



# Uncertainty Reduction of Seismic PSA through Realistic Condition Assessment

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# Introduction

- Seismic safety assessment for Korean NPPs
  - Seismic PSA for most NPPs
  - Seismic Margin Analysis for Old Plants
    - Lack of design data
    - Lack of SSCs' information
  - Reliability of Seismic PSA result (CDF)
    - Large uncertainty of PSHA
    - Lack of fragility data for components

# Uncertainty in Seismic PSA

- Seismic Hazard
  - Lack of strong earthquake data
  - Depend on historical earthquake data
  - Large variation in estimation of historical earthquake data
- Seismic Fragility
  - Lack of fragility test data
  - Reference response spectrum without site specific consideration
- Seismic Risk Quantification
  - No reference model for system analysis
  - Need risk quantification tools
- Great gap of the reliability between internal and seismic PSA results

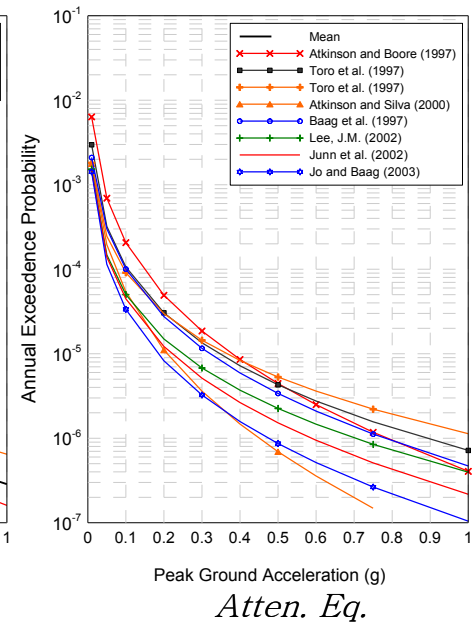
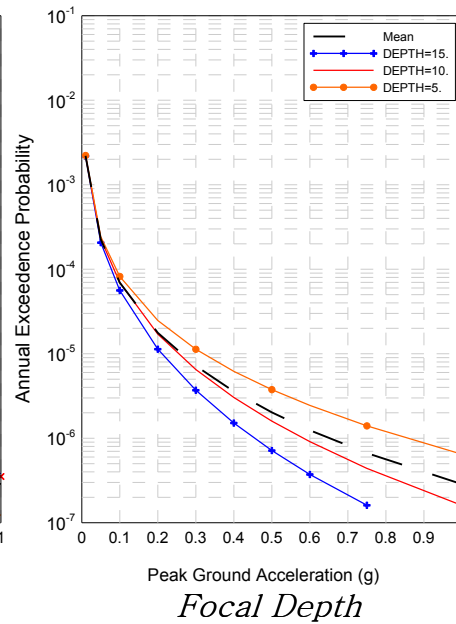
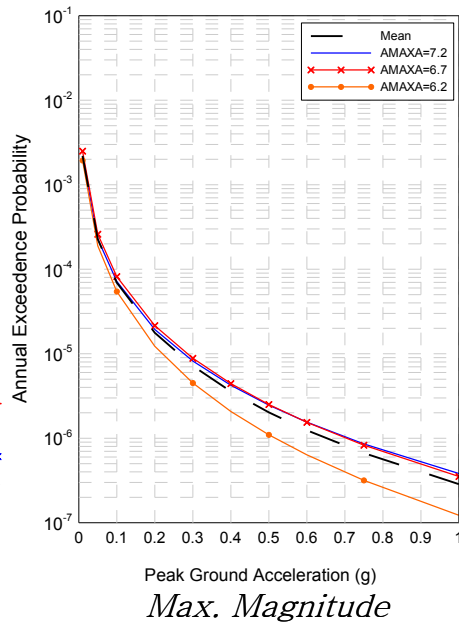
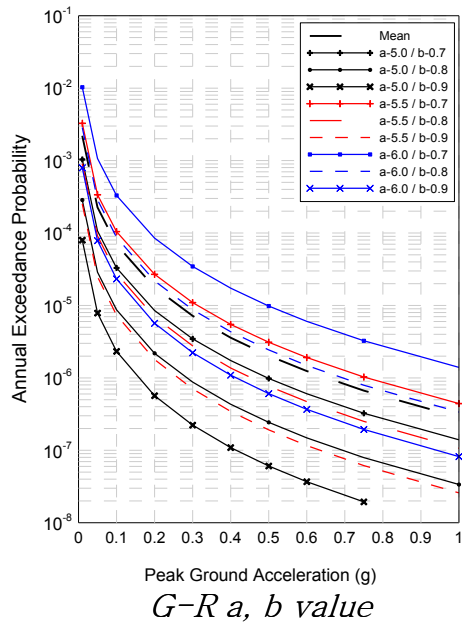
# Uncertainty Reduction in PSHA

