CRA risk analysis

Methods for including uncertainty in seismic PSA

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Background

- Earthquakes – we model them as random events with uncertainty in intensity
- We want to study their effect on NPP safety and other risk significant infrastructure
- Traditionally we use a conservative approach in the design of structures and systems
- Seismic PSA used to quantify residual risk to NPP and other plant from seismic events
- Important to estimate uncertainty in S-PSA results

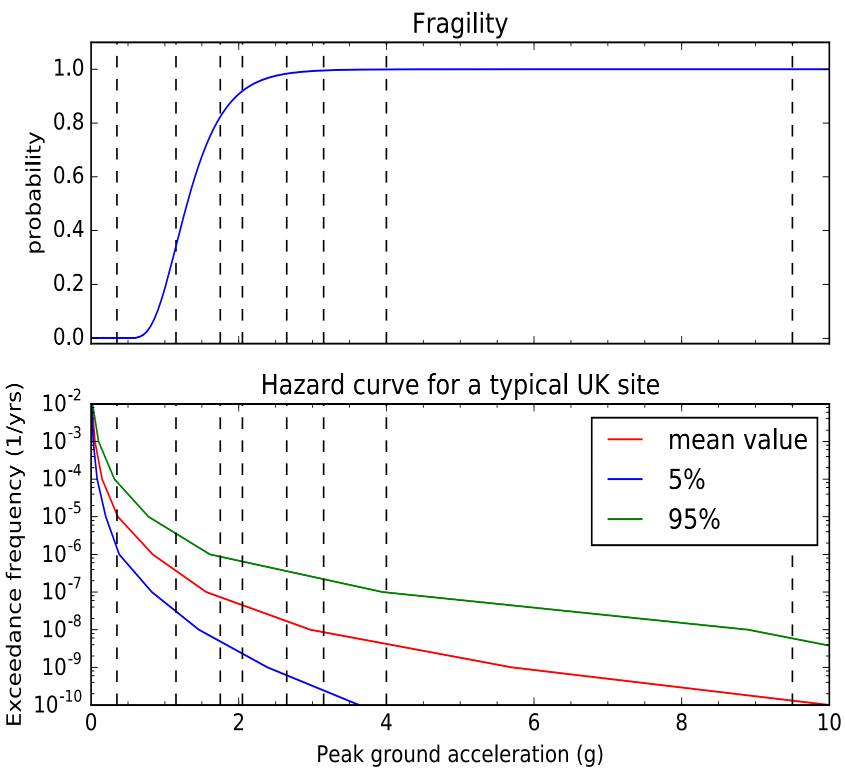
Main components for seismic risk assessments

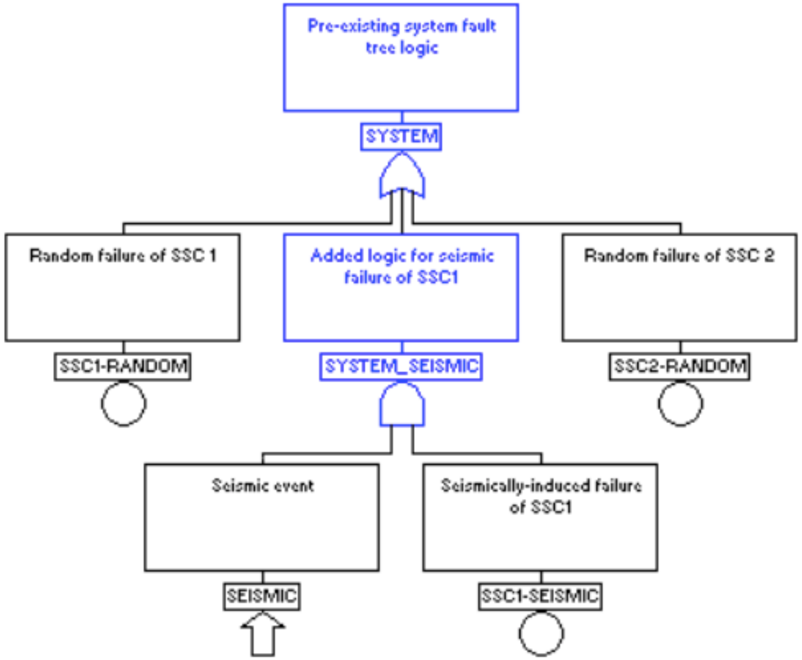
- Frequency of core melt or large release is combination of two components
  - Frequency of having earthquake of size X
  - Probability of core melt/large release for earthquake of size X

$$F(E_X)P(CM|E_X) = CMF_X$$

$$\text{frequency of earthquake of size X} \cdot \text{probability of core melt given earthquake of size X}$$
$$= \text{Frequency of core melt due to earthquake of size X}$$

