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# Insights on Aggregating Risk of Hazards with Varying Levels of Uncertainties

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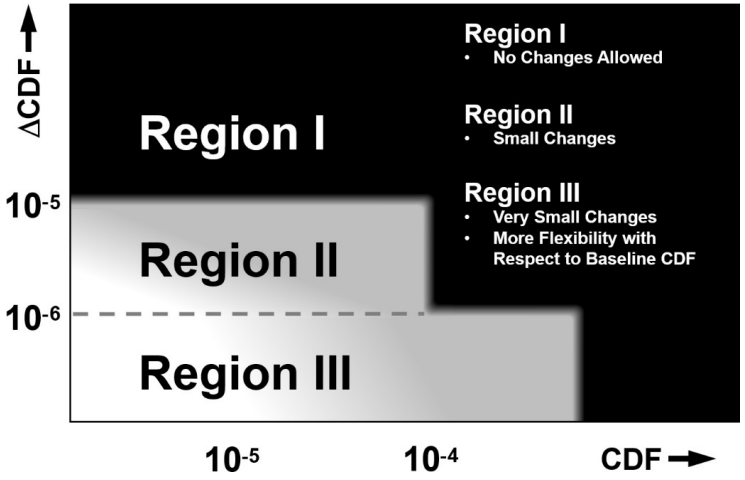
# Introduction

- A study was performed to develop insights from adding contributions of different hazard groups to the total core damage frequency (CDF) expressed in the form of distribution functions.
- The study focused on three hazard types: internal events, seismic hazards, and internal fire hazards.
- The problem of combining CDF distributions derived with analyses of different quality was not examined, nor the problem where the distribution represents different uncertainty types.

# Background

- Regulatory Guide 1.174, provides general guidance concerning analysis of the risk associated with proposed changes in plant design and operation.
- Relevant hazard groups should be addressed in risk-informed applications.
- CDF mean values are used in the comparison of the PSA results to the acceptance guidelines.
- Differences in the nature, quality, and completeness of uncertainties in the supporting hazard analyses led to questions on the appropriateness of simple addition of mean values to estimate the total risk.