- Need to reduce the conservative parameter due to lack of strong earthquake data
  - Over estimation of historical earthquake records
  - Use conservative approach for estimation of PSHA parameter for NPP sites
- Sensitivity analysis for PSHA input parameter
  - Seismic source map
  - Gutenberg–Richter a and b value
    - a value : 4.32–6.25 (proposed by experts)
    - b value : 0.43–0.99 (proposed by experts)
  - Maximum magnitude for seismic source
    - 6.2/6.7/7.2
  - Focal depth
  - Attenuation equation
    - Using Korean specific, CEUS and China attenuation equation

# Uncertainty Reduction in PSHA

## ■ Results of Sensitivity Analysis

- Dominant Parameter : Gutenberg–Richter a, b value and Attenuation equation

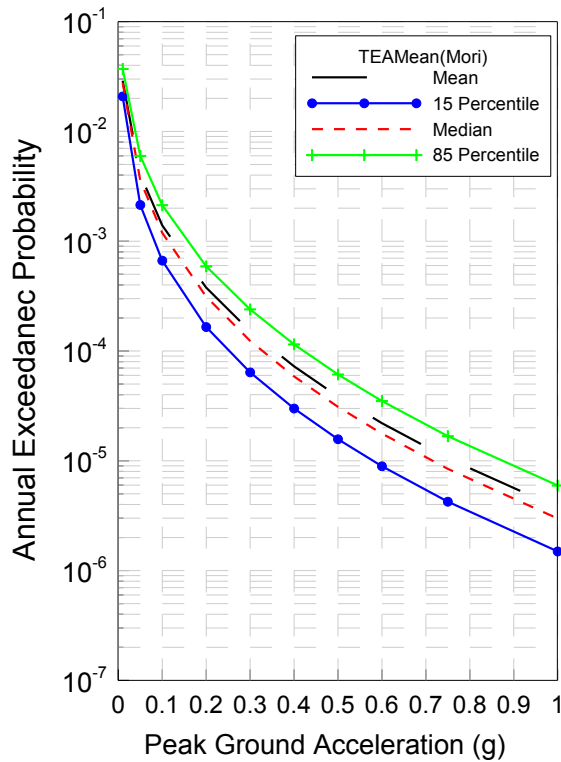


# Uncertainty Reduction in PSHA

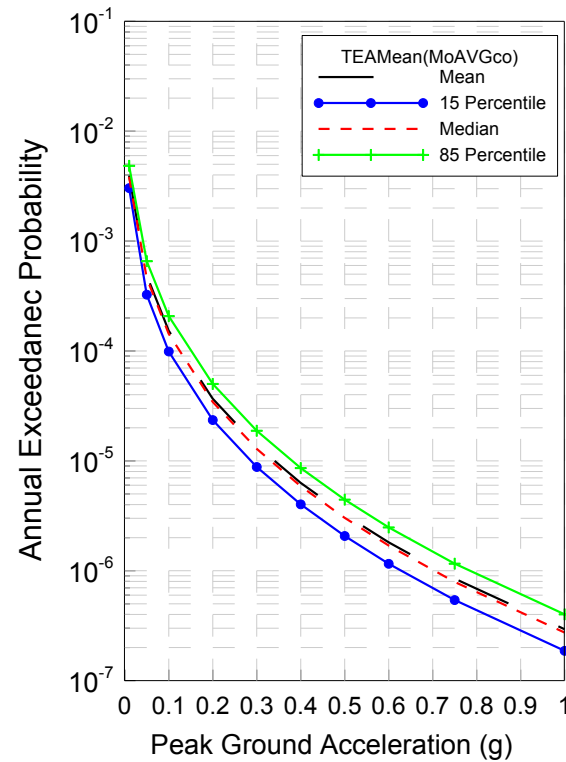
- Reevaluation of input parameter for PSHA
  - Re-evaluation of historical earthquake data
  - Using best estimated value for G-R a, b value
    - $M_{\max} \doteq 6.3$
    - $a = 5.32 \pm 0.21$
    - $b = 0.95 \pm 0.19$
  - Using best estimated seismic source map considering experts' opinion
  - Construct logic tree for PSHA considering reevaluated PSHA parameters