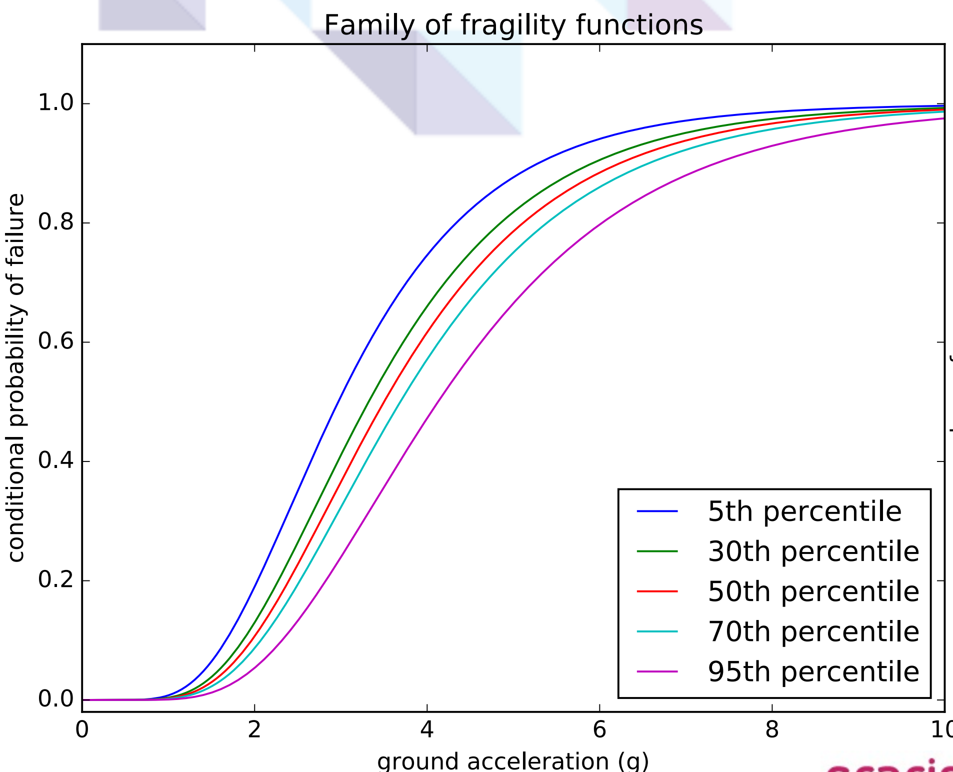
State of the art seismic PSA

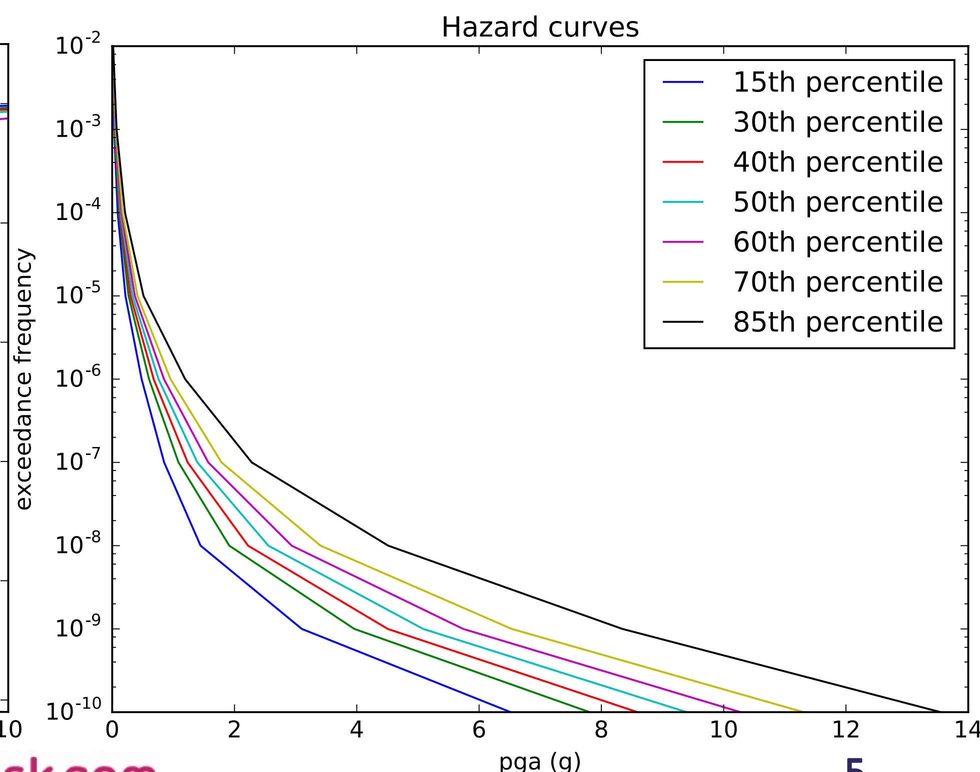




Uncertainty quantification

- Seismic hazard curves and the fragility curves are uncertain – we represent uncertainty data like this:





Uncertainty quantification

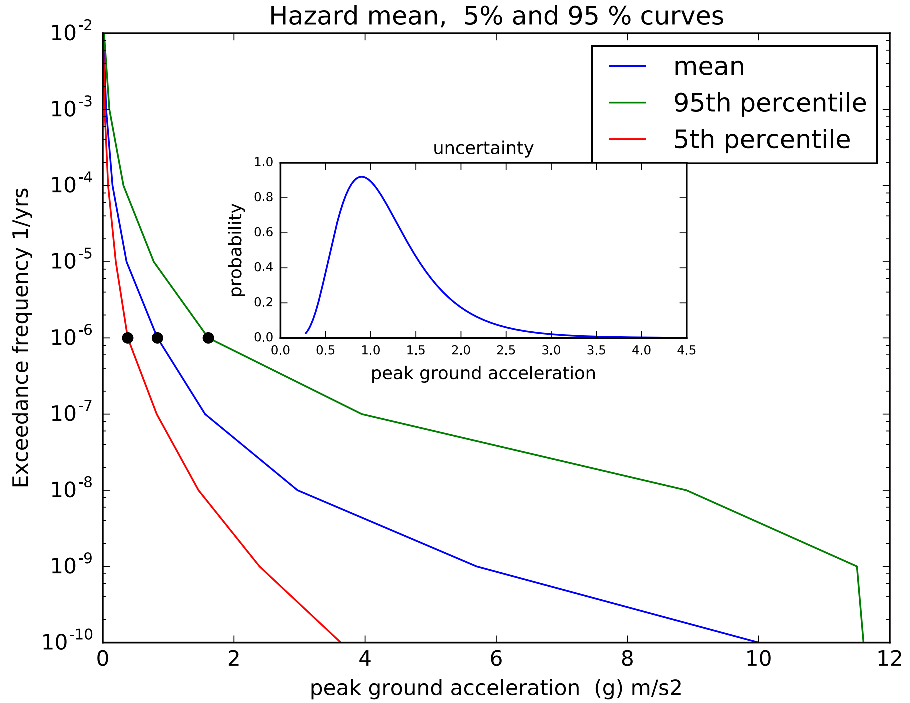
- Uncertainties in seismic fragility of plant components for a given seismic magnitude (pga) exist due mainly to:
  - imperfect knowledge of component response
  - uncertainties in the seismic motion time history associated with a specified pga
- Uncertainties also exist in the magnitude (pga) of a seismic event of a specified return frequency especially for events with a high return frequency
- Both types of uncertainty need to be taken into account in S-PSA