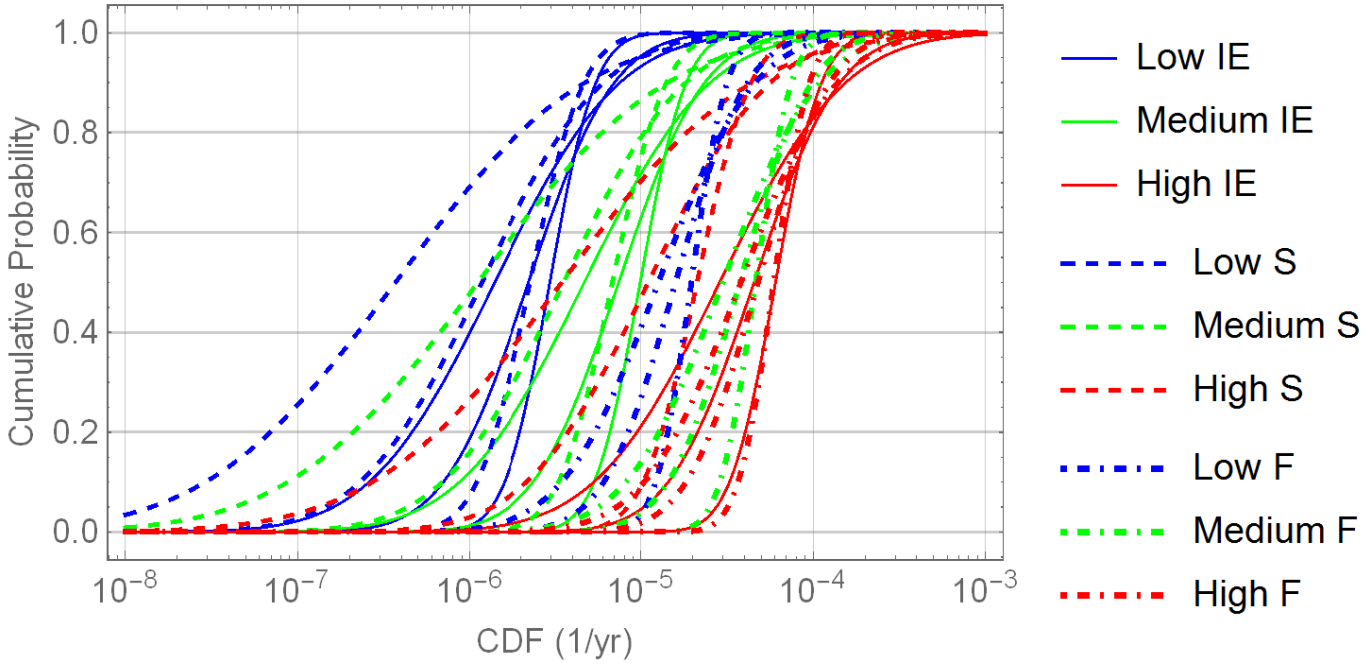


# Technical Approach

- Reference distributions were proposed for the CDF associated with internal, seismic, and fire initiating events.
  - Reference distributions were constructed by considering CDF point estimates for internal events and seismic initiating events in GI-199 Safety/Risk Assessment, and internal fire CDF values obtained from literature.
  - In general, log-scale distributions were determined to be most appropriate for characterizing CDF uncertainty.
  - Point estimates were combined with values of the log-standard deviation, $L\sigma$ [=Ln(GSD)], inferred from a few studies that are available in the literature, and assuming lognormal distributions, to define reference CDF distributions.

