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Implementation Guidelines for Seismic PSA

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Content

- Objectives
- General Structure of the Implementation Guidelines
- Workflow process for developing S-PSA
- Fragility Analysis
- System Analysis
- Recent Enhancements
- Final remarks

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Objectives

- Develop a ("how to do") document called Implementation Guidelines for S-PSA, observing IAEA NS-G-2.13 and ASME/ANS standard RA-Sa-2009 technical requirements for capability category 2.
- Maintain compatibility with Internal Events PSA aimed to integrate all internal and external events in one PSA model
- Incorporate recent enhancements that will contribute to meet capability category 2 technical requirements

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General Structure of the IAEA Technical Document

The Implementation Guidelines for S-PSA addresses the main tasks of the S-PSA using the following structure for each task:

- Objective and scope of the task
- Applicable Technical Requirements
- Input data
- Description of the task work/process
- Results of the task (outcome)
- Interface with other tasks

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Workflow process for developing S-PSA

- The main steps and workflow process for developing the S-PSA illustrative examples:
  - Define the scope of the S-PSA and Initial assumptions
  - Observe the ASME, Standard RA-S-2009 Requirements
  - Review the Internal Event PSA (generic mode available)
  - Review the PSHA results
  - Review internal IE for seismic considerations and establish the link between Seismic Hazard impact for different acceleration ranges and Internal IEs
  - Develop Seismic Initiating Events (S-IE) and calculate S-IE frequencies
  - Develop S-IE – versus Fault trees matrix

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Workflow process for developing S-PSA

- Develop Seismic Equipment List (SEL):
  - Observe Applicable Technical Requirements (e.g. ASME, Standard RA-Sa-2009)
  - Set criteria for screening and grouping of the internal PSA Basic Events (BE)
  - Review the Internal PSA BE list
  - Set Seismic BE boundary conditions
  - Develop seismic screening criteria and screening limits, based on the applicable seismic hazard curve(s).
  - Perform SEL Screening (conduct Screening Walkdowns)

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Workflow process for developing S-PSA

- Develop Seismic Fragility parameters for Seismic Basic Events (SEL):
  - Observe applicable technical requirements (e.g. ASME, Standard RA-Sa-2009)
  - Review Seismic Qualification and Design information
  - Review applicable generic seismic capacity data
  - Conduct Seismic Capability Walkdowns
  - Perform Fragility Analysis and derive seismic fragility parameters (Am, HCLPF, βc)
  - Consider Correlations between seismic induced failures

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Workflow process for developing S-PSA

- System Analysis:
  - Observe applicable requirements (e.g. ASME, Standard RA-Sa-2009)
  - Edit/develop Event Trees (ET):
    - Add seismic ETs and associated S-IE frequencies
  - Edit/develop Fault Trees (FT)
    - Add Seismic Basic Events and associates properties
  - Evaluate and include Human Errors associated to recovery actions

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Workflow process for developing S-PSA

- Seismic Quantification:
  - Run the model for all Seismic IEs
  - The plant damage state frequency is obtained by Boolean summation of frequencies of all seismic sequences.
  - First quantification is based on preliminary fragility parameters
  - Identify significant seismic contributors

$$P_f(DS) = 1 - \prod (1 - P_f(C_i))$$

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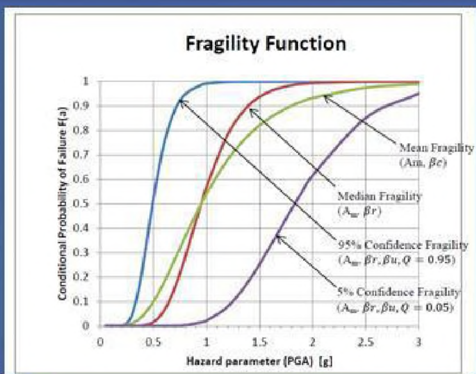
Workflow process for developing S-PSA

- Develop Final S-PSA Results
  - Refine Fragility Analysis for the major contributors
  - Perform quantification including refined fragilities
  - Perform sensitivity analysis and develop seismic insights.
  - Document the S-PRA