PhD objective

- Develop an approximate method of including uncertainty in S-PSA which can be run in a single MC iteration
- Benchmark it against exact method – which we called ‘complete’ MC method
- Test both methods on a simplified PSA model
- Compare the results with a point value evaluation (neglecting uncertainties in pga magnitude & component fragilities)

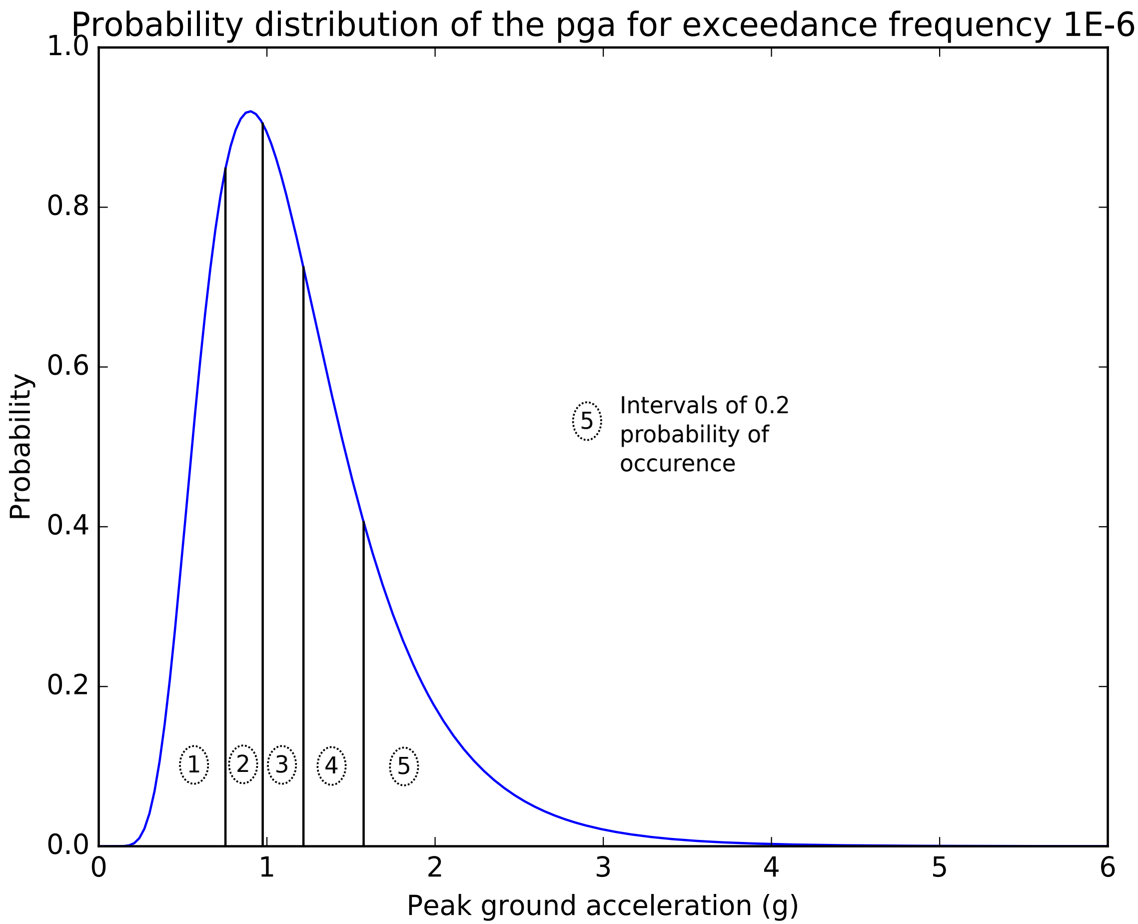
What we did – hazard data

- First step we selected a return frequency from the hazard curve – we assume the pga uncertainty associated with a given return frequency is log-normal



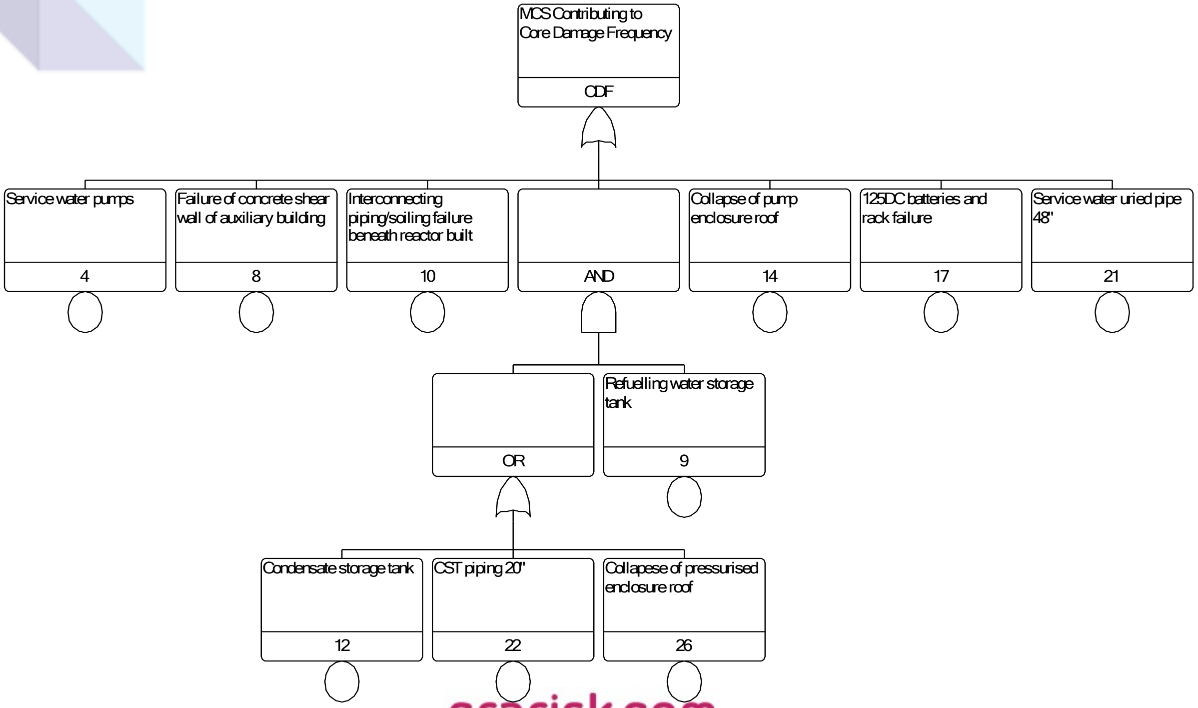
What we did – seismic uncertainty division

- Now we divide the pga uncertainty distribution into 5 intervals of equal area = 0.2 and find the mid-point pga for each interval.



