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Selection of Strategy for Seismic Qualification of Equipment for Design Extended Conditions ("Beyond Design")

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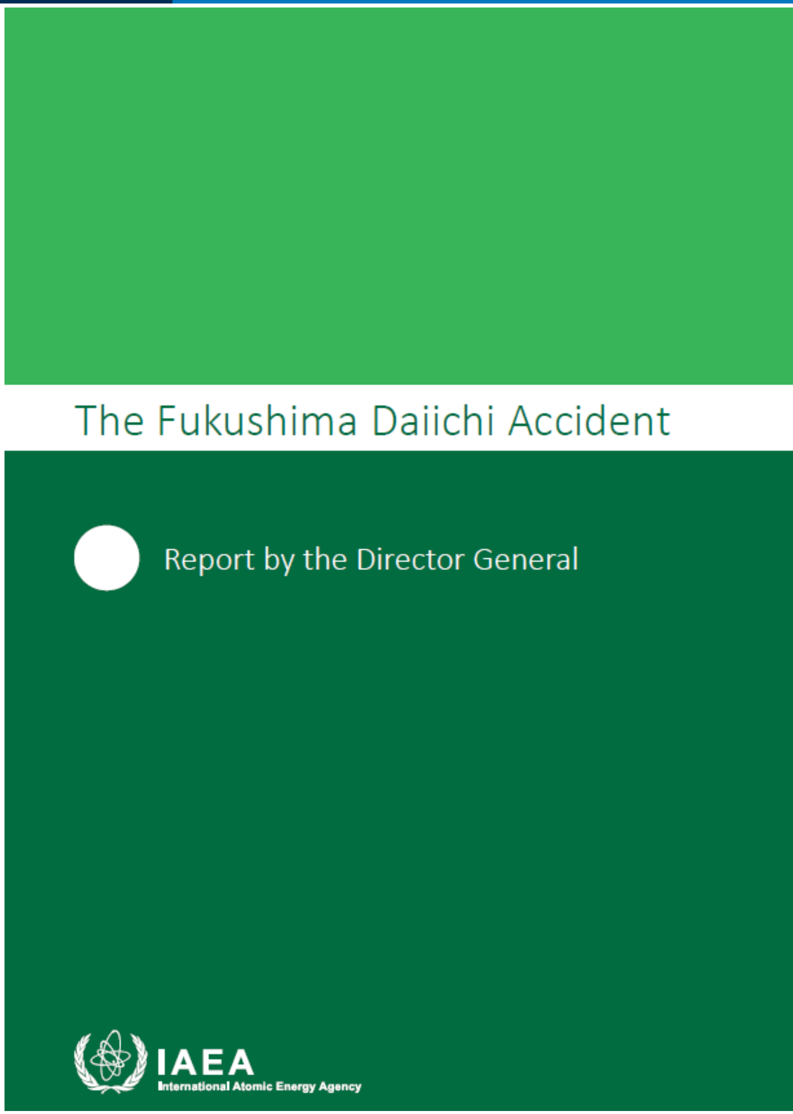
ABSTRACT

- The subject of equipment seismic qualification is to verify functional capabilities in cases of postulated design earthquake events. Usually, for licenses purpose, there are stipulated minimally two levels of earthquakes. One is dedicated for earthquake events that can occur repeatedly during the facility operational lifetime and equipment shall sustain motions without any impairment and shall be ready for further operation. The second level is much stronger where the probability of the occurrence is very rare and only specific systems, its components, and structures shall withstand such motion in order to meet essential seismic safety mission. After this earthquake level, there is not count with further exploitation.
- The two levels of earthquake determine a basic design robustness, all anti-seismic provisions and appropriate grade of documentations with respect to distinguished design codes, qualification standards and applicable design verification procedure.

ABSTRACT

- In case of “beyond design” issues, gets on the evaluation of residual design capacity that stay above allowable limits given either design code or functional limitation defined by manufacturer. Critical aspect of seismic qualification for design extended conditions (i.e. loading parameters above postulated extreme conditions) is determination of seismic safety goals. The appropriate margin of design shall be accordingly quantified. The very useful and proven technique of the margin quantification is Seismic Margin Assessment (SMA). Application of SMA in the phase of plant equipment design is comprehensive method to assessed available reserves in the equipment design and herewith control predefined plant safety targets.

