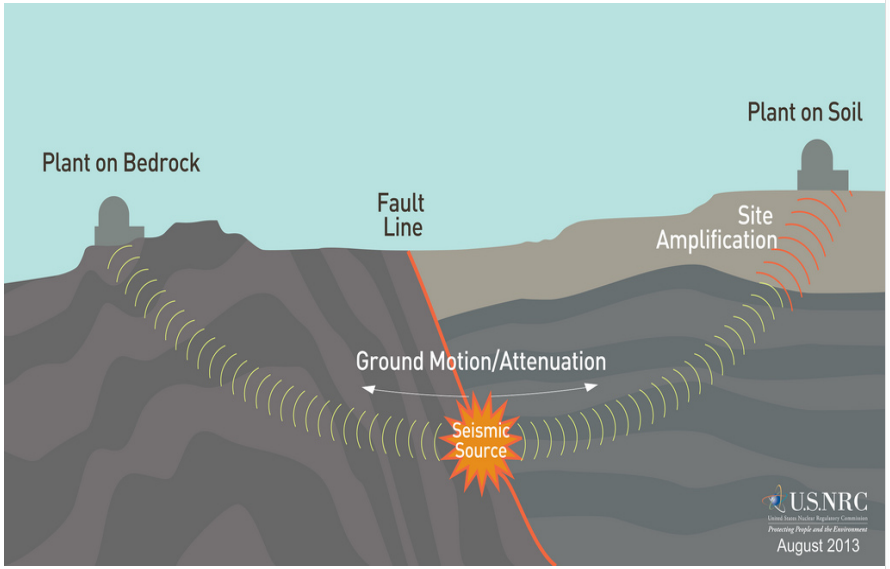
- Dependencies rooted in proximity, organizational factors or human error may also lead to a class of dependencies called causal or cascading sequences
- A mishap (e.g., pipe break or fire) in a shared area between multiple units could cascade into diverse failures or initiating events in the other units
- An external event may cause different responses in terms of SSC failures, initiating events and human actions in the other units
- Deficient fuel cooling resulted in overheating of the fuel, enabled rapid oxidation and generation of large amounts of hydrogen, ultimately led to the explosion/destruction of the reactor buildings at Fukushima units 1 and 3
- Hydrogen leaked into the reactor buildings from the containment vessel head when the pressure in the containment rose significantly (Dependency that Schroer named “proximity”)

Misconception 7

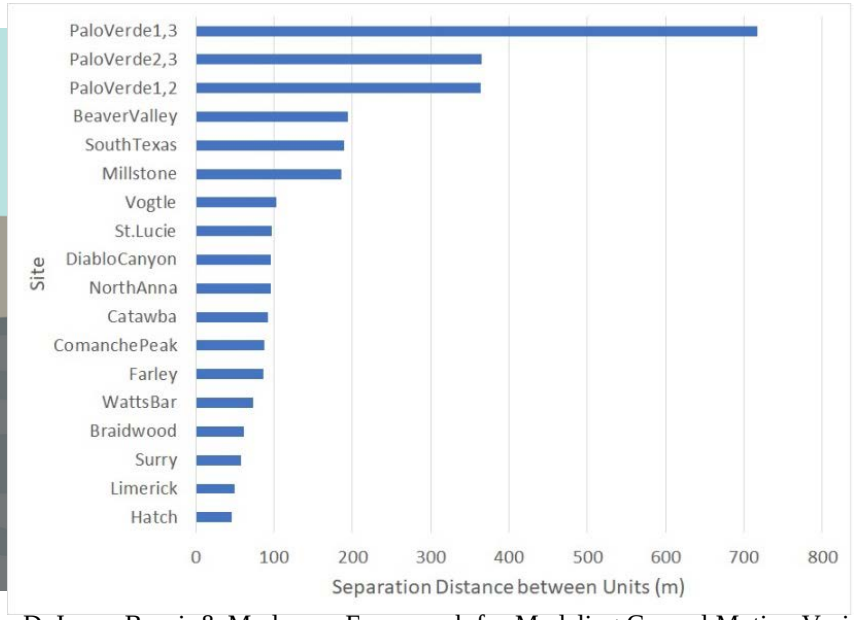
Identical probabilistic seismic hazard frequency and use of fully dependent or fully independent seismic fragilities are appropriate for seismic-MUPSA

- Perfect correlation (zero variability) assumption is not accurate
- At a large-scale site, due to various factors such as geological and topological differences, spatial variability is expected in the ground motion and site response at different locations
- Soil deposits tend to act as “filters” to seismic waves by attenuating (or de-amplifying) motion at certain spectral frequencies and amplifying it at others
- Soil conditions often vary over short distances, so ground motion can vary significantly within a small area

Misconception 7 (Cont.)