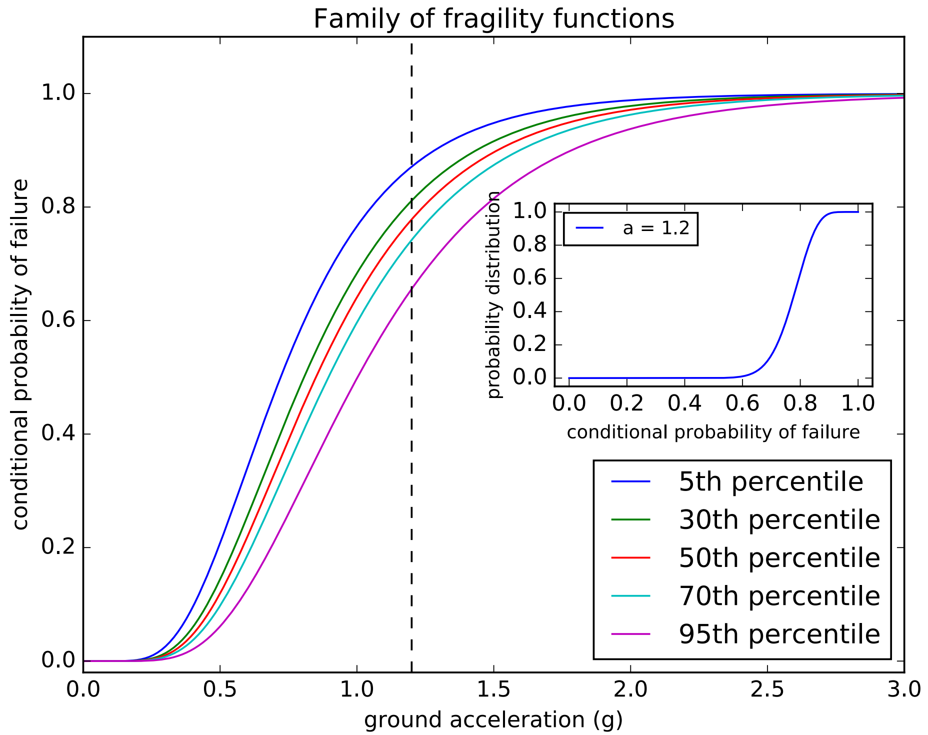
What we did – system model

- We used a simplified seismic fault tree for Zion NPP to compare methods – fault tree structure & fragility data were available from literature



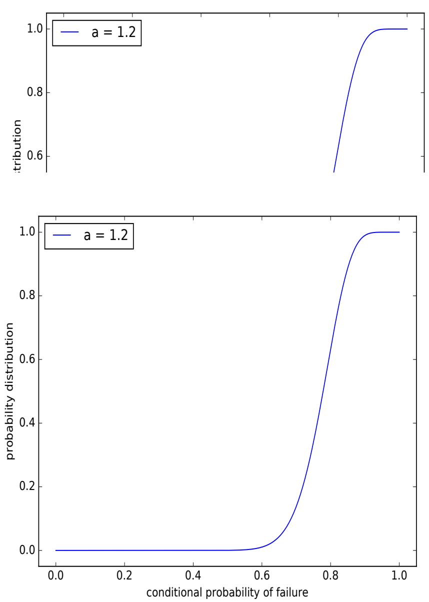
What we did - component failure probability

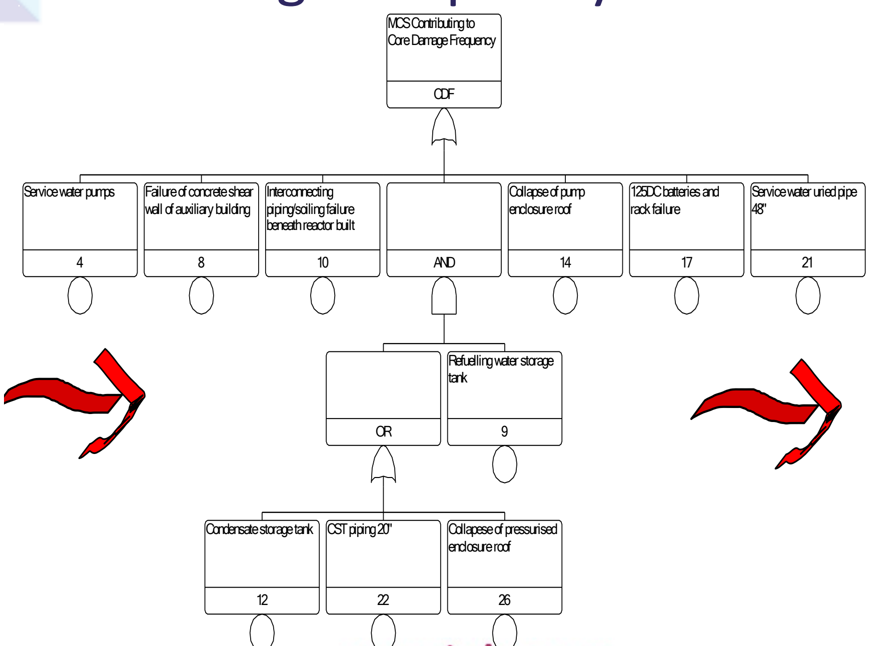
- If we look at the distribution of the conditional probability of failure of each component – fixing the acceleration we get this