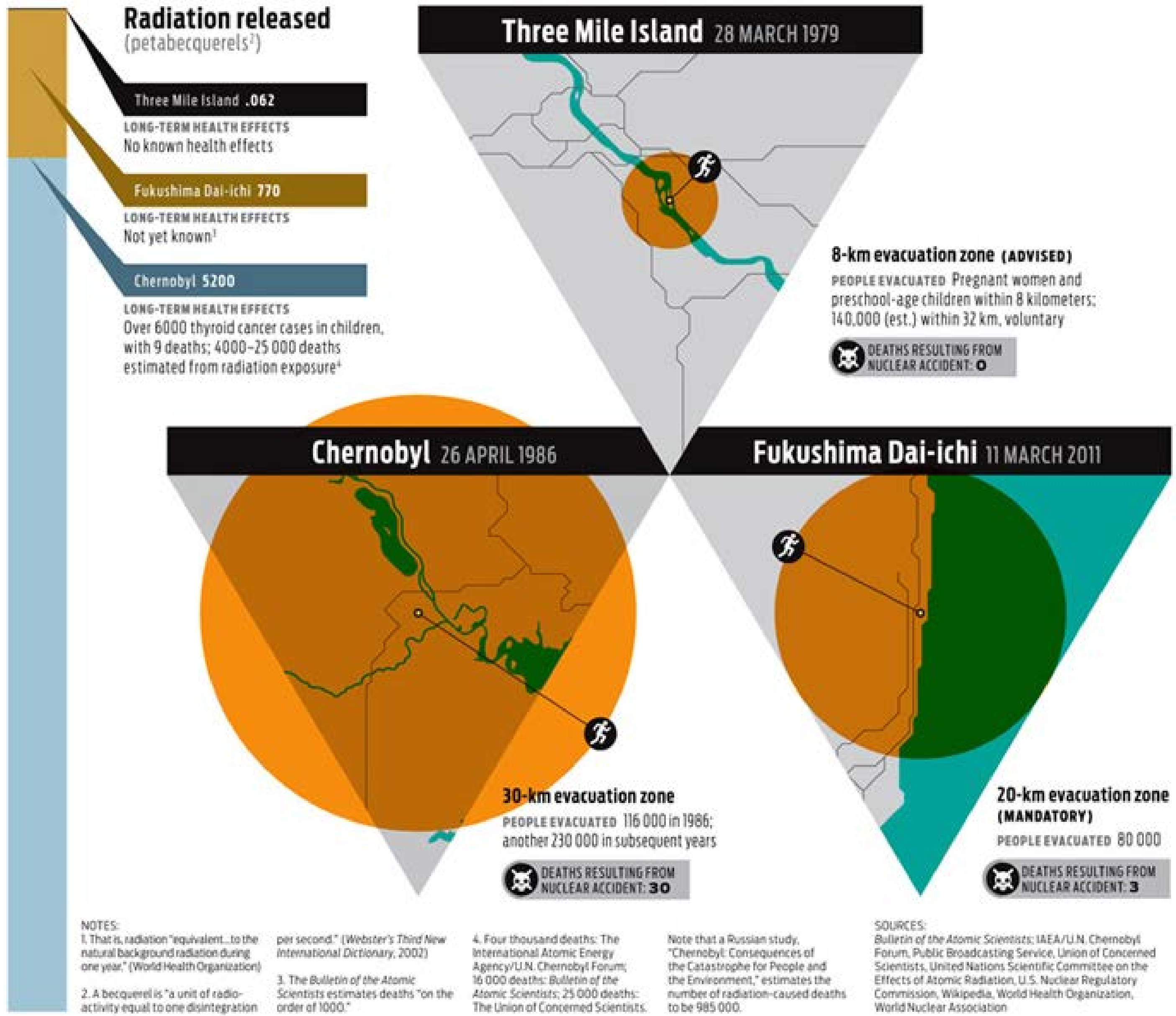
Lessons Learned and Challenges Outlined by IAEA Fukushima Daiichi Accident


The Fukushima Daiichi Accident

Report by the Director General

IAEA
International Atomic Energy Agency

- Importance of adequate design basis
- Our knowledge of natural hazard phenomena is uncertain and continually evolving; periodic assessments is necessary
- Common-cause effects of external events can compromise several layers of defense in depth at the same time
- External events affect the entire site and the civil infrastructure
- Combined effects of natural events need to be considered
- Develop mitigating strategies for beyond-design-basis external events considering impact of external hazards