Seismic Wave from source to a Site

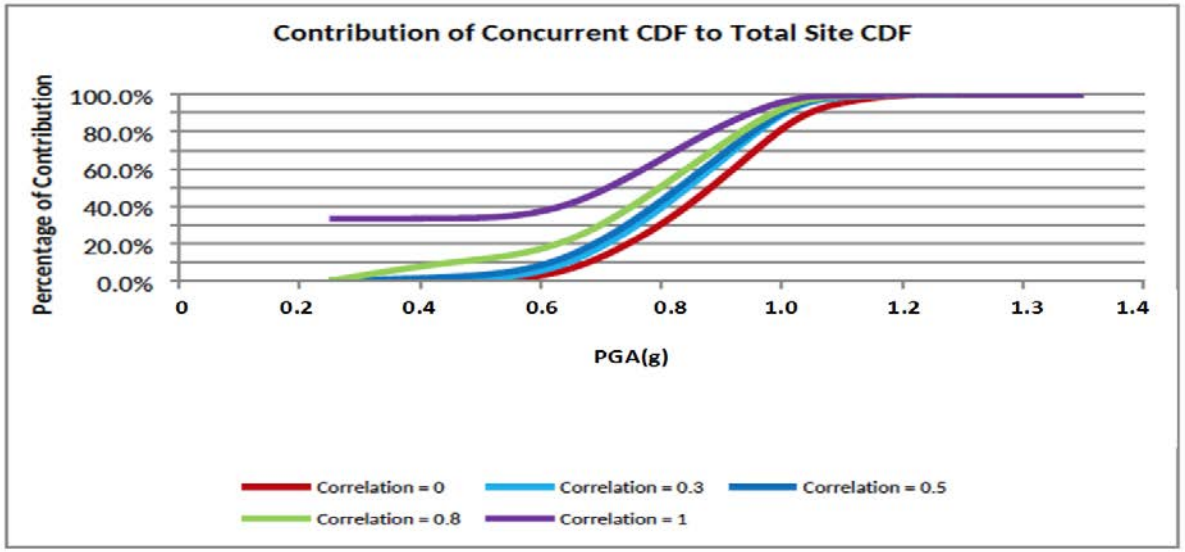


DeJesus, Bensi, & Modarres, Framework for Modeling Ground Motion Variability at a Nuclear Power Plant Site for Use in a Seismic MUPRA. PSAM14, Sept. 2018

- Current research by DeJesus, Bensi and Modarres shows progress in quantifying ground motion variability over short distances
- A paper on this topic would be shortly presented at the PSAM14 Conference in UCLA in September 2018

Misconception 7 (Cont.)

- The β-factor model is NOT equal to the correlation coefficient used in SSMRPs
- The popular method of Reed-McCann proposed in1985 to characterize the correlation in fragilities, and ultimately quantify the joint fragility by an analytical approach (also proposed in NUREG/CR-7237) is good but sometimes very limited
- Seismic response and effect of the seismic capacity of SSCs on site safety is shown to be more important in the midrange intervals of PGA based on a more appropriate copula approach to modeling correlations