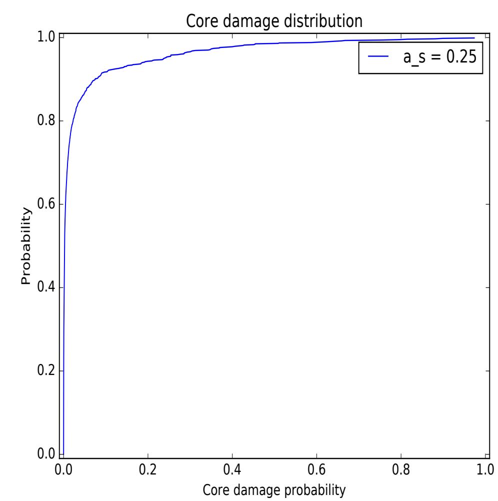


What we did – MC to solve the fault tree

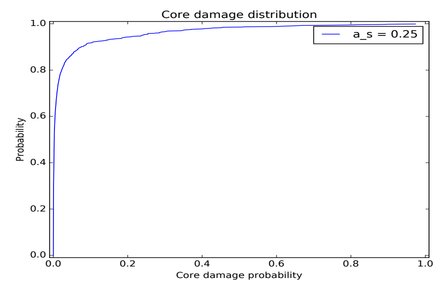
- For each mid pga value find the cdf of the core damage frequency by MC analysis using the cdfs of the failure probabilities of each of the 10 components. Result is 5 cdfs for core damage frequency







What we did – combination of core melt probabilities



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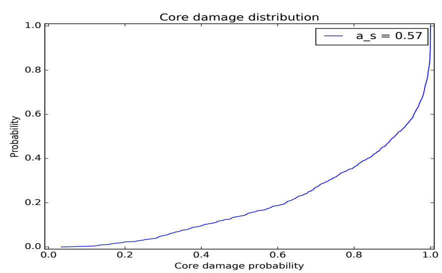

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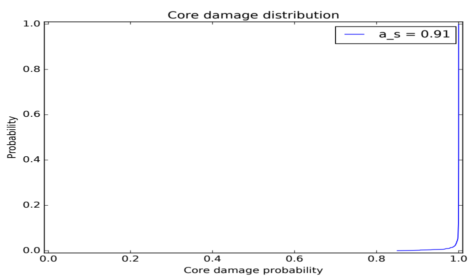

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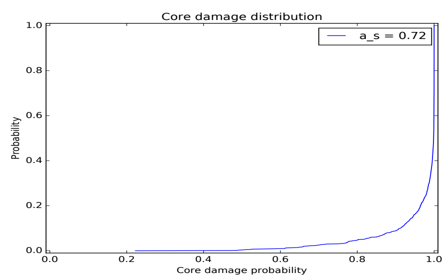

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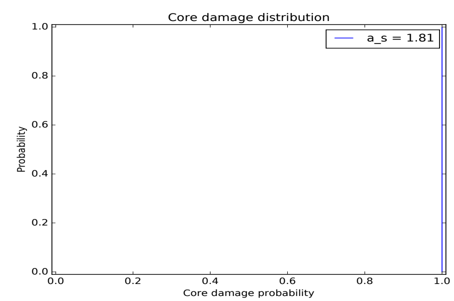
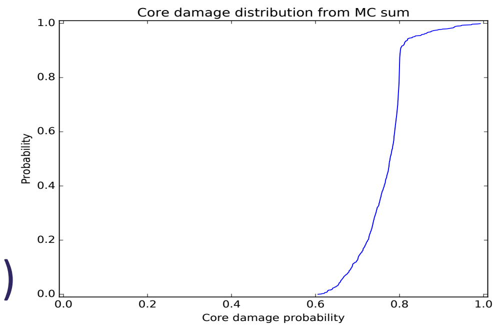
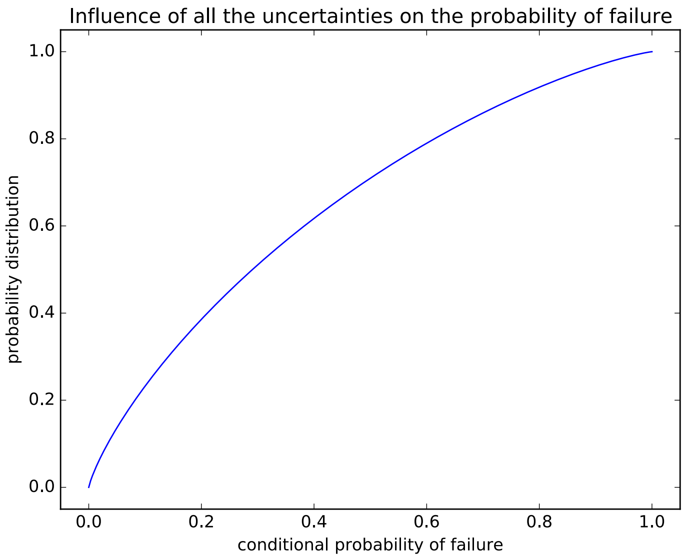


- We use a further Monte Carlo step to find the cdf of the overall core melt frequency (due to all possible pga values) by combining the 5 different cdfs, each assigned a weight of 0.2
- We repeat the process for other return frequencies



What we did – simplified method overview

- We developed an approximate method which the cdfs of the component failure probabilities are modified to include the pga uncertainties. Allows cdf of core melt probability to be found in one Monte Carlo run.
- Drawback – dependency between basic events is introduced leading to errors