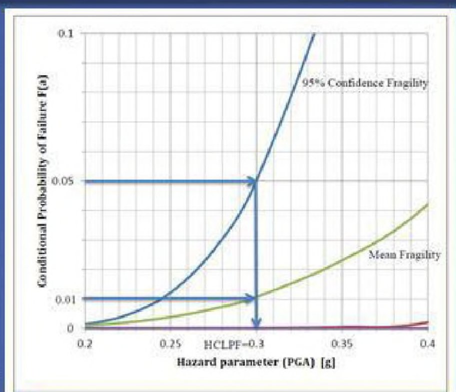
IAEA 9

Fragility Analysis



IAEA 10

Fragility Analysis



IAEA 11

Recent Enhancements

- Recover β_r and β_u from the mean plant state fragility based on the properties of the log-normal distribution and definition of the HCLPF:

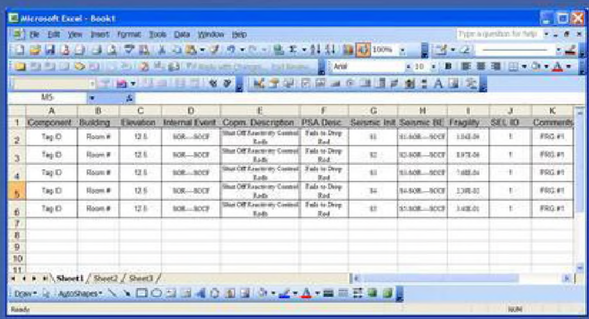
$$A = 2 \qquad B = \frac{\ln\left(\frac{HCLPF}{A_m}\right)}{\phi^{-1}(0.05)} \qquad C = \left(\frac{\ln\left(\frac{HCLPF}{A_m}\right)}{\phi^{-1}(0.05)}\right)^2 - \beta_C^2$$

$$\beta_U = \frac{-2B + \sqrt{B^2 - 4AC}}{2A}$$

$$\beta_R = \frac{-2B - \sqrt{B^2 - 4AC}}{2A}$$

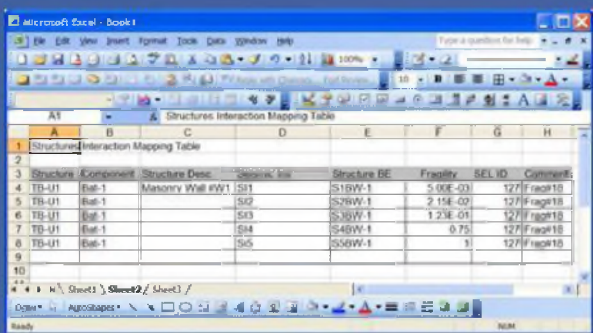
IAEA 12

System Analysis / S-PSA Database



IAEA 13

System Analysis / S-PSA Database



IAEA 14

System Analysis / S-PSA Database

Seismic Correlation Table

Seismic Correlation BE	Seismic IE	Components	Seismic Correlation Description	Fragility	Comments
S1PUMP_ABC	SI1	Pumps ABC	Seismic Induced Failure Pumps A,B & C	5.00E-05	Frag #21
S1PUMP_ABC	SI2	Pumps ABC	Seismic Induced Failure Pumps A,B & C	2.12E-04	Frag #22
S1PUMP_ABC	SI3	Pumps ABC	Seismic Induced Failure Pumps A,B & C	1.27E-03	Frag #23
S1PUMP_ABC	SI4	Pumps ABC	Seismic Induced Failure Pumps A,B & C	3.56E-02	Frag #24
S1PUMP_ABC	SI5	Pumps ABC	Seismic Induced Failure Pumps A,B & C	1.20E-01	Frag #25