# Representative distributions for internal events, seismic, and internal fire CDF

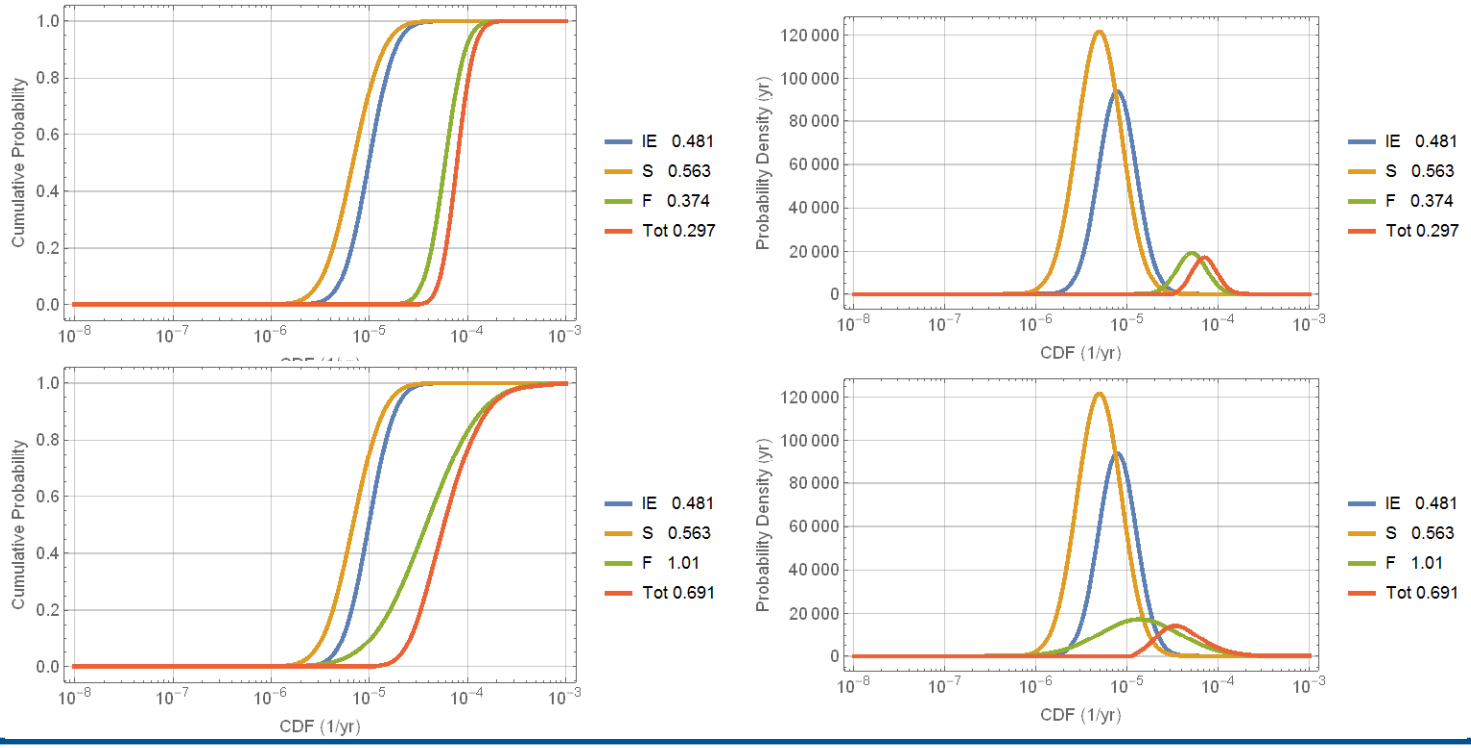
| | Internal Events | | | Seismic Events | | | Internal Fire Events | | |
|---|---|---|---|---|---|---|---|---|---|
| | Lμ | Lσ | Mean | Lμ | Lσ | Mean | Lμ | Lσ | Mean |
| Low | -12.73 | 0.48 | 3.32E-6 | -13.00 | 0.56 | 2.65E-6 | -10.84 | 0.37 | 2.1E-5 |
| | -13.02 | 0.90 | 3.32E-6 | -13.65 | 1.27 | 2.65E-6 | -11.05 | 0.75 | 2.1E-5 |
| | -13.48 | 1.31 | 3.32E-6 | -14.81 | 1.99 | 2.65E-6 | -11.28 | 1.01 | 2.1E-5 |
| Medium | -11.53 | 0.48 | 1.11E-5 | -11.90 | 0.56 | 7.99E-6 | -9.98 | 0.37 | 4.97E-5 |
| | -11.81 | 0.90 | 1.11E-5 | -12.55 | 1.27 | 7.99E-6 | -10.19 | 0.75 | 4.97E-5 |
| | -12.27 | 1.31 | 1.11E-5 | -13.71 | 1.99 | 7.99E-6 | -10.42 | 1.01 | 4.97E-5 |
| High | -9.71 | 0.48 | 6.79E-5 | -10.76 | 0.56 | 2.48E-5 | -9.74 | 0.37 | 6.33E-5 |
| | -10.00 | 0.90 | 6.79E-5 | -11.42 | 1.27 | 2.48E-5 | -9.95 | 0.75 | 6.33E-5 |
| | -10.46 | 1.31 | 6.79E-5 | -12.57 | 1.99 | 2.48E-5 | -10.18 | 1.01 | 6.33E-5 |