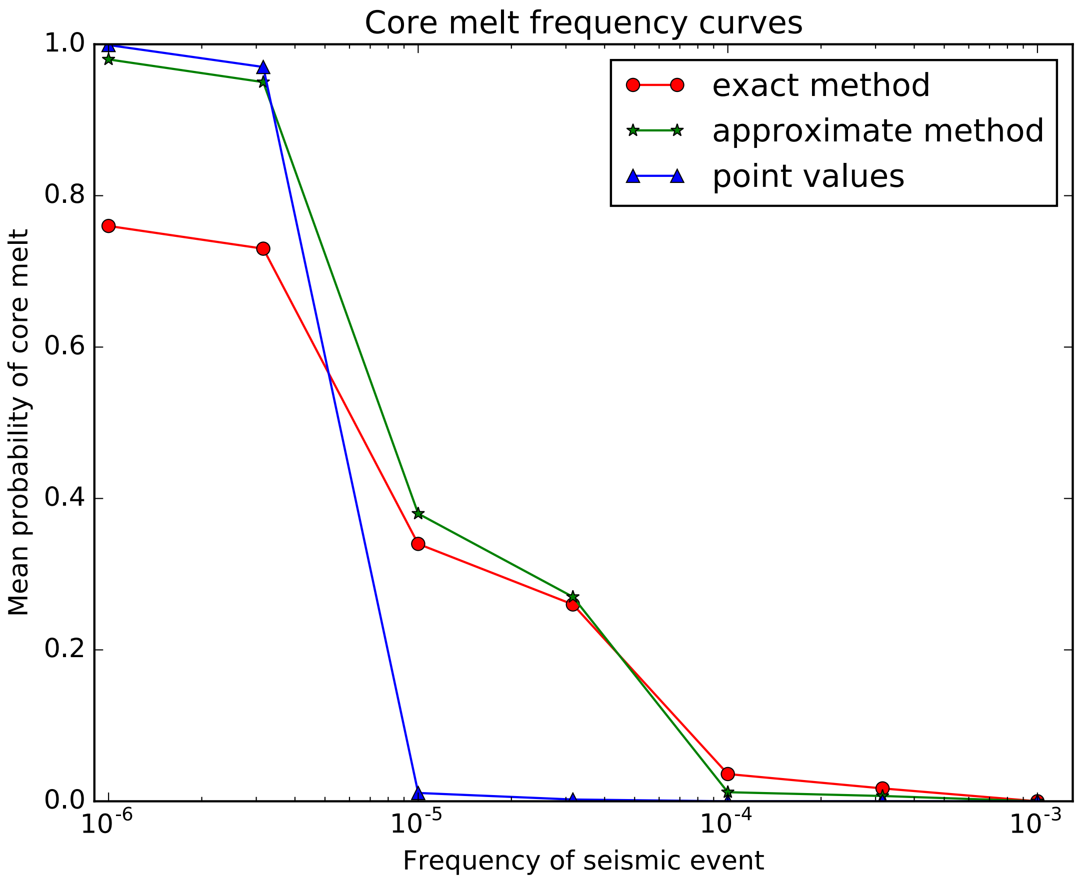


Results – table with mean values

Mean Core Melt probabilities			
Frequencies	First exact method	Second 'quick' method	Point values
1.00E-03	0	1.50E-06	0
1.00E-04	0.035	0.017	5.887E-08
1.00E-05	0.34	0.38	0.011
1.00E-06	0.77	0.98	0.999

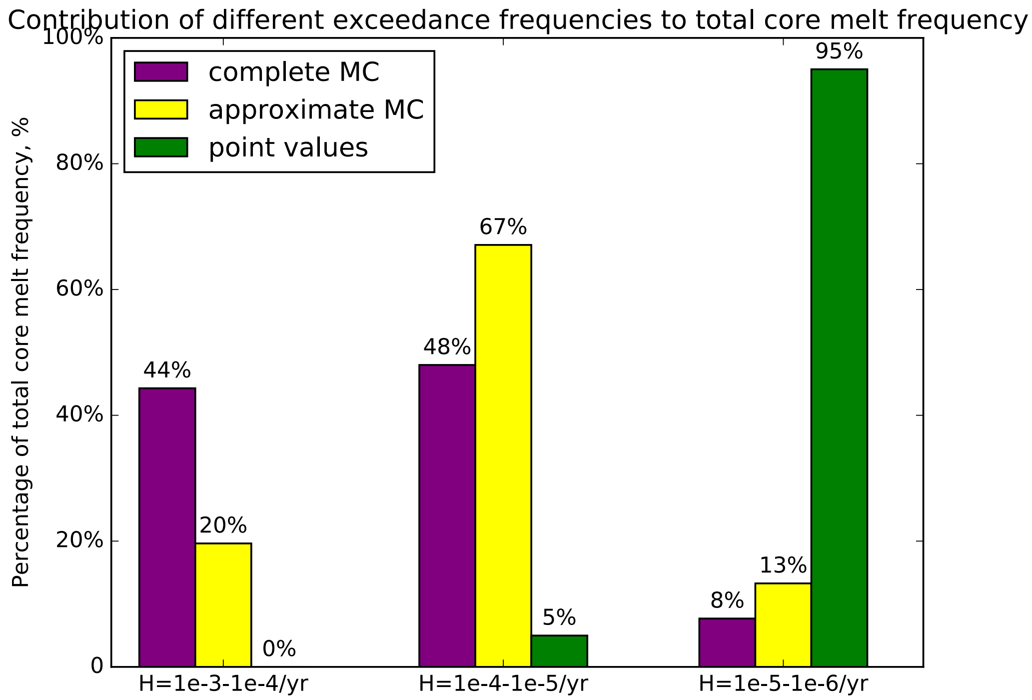
Total core melt frequency - obtained by integration with three methods		
First exact method	Second 'quick' method	Point values
2.65E-05	2.22E-05	3.87E-06