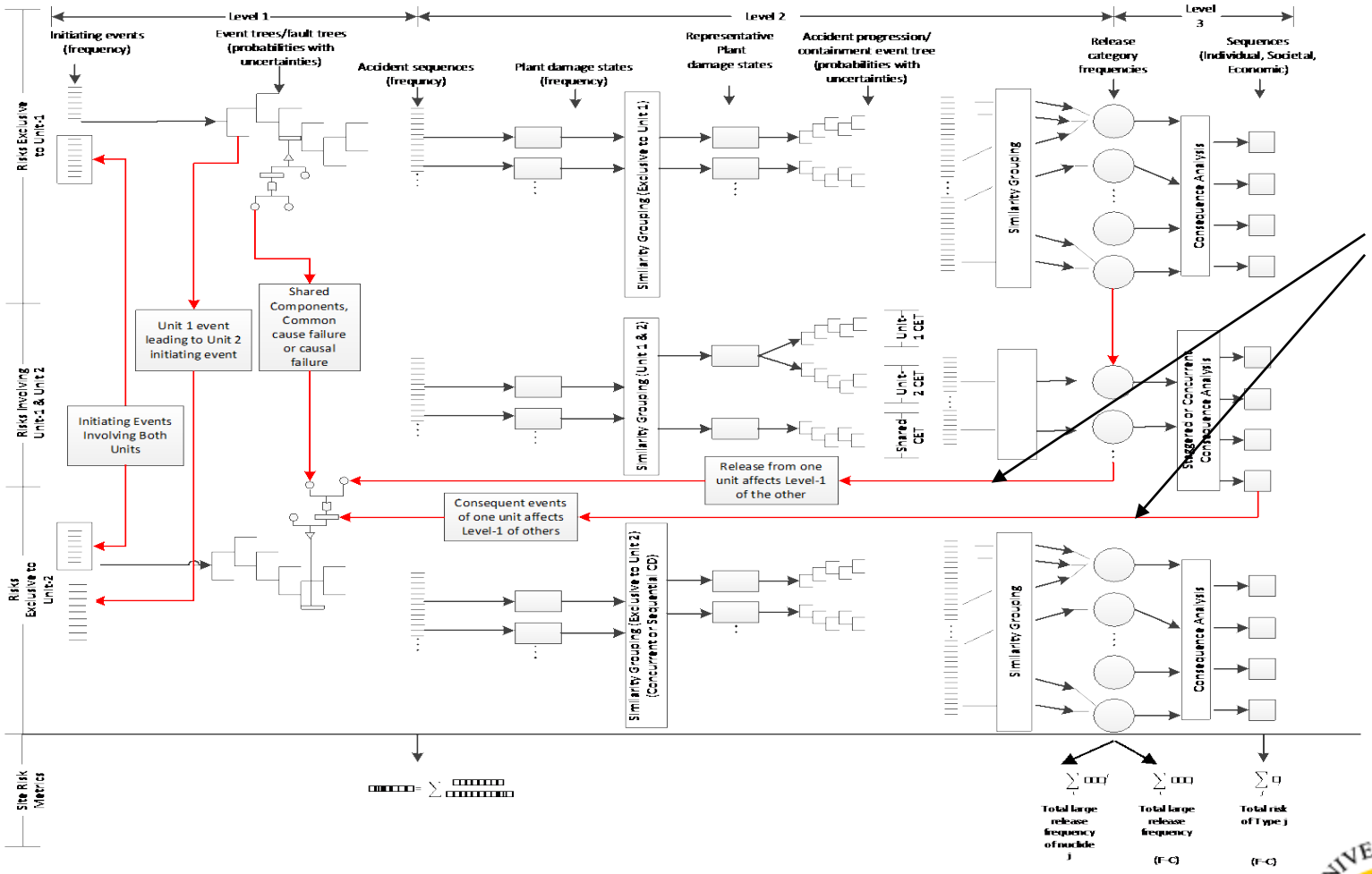
Relative contribution of concurrent CDF to total site CDF as a function of PGA for various fragility correlations

Misconception 8

The concept of accident progression levels 1-3 mindset continue to be valid for multi-unit PSA

- There is possibility of ”feedback” loops in MUPSAs which does not exist in single unit PSAs so the concept of independent Levels 1-3 PSA is a weaker proposition for MUPSAs
- Site contamination may reduce availability or effectiveness of recovery actions, personnel and equipment
- Consumption of limited site resources, such as fire brigade, emergency power, and FLEX equipment for a level-2 or level-3 response, may affect another unit experiencing a level-1 accident progression
- Human reliability in a unit experiencing a level-1 accident (due to human stress performance shaping factor) may be influenced by the severity of the conditions in another unit experiencing level-2 or a major release.

Misconception 8 (Cont.)