# Uncertainty Reduction in PSHA

- After reevaluation of Gutenberg–Richter b value



Before



After

# Uncertainty Reduction in Fragility

- Uncertainty in Seismic Fragility Analysis
  - Assessment of the Fragility Level
    - Used seismic qualification data
    - Screen-out many components by generic data (ex. piping, valve)
  - Dominant Failure Mode and Criteria
    - Inaccurate dominant failure mode
    - Causes inaccurate fragility result
  - Component Degradation Effect on Fragility
    - Realistic condition should be considered for the fragility analysis
    - Degradation can cause change of
      - Seismic capacity
      - Seismic response
      - Dominant failure mode

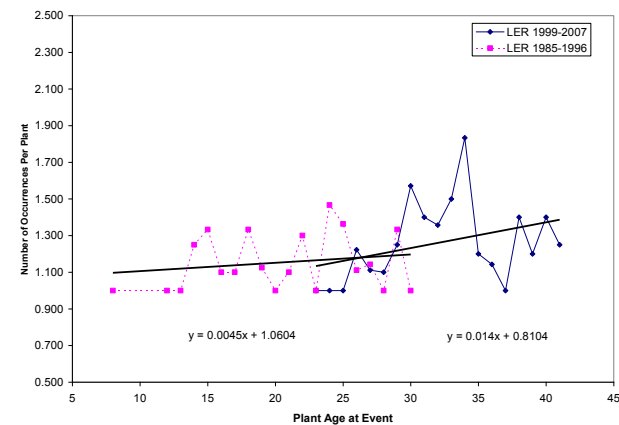
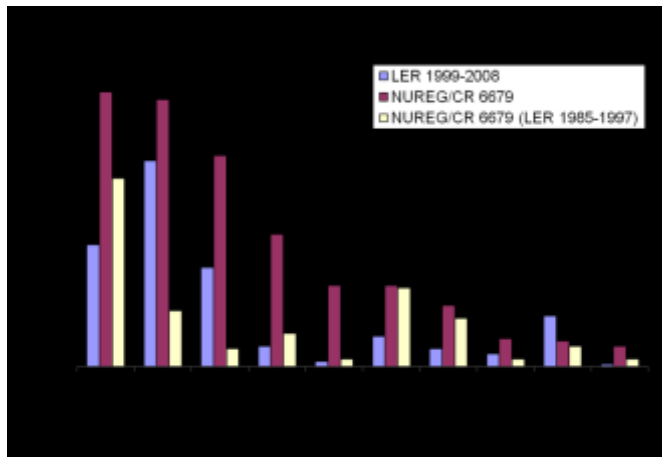
# Uncertainty Reduction in Fragility

- Aging-Related Degradation in NPP
  - Major degradation : crack and corrosion



# Uncertainty Reduction in Fragility

- Aging related component degradation in NPP
  - KAERI-BNL collaboration
    - Ten categories of components that are of high risk significance in Korean NPPs were selected
    - Collect aging related degradation data from open documents of NRC
      - Licensee Event Reports
    - Develop DB for SSCs degradation and perform trending analysis



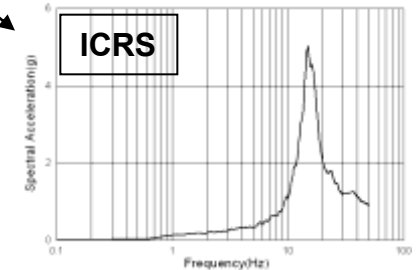
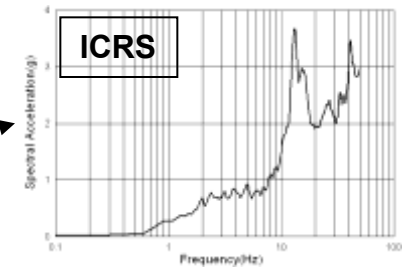
# Uncertainty Reduction in Fragility

## ■ Fragility Test of Electrical Cabinet

- 480V MCC for Shin-Ulchin NPP
- Three kinds of input motions
  - Design earthquake
  - FRS
  - Site-specific UHS

## ■ Result of Test

- Evaluation of Failure Mode
- Evaluation of Fragility Level
- Effect of input motion on ICRS



# Uncertainty Reduction in Fragility

- Fragility test for anchorage system
  - Shaking table test
  - With/without cracks
    - Tensile failure of anchor (no crack/crack passes anchorage)
    - Concrete cone failure (crack passes near the anchorage)
  - Static pull-out test vs. dynamic test



Tensile failure of bolt (no crack model)



Test model setup



Concrete cone failure (crack model)