Results - core damage frequency curves

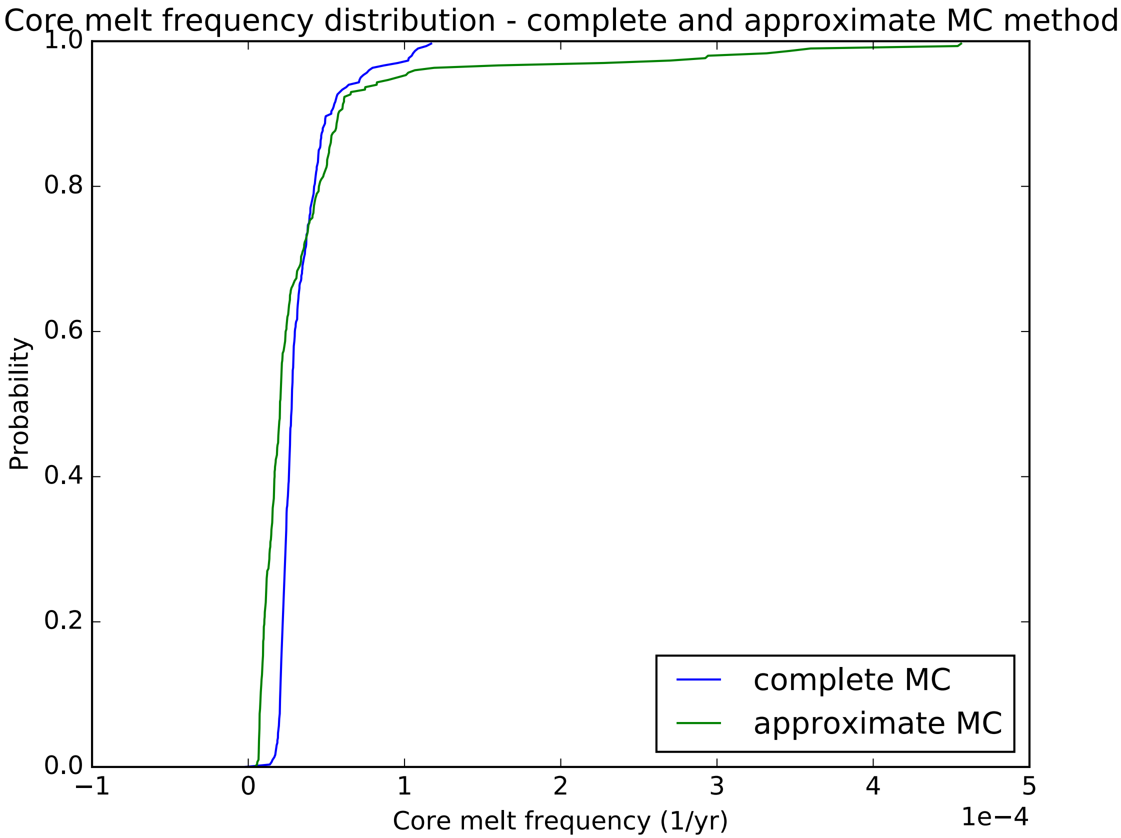


Results – contributions to total core melt frequency

- Contributions of different seismic events to total seismic core melt frequency



Core melt frequency distribution



Conclusions

- For simplified NPP example – taking into account uncertainties in component fragilities & pga increases mean seismic core melt frequency by x10 compared with S-PSA ignoring uncertainty
- Rigorously including uncertainties in S-PSA is complex – requires multiple MC calculations. Alternative simplified approach is proposed in our study – gives reasonable results for test problem
- Simplified method introduces errors due to dependency between basic events as basic events linked to seismic magnitude.
- Work should be expanded to a more realistic PSA model –including operator actions, random failures etc. Can we automate ‘exact method?’ Is approximate method good enough?

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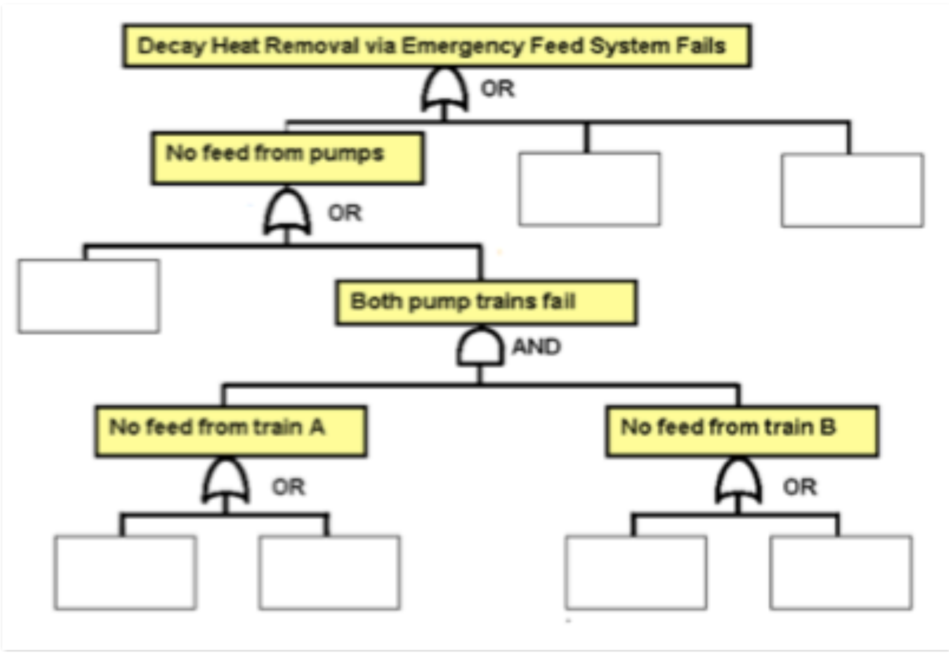
System modelling

- Fault tree and event trees allow us to model interactions between different systems