# Technical Approach (Cont.)

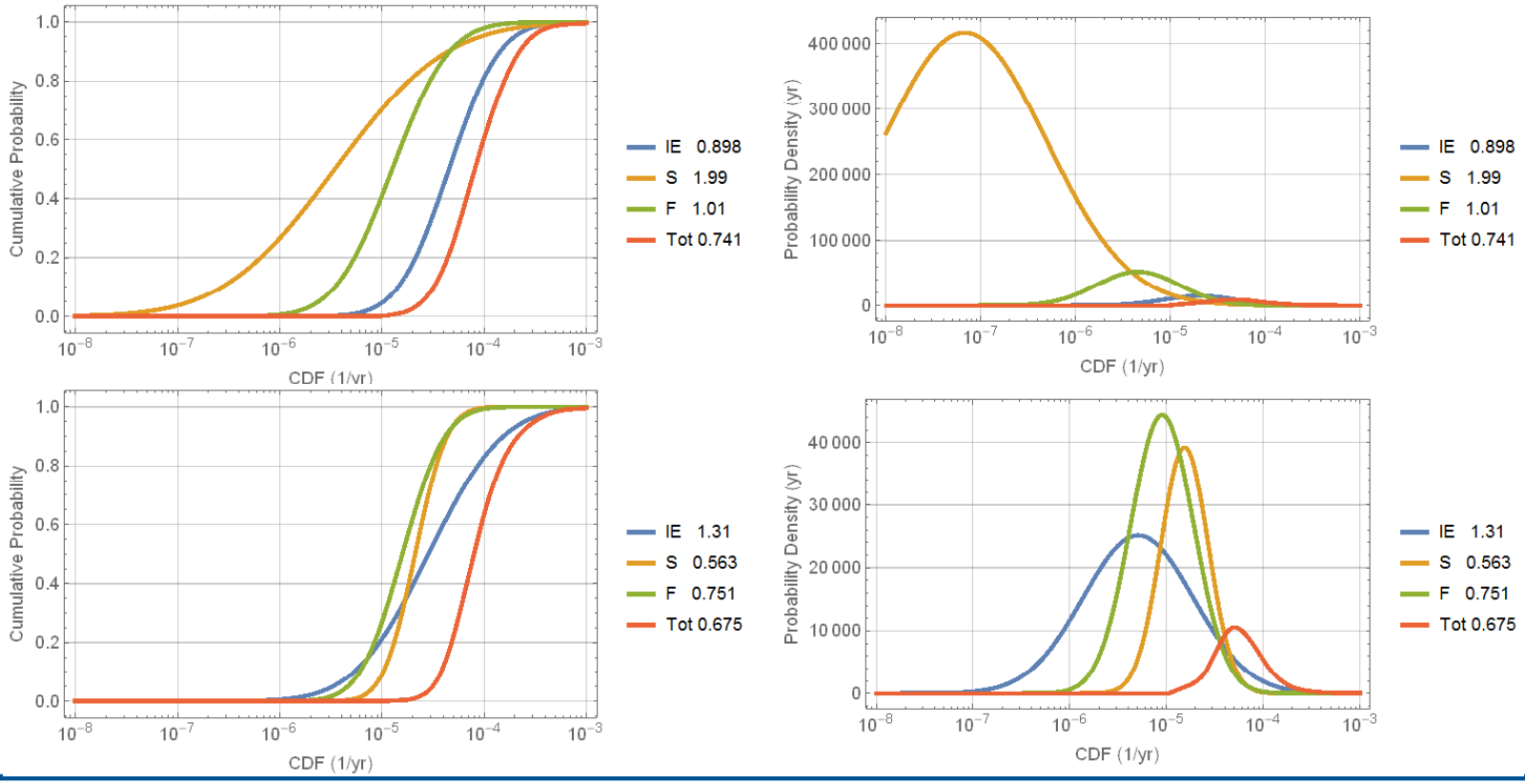
- Reference distributions were used to generate combinations to compute CDF sums. They were used to generate a reasonable range of CDF values and explore features of distributions arising by adding CDF values.