# Uncertainty Reduction in Fragility

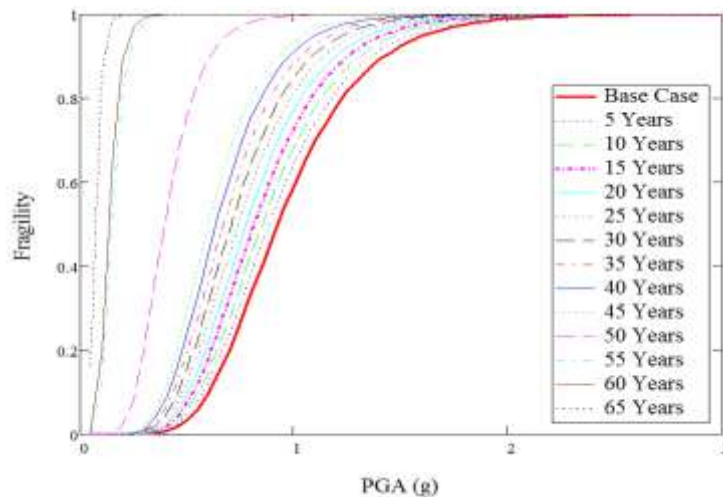
- Time dependent fragility analysis
  - A typical condensate storage tank (CST) in Korean NPPs was chosen as a representative one for seismic fragility analysis with various postulated degradation scenarios
  - The failure of a particular CST has a 17.7% contribution to the seismic CDF for a Korean nuclear power plant
  - The seismic fragility capacity of the CST will be developed for five cases:
    - Undegraded for baseline (Design condition)
    - Degraded stainless tank shell
    - Degraded anchor bolts
    - Anchorage concrete cracking (two models)
    - Multiple degradation ((2) + (3) + (4))
  - The seismic fragility of a degraded SPC is a function of time



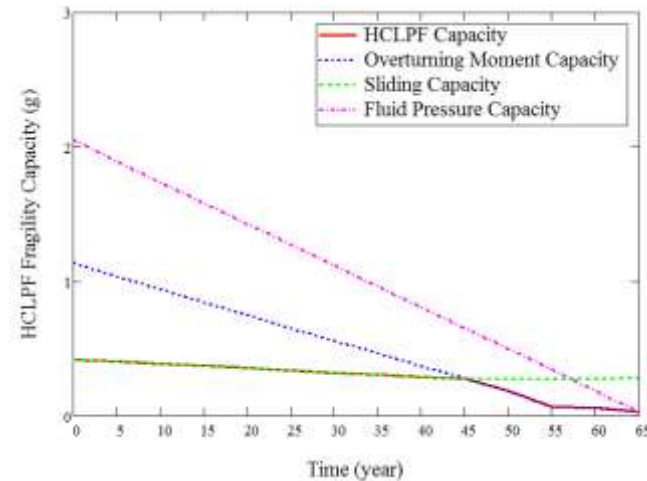
$$F(a, Q, t) = \Phi \left[ \frac{\ln \left( \frac{a}{A_m(t)} \right) + \beta_U(t) \Phi^{-1}(Q)}{\beta_R(t)} \right]$$

# Uncertainty Reduction in Fragility

- Time dependent fragility analysis
  - Degradation Models
    - stress corrosion cracking (SCC) in stainless steel components
    - Degraded anchor bolts : reduction of bolt diameter
    - Degradation of anchorage concrete : cracks in concrete