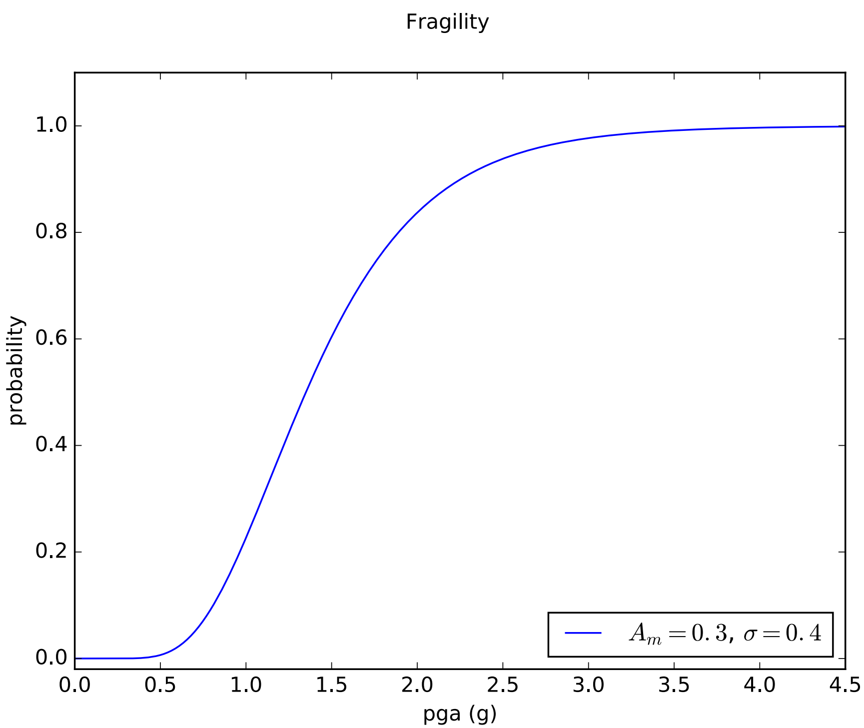


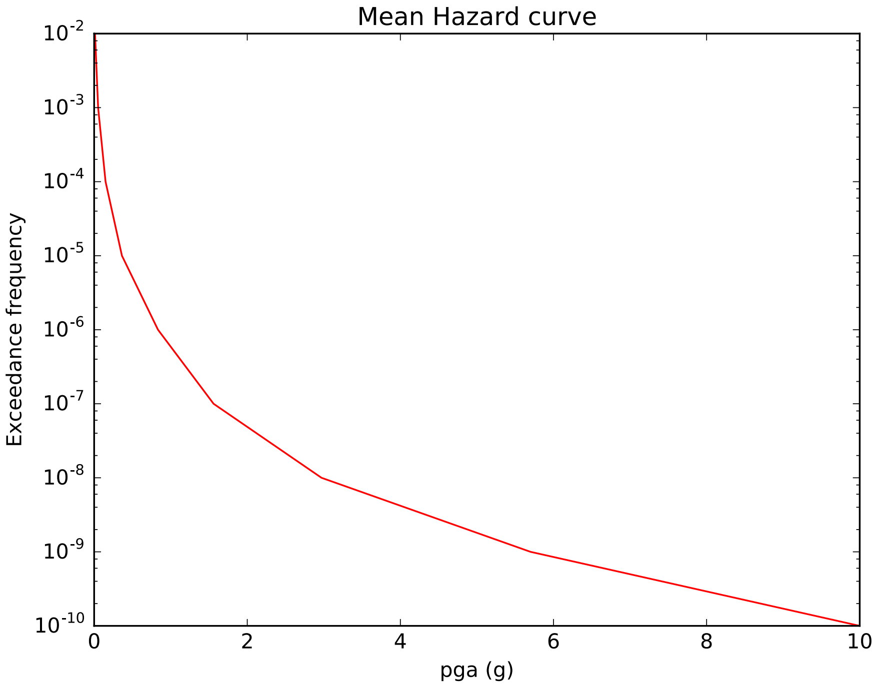
Combining the seismic data

- Mainstream PSA codes not well adapted to address S-PSA
- What do analysts do?
- Divide the domain of hazard and fragility curves in small acceleration intervals, create a set of basic events to be switched on/off for each interval and ‘reconstruct’ the acceleration dependency post PSA code calculations

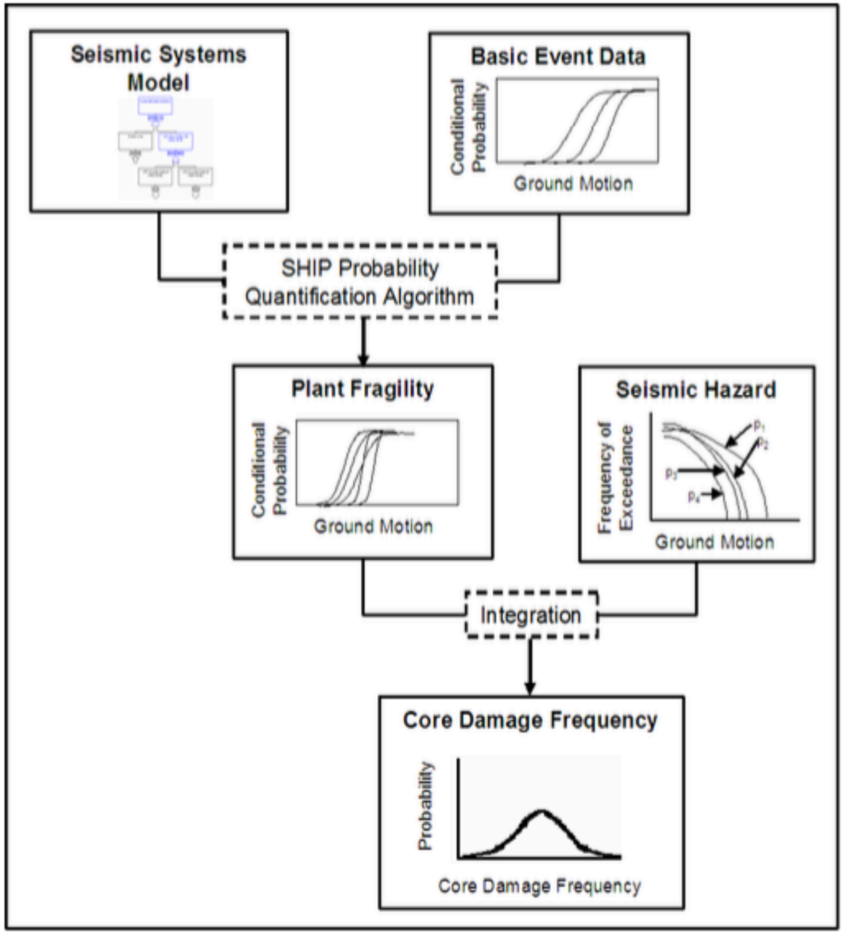
Seismic data

- We need two sets of data – one for earthquake frequency and one for conditional failure probability of structures/ components





State of the art approaches



- Kaplan (1981) proposed using a semi-analytical Discrete Probability Distribution (DPD) approach for including uncertainty in S-PSA. It is unclear how to extend this method to large PSA models
- Recently software packages such as the Westinghouse Seismic Hazard Integration Package (SHIP) and the RiskSpectrum HazardLite include uncertainty quantification in S-PSA - these methods generally involve proprietary software