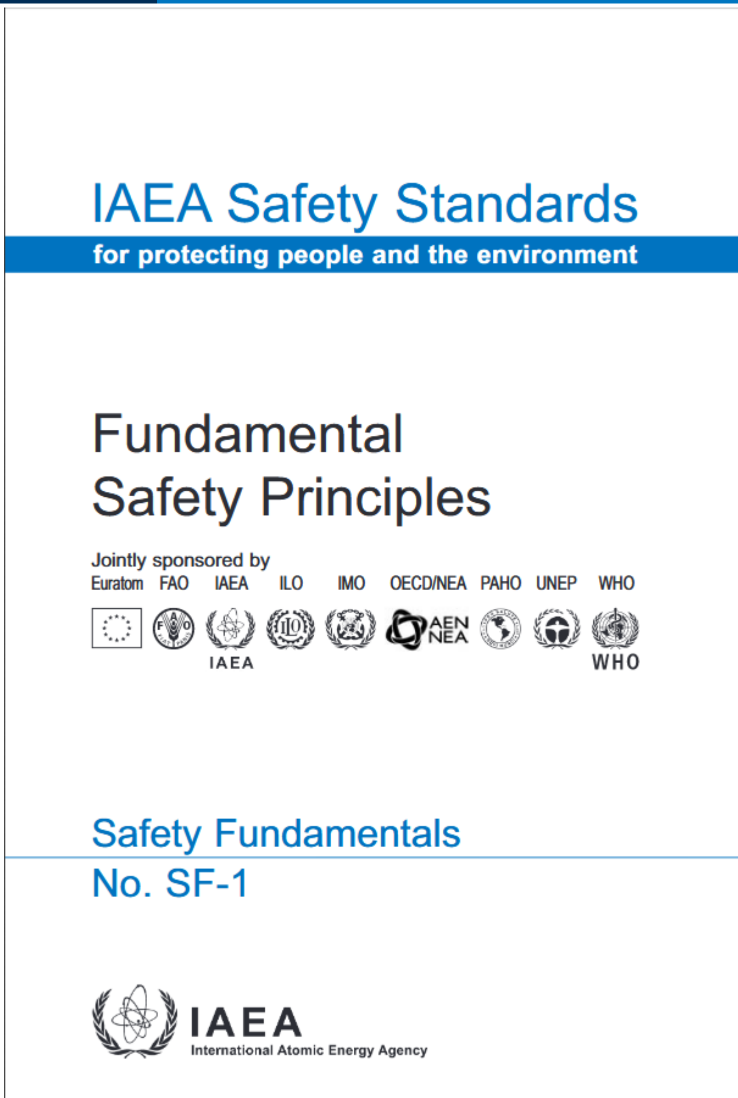
„Three Mile Island, Chernobyl, and Fukushima A comparison of three nuclear reactor calamities reveals some key differences“, In: IEEE Spectrum, {Posted 31 Oct 2011 | 21:23 GMT By Prachi Patel}

Safety Objectives as Recognized by IAEA

Adequate Defence in Depth (DiD) and Safety Margins for all loading and operating conditions considered in design are aimed to:

- Ensure appropriate barriers, controls, to prevent, contain, and mitigate exposure to radioactive material considering all relevant hazards scenarios, and the associated uncertainties; and
- Ensure that the risks resulting from the failure of some or all of the established barriers and controls, including human errors, are maintained acceptably low.

Safety Objectives as Recognized by IAEA


IAEA Safety Standards
for protecting people and the environment

Fundamental Safety Principles

Jointly sponsored by
Euratom FAO IAEA ILO IMO OECD/NEA PAHO UNEP WHO

Safety Fundamentals
No. SF-1

IAEA
International Atomic Energy Agency

<u>Principle 8 – Prevention of Accidents</u>

Defence in Depth" is provided by combination of:

- Effective management system – safety culture
- Adequate site selection, **good design** and engineering safety features providing **safety margins**, diversity and redundancy, by use of:
    - Design, technology, materials of high quality and reliability.
    - Control, limiting and protection systems and surveillance features.
    - Appropriate combination of inherent and engineered safety features.
- Comprehensive operational procedures and practices, as well as accident management procedures

Safety Objectives as Recognized by IAEA

Specific Safety Requirements No. SSR-2/1, Revision 1, „Safety of Nuclear Power Plants Design“

5.21. The seismic design of the plant shall provide for **a sufficient safety margin** to protect against seismic events and to avoid **cliff edge effects** (see footnote 5).