Mean fragility curves for multiple degradation



HCLPF vs. Time for Multiple Degradations

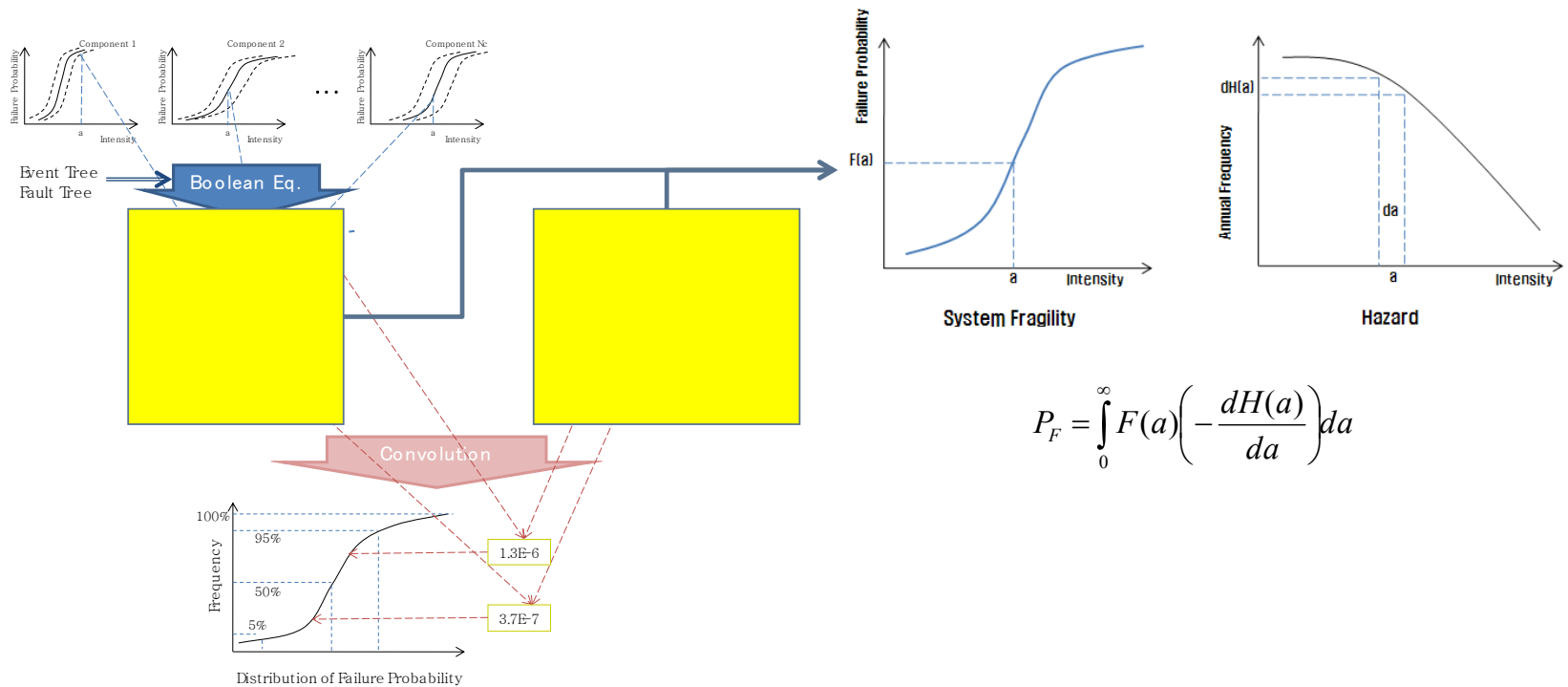
# Uncertainty Reduction in Quantification

- Seismic Risk Quantification
  - Development of initiating event frequency calculation program (PRASSE)
    - Used EQESRA, Seismic code
    - Fortran 90
    - Uncertainty analysis by LHS, MCS
      - Increase the reliability of results
    - User friendly GUI
  - System analysis model
    - Develop AIMS based One-top model
      - Automatic generation of seismic system model
      - Reduce error in system model
      - Support integrated PSA tool
    - Develop integrated PSA software package (Oceans)
      - Internal + External events