*Examples of cases of the medium (IE), medium (S), high (F) combination*

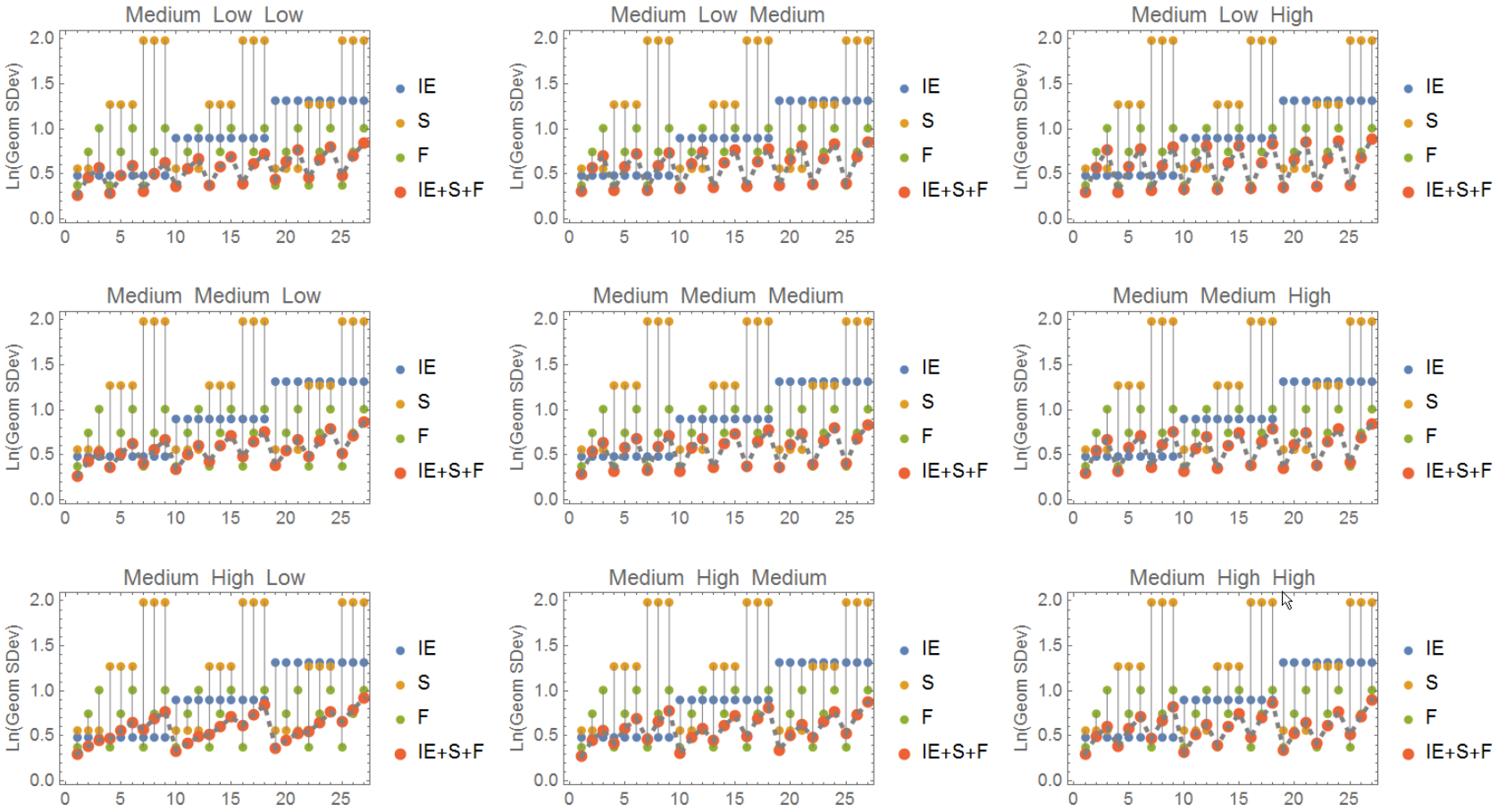


# Technical Approach (Cont.)

- *Examples of cases of the medium (IE), medium (S), high (F) combination*



# Example of Medium internal events reference CDF
## Values of Lσ of the internal events (IE), seismic (S), internal fire (F), and sum (IE+S+F) CDF distributions for 729 combinations of reference distributions



# Observations

- log-mean, $L\mu$ [=Ln(GM)], for the sum, $L\mu$(sum), is always greater than the individual $L\mu$ values of the reference distributions [i.e., $L\mu$(sum) > Max{$L\mu$'s of the individual distributions}].
- $L\sigma$(sum) is bounded by the $L\sigma$ values of the individual reference distributions [i.e., $L\sigma$(sum) ≤ Max{$L\sigma$'s of the individual distributions}], and often is close to the $L\sigma$ value of the dominant term of the sum.
- Together, these two observations mean that the distribution of the CDF sum is shifted to the right with respect to the individual reference distributions, but the spread of the distribution of the sum is constrained by the $L\sigma$'s of the reference CDF distributions, and the spread of the combined CDF is often narrower that the individual CDFs.

# Observations (Cont.)

- Values of *Lσ* of the reference CDF distributions were varied while keeping the means constant. The distribution of the sum exhibited less variation in spread compared to the changes applied to the reference distributions.
- No anomaly was identified in the concept of adding CDFs to derive a distribution for the sum. Tails of the distribution of the sum are constrained by the spread of individual hazard distributions.
- If the metric of performance is a mean value, it is mathematically valid to add mean CDF values of individual hazards to compute a total mean.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