Footnote 5

A cliff edge effect, in a nuclear power plant, is an instance of severely abnormal plant behaviour caused by an abrupt transition from one plant status to another following a small deviation in a plant parameter, and thus a sudden large variation in plant conditions in response to a small variation in an input.

{see also definition in IAEA Safety Glossary}

Safety Margins

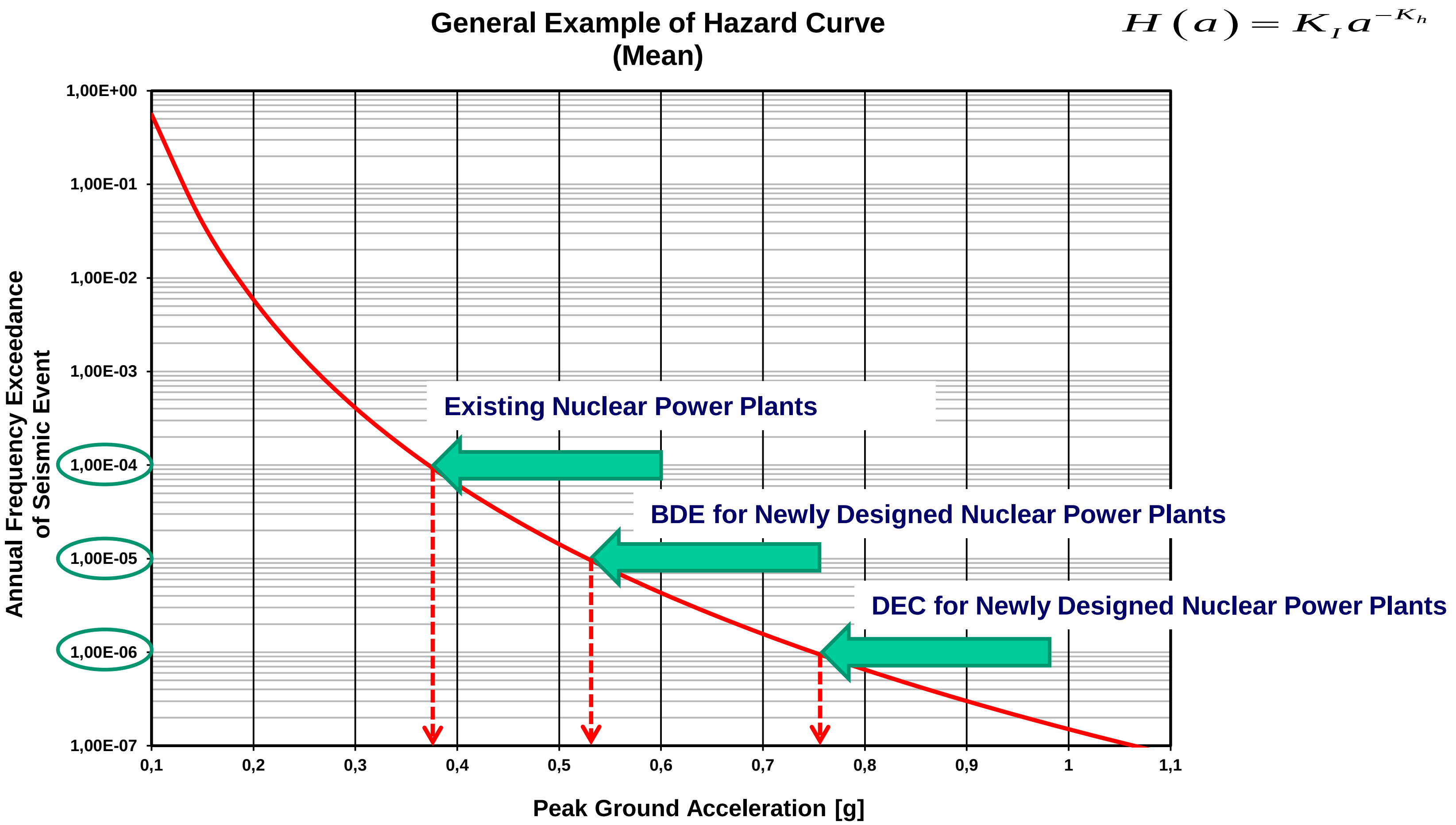
- The safety analysis shall provide assurance that adequate margins are available to avoid cliff edge effects and large radioactive releases.
- Adopting margins in the design of a NPP is a common practice to improve the robustness of the design and providing an effective mean to deal with uncertainties.
- Extension of the design basis with the introduction of DECs (Design Extended Conditions) has introduced new elements that need to be addressed.