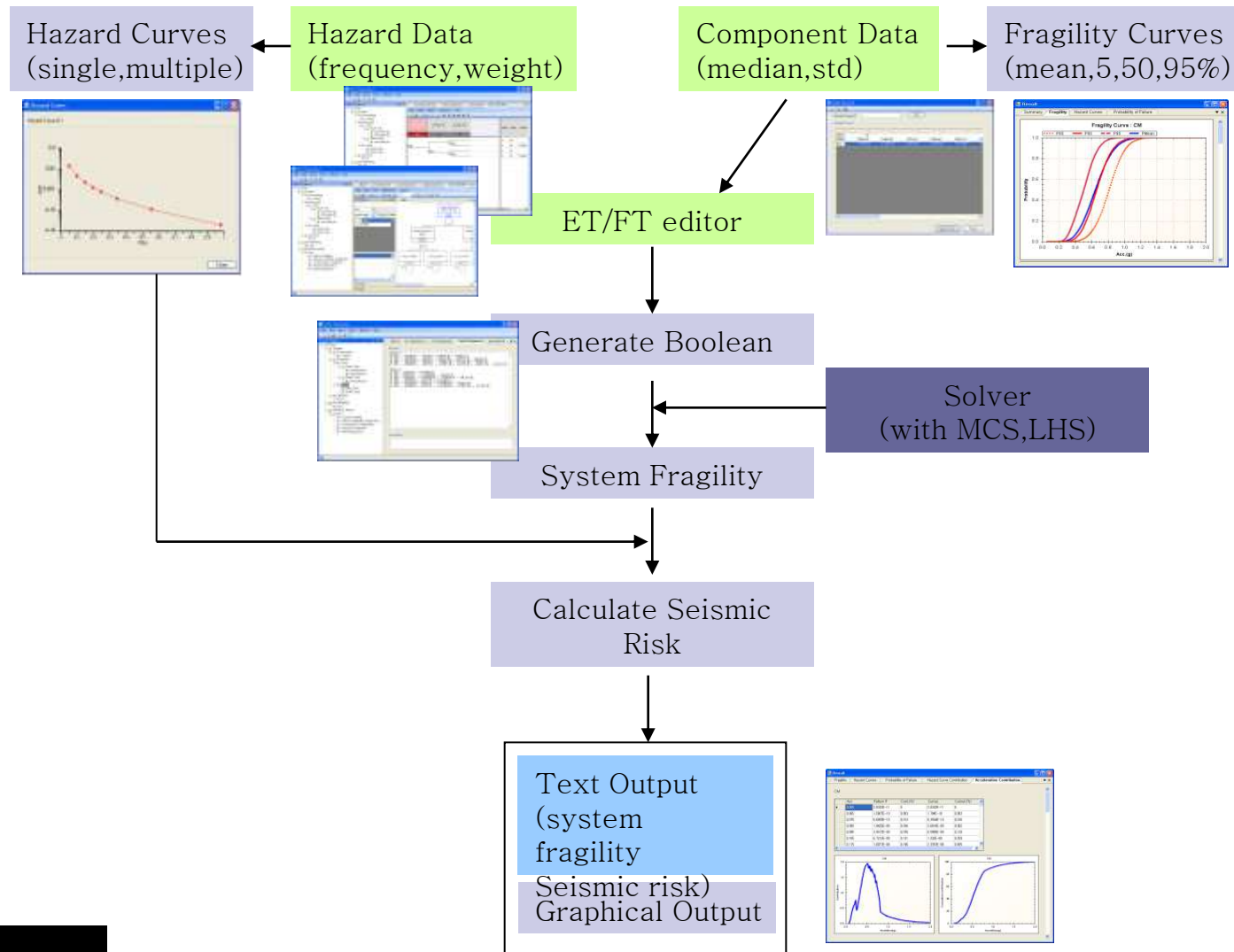
# Uncertainty Reduction in Quantification