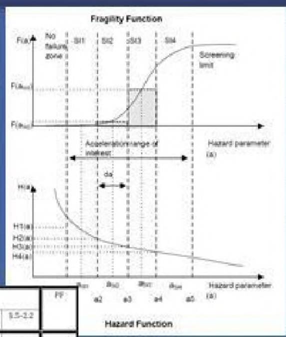
IAEA 15

Recent Enhancements

- Quantification

$$P_F = \int_{a1}^{a2} \frac{dH(a)}{da} F(a) da$$

$$P_F = \sum (F(a_{SIi}) \times da) \times \frac{H_{i+1}(a) - H_i(a)}{da}$$



End-state Fragility Parameters			Item	Acceleration range						PF
HCLPF	β_c	A_m		0.05-0.2	0.2-0.4	0.4-0.6	0.6-1.0	1.0-1.5	1.5-2.2	
0.3	0.6	1.21	Average acc.	0.125	0.3	0.5	0.8	1.25	1.85	
			H(a0)-H(a1)	0.100	9.00E-4	7.40E-5	2.10E-5	1.70E-6	7.20E-7	
			F(a-average)	7.56E-5	9.90E-3	6.96E-2	2.43E-1	5.19E-1	7.59E-1	
			Eq. Frag	1.20E-6	6.22E-3	1.23E-1	4.76E-1	8.11E-1	9.72E-1	
			Approx. Integ	7.56E-6	8.91E-6	5.15E-6	5.11E-6	1.92E-6	5.46E-7	2.92E-5
			Num. Integ	8.00E-7	5.10E-6	4.40E-6	4.50E-6	1.60E-6	5.10E-7	1.71E-5

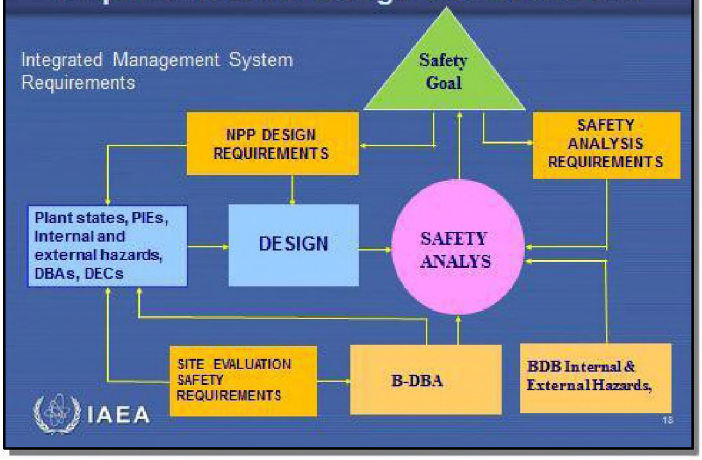
16

Final Remarks

- The IAEA/ISSC Implementation Guidelines for S-PSA (under development) provides "how to do" guidelines aimed to show the development process for the S-PSA illustrated with various results produced by a generic S-PSA model observing IAEA NS-G-2.13 and ASME/ANS standard technical requirements for capability category 2.
- Practical S-PSA enhancements allow integration of S-PSA with Internal Events PSA model. The authors believes that these enhancements makes S-PSA process very effective and significantly contribute meeting the capability category II requirements of the standard.

IAEA 17

Linking Safety Goal with Safety Requirements for Design Site Evaluation



Final Remarks

Traditional "Deterministic" safety analysis approach is characterized by:

- Un-quantified probabilities associated to hazard assessment and potential induced accidents
- Defense in Depth and Safety Margins introduced by design rules (not explicitly quantified)
- Incomplete

Risk based approaches methodologies are characterized by:

- Quantified Probabilities
- Hundreds thousands or millions of accident sequences are considered
- Realistic
- Incomplete

IAEA 19

Final Remarks

There are advantages and disadvantages to both deterministic and probabilistic safety assessment methodologies. These methodologies are complementary:

- first (deterministic approach) is based on the success path approach aimed to prevent occurrence of an accident;
- second (probabilistic approach) consider a large number of combinations of failures and accident sequences that may lead to a accident.
- and together (deterministic complemented by probabilistic safety assessment) seems to provide the best basis for safety and licensing decisions establishing an appropriately balances between defense in depth and risk considerations.
- This risk-informed approach uses the combination of traditional deterministic and risk-based approaches.

IAEA 20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