Safety Margins Descriptor - HCLPF

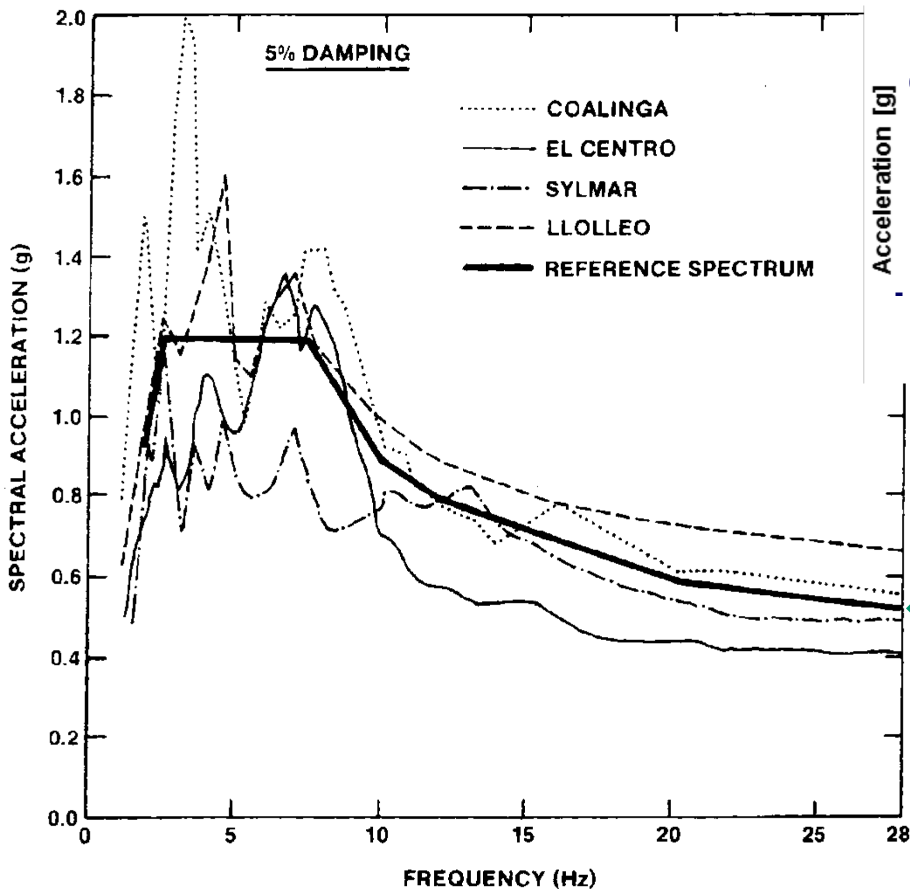
- The Seismic Margin descriptor was chosen as the High Confidence-Low-Probability-of-Failure (HCLPF) capacity, which corresponds to about 95 % confidence of less than about a 5 % probability of failure or alternatively more recently to a composite fragility curve with less than about 1% probability of failure, (Kennedy).
- The concept of a High Confidence of Low Probability of Failure (HCLPF) capacity is used in the Seismic Margin Assessments to quantify the seismic margin of individual Structures, Systems and Components, SSC and collectively of a nuclear power plant.
- **Due to the practical enginneering reasons only the CDFM method could be applied within the process of Equipment Qualification.**

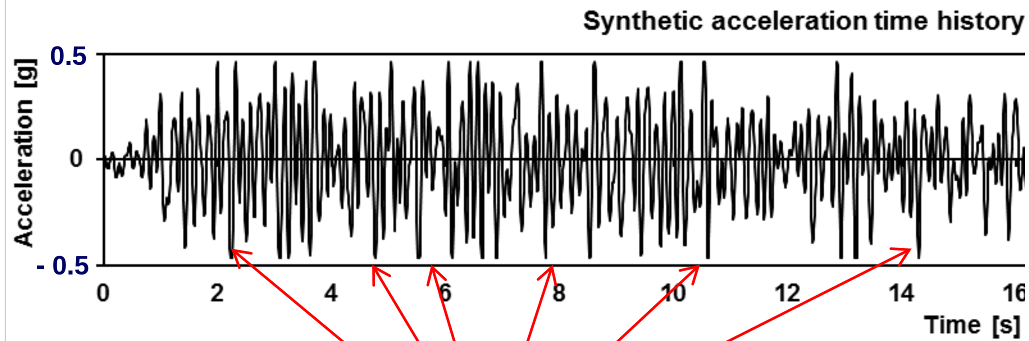
Seismic Hazard – Seismic Loads

$$H(a) = K_I a^{-K_h}$$



Seismic Hazard – Seismic Loads



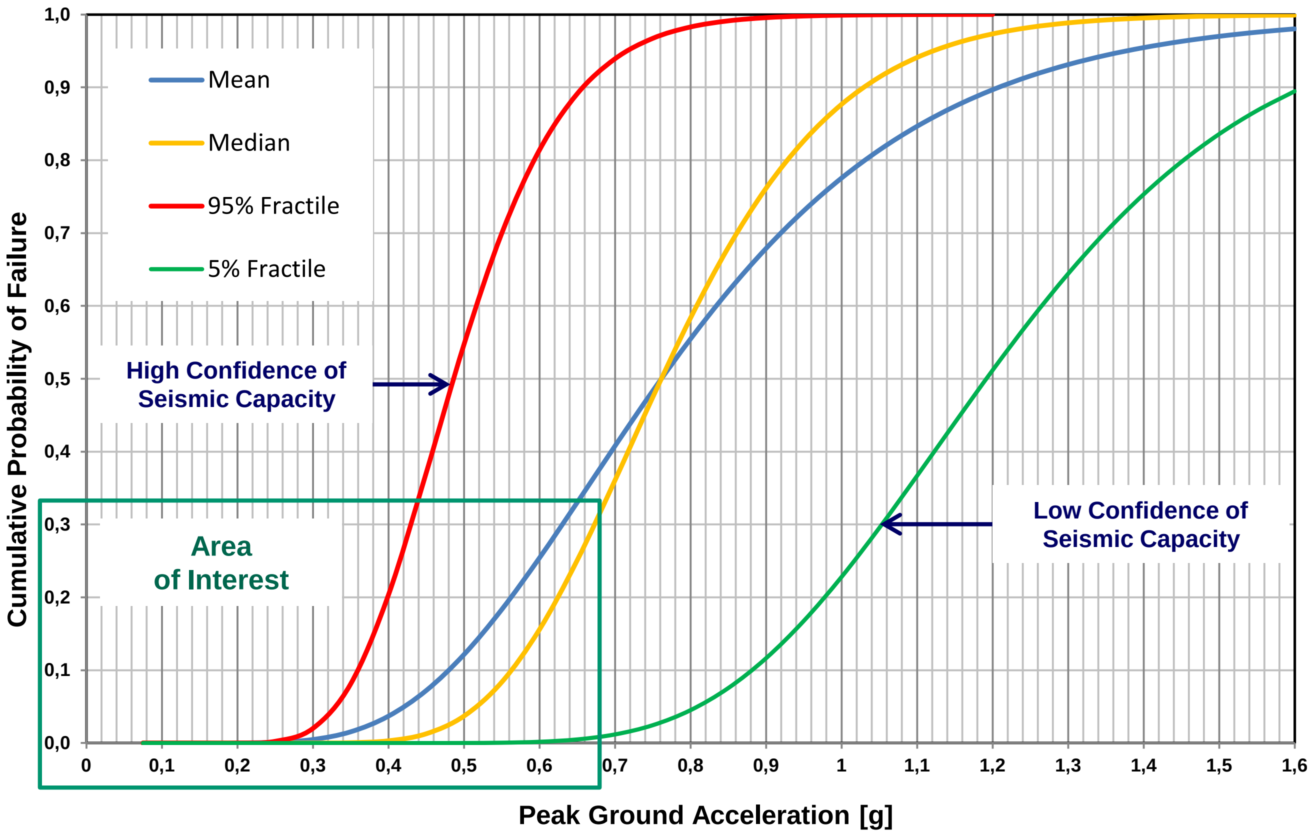


Peak Ground Acceleration (PGA) expressed by „gravity constant“