## ■ Uncertainties in Seismic PSA

- System level fragility
- Seismic induced risk with various confidence level

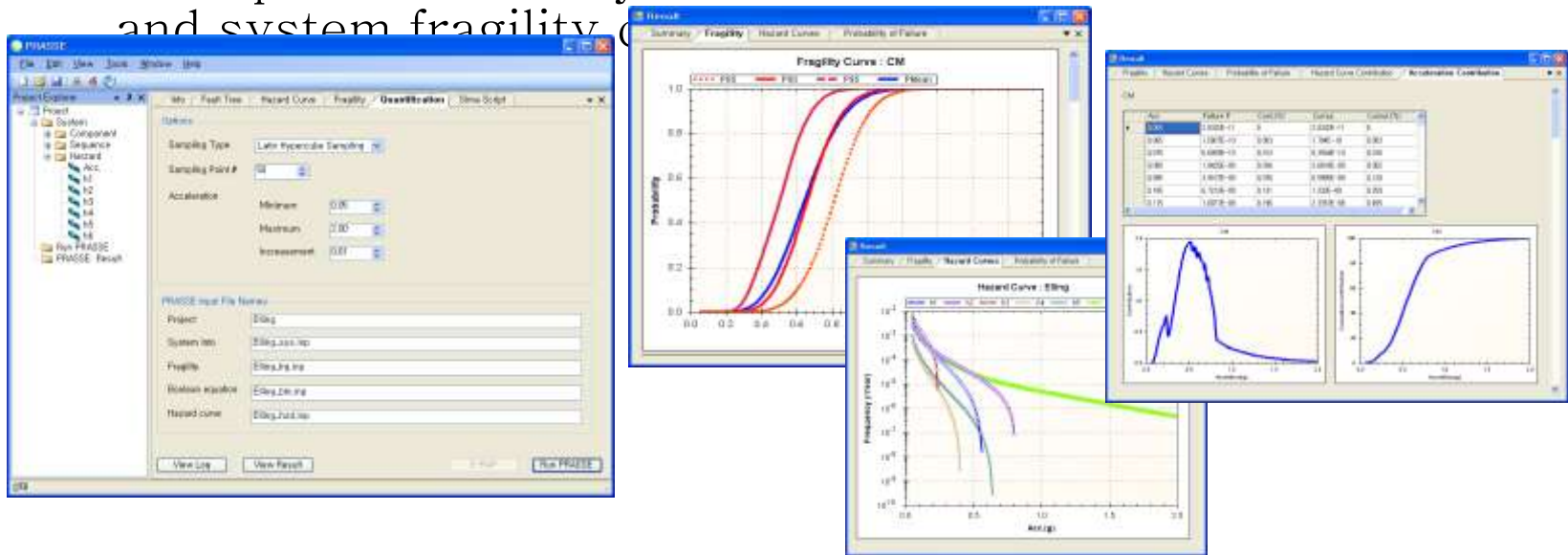


# Uncertainty Reduction in Quantification



# Uncertainty Reduction in Quantification

- Development of System Analysis Model for SPRA
- Develop seismic risk quantification program (PRASSE)
  - For the seismic PRA of a nuclear power plant
  - Uncertainty analysis for system fragilities by MCS and LHS method
  - Risk quantification by convolution of seismic hazard curves and system fragility



# Uncertainty Reduction in Quantification

- Verification by Limerick Generating Station Severe Accident Risk Assessment (LGS-SARA)
  - NUREG CR-3493
  - Ellingwood, 1990 (NED)

LGS component fragility parameters:

No.	Component	$A_m(g)$	$\beta_R$	$\beta_U$
S1	Offsite power	0.20	0.20	0.25
S2	Condensate storage tank	0.24	0.23	0.31
S3	Reactor internals	0.67	0.28	0.32
S4	Reactor enclosure structure	1.05	0.31	0.25
S6	Reactor pressure vessel	1.25	0.28	0.22
S10	SLC tank	1.33	0.27	0.19
S11	440-V bus/SG breakers	1.46	0.38	0.44
S12	440-V bus transformer breaker	1.49	0.36	0.43
S13	125/250-VDC bus	1.49	0.36	0.43
S14	4-kV bus/SG	1.49	0.36	0.43
S15	Diesel generator circuit	1.56	0.32	0.41
S16	Diesel generator heat and vent	1.55	0.28	0.43
S17	RHR heat exchangers	1.09	0.32	0.34

LGS component random failures.

Description of failure	Mean failure rate (/yr)
DGR – Diesel generator common mode	1.25e-3
WR – Containment heat removal	2.6e-4
CR – Scram system mechanical failure	1.0e-5
SLCR – Standby liquid control	1.0e-2

$$T_S E_S U X = S_1 \cap A$$

$$T_S R_b = S_4$$

$$T_S R_{pv} = S_6$$

$$T_S E_S C_m C_2 = S_1 \cap (S_3 \cup C_R) \cap (A \cup S_{10} \cup S_{LCR})$$

$$T_S R_b C_m = S_4 \cap (S_3 \cup C_R)$$

$$T_S E_b W_m = S_1 \cap \bar{A} \cap (\bar{S}_{17} \cap W_R \cup \bar{S}_2 \cap S_{17})$$

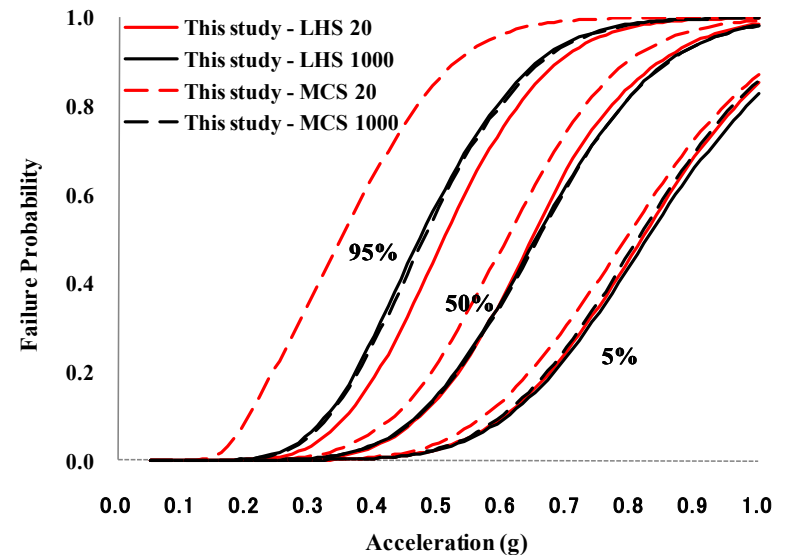
$$CM = S_4 \cup S_6 \cup S_1 \cap [A \cup (S_3 \cup C_R) \cap (S_{10} \cup S_{LCR}) \cup (S_{17} \cup W_R)]$$

in which

$$A = S_{11} \cup S_{12} \cup S_{13} \cup S_{14} \cup S_{15} \cup S_{16} \cup DGR$$

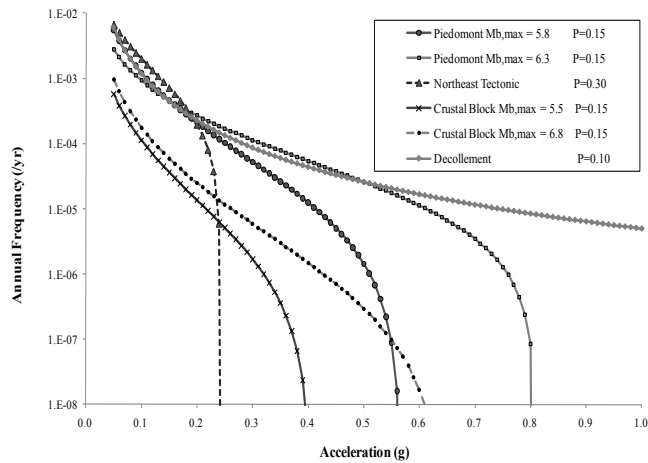
# Uncertainty Reduction in Quantification

- System HCLPF of CM sequence
  - Comparison of system HCLPF
    - By Ellingwood : 0.32g (LHS with 20 sample)
    - EQESRA : 0.32g (DPD)
    - PRASSE :
      - 0.32g by LHS with 20 sample
      - 0.29g by LHS or MCS with 1000 sample



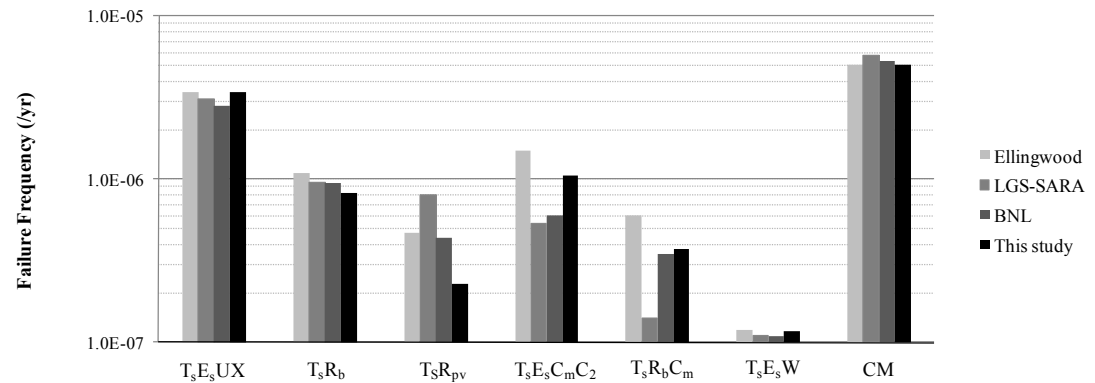
# Uncertainty Reduction in Quantification

## ■ Comparison of Mean CDF



Mean frequencies of core melt sequences.

Sequence	Ellingwood	LGS-SARA	BNL Est.	This study by MCS	This study by LHS
$T_sE_sUX$	3.4e-6	3.1e-6	2.8e-6	3.43e-6	3.41e-6
$T_sR_b$	1.1e-6	9.6e-7	9.5e-7	8.01e-7	8.28e-7
$T_sR_{pv}$	4.7e-7	8.0e-7	4.4e-7	2.26e-7	2.28e-7
$T_sE_sC_mC_2$	1.5e-6	5.4e-7	6.0e-7	1.07e-6	1.06e-6
$T_sR_bC_m$	6.0e-7	1.4e-7	3.5e-7	3.66e-7	3.72e-7
$T_sE_sW$	1.2e-7	1.1e-7	1.1e-7	1.17e-7	1.17e-7
CM	5.0e-6	5.7e-6	5.3e-6	4.98e-6	5.00e-6



# Summary

- Uncertainty reduction considering Korean specific condition
  - In PSHA, practical way was adopted to overcome the lack of strong earthquake data
  - In seismic fragility, fragility level test for several components were performed to reduce the large conservatism
  - Also, fragility analysis methods were developed to estimate current and long-term seismic capacity of components by considering aging related degradation and time dependent fragility analysis
  - In system analysis and seismic risk quantification, integrated PSA model and quantification tool were developed for easy and error free PSA analysis
- Important to reduce the uncertainty and conservatism in Seismic PSA results for risk informed application