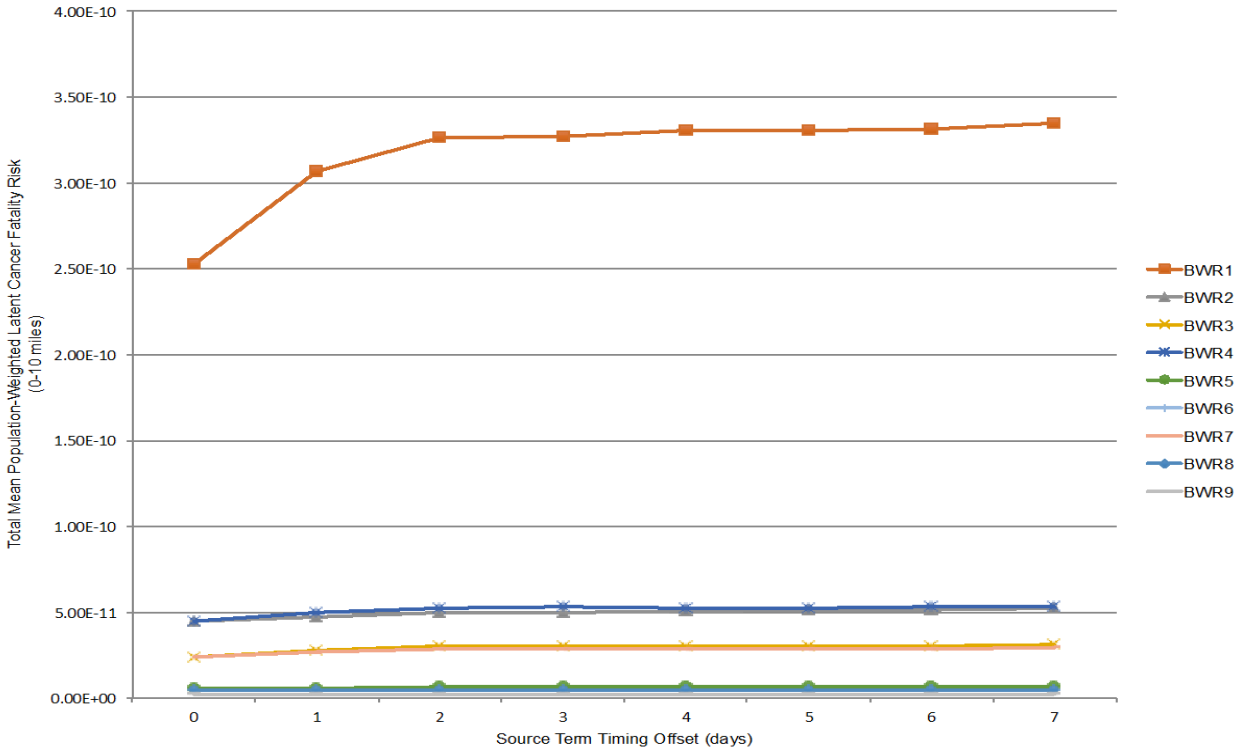
Note These feedbacks

Misconception 9

The worst site risk corresponds to simultaneous release from the site's radiological sources

- This assumption is mostly true BUT not always!
- Depending on the nature of the accident, timing of the release, condition of evacuation and weather conditions, it is possible that concurrent releases pose a less significant consequence than staggered ones
- Many factors, including nonlinear dose-consequence could play a role
- Hudson shows that variation in the timing offset between nine different release scenarios from multiple units does not significantly impact latent cancer fatality risk for a representative two-unit boiling-water reactor site
- Counter-intuitively, a mild increasing trend is observed attributed to the latent cancers arising from long-term exposures during the recovery

Misconception 9 (Cont.)



Source: Hudson, D. W., & Modarres, M. (2017). Multiunit Accident Contributions to Quantitative Health Objectives: A Safety Goal Policy Analysis. Nuclear Technology, 197(3), 227-247

Conclusions

- MUPSA is an important consideration to identify and risk-inform site-level contributors and decisions, BUT misconceptions can generate bias in results that could mask important contributors
- It is important to model all dependencies among the site's units and other radiological sources such as the spent fuel pool
- It is important to consider differences between single- and multi-unit PSAs that impact site-level risk information and decisions
- There are differences between dependencies at the single-unit (structural-level), multi-unit (site-level) and multi-site (regional-level) in PSAs that "band aid solutions" might not work best
- While nine misconceptions are chosen in this presentation, there are more not covered in this paper (albeit possibly less important)

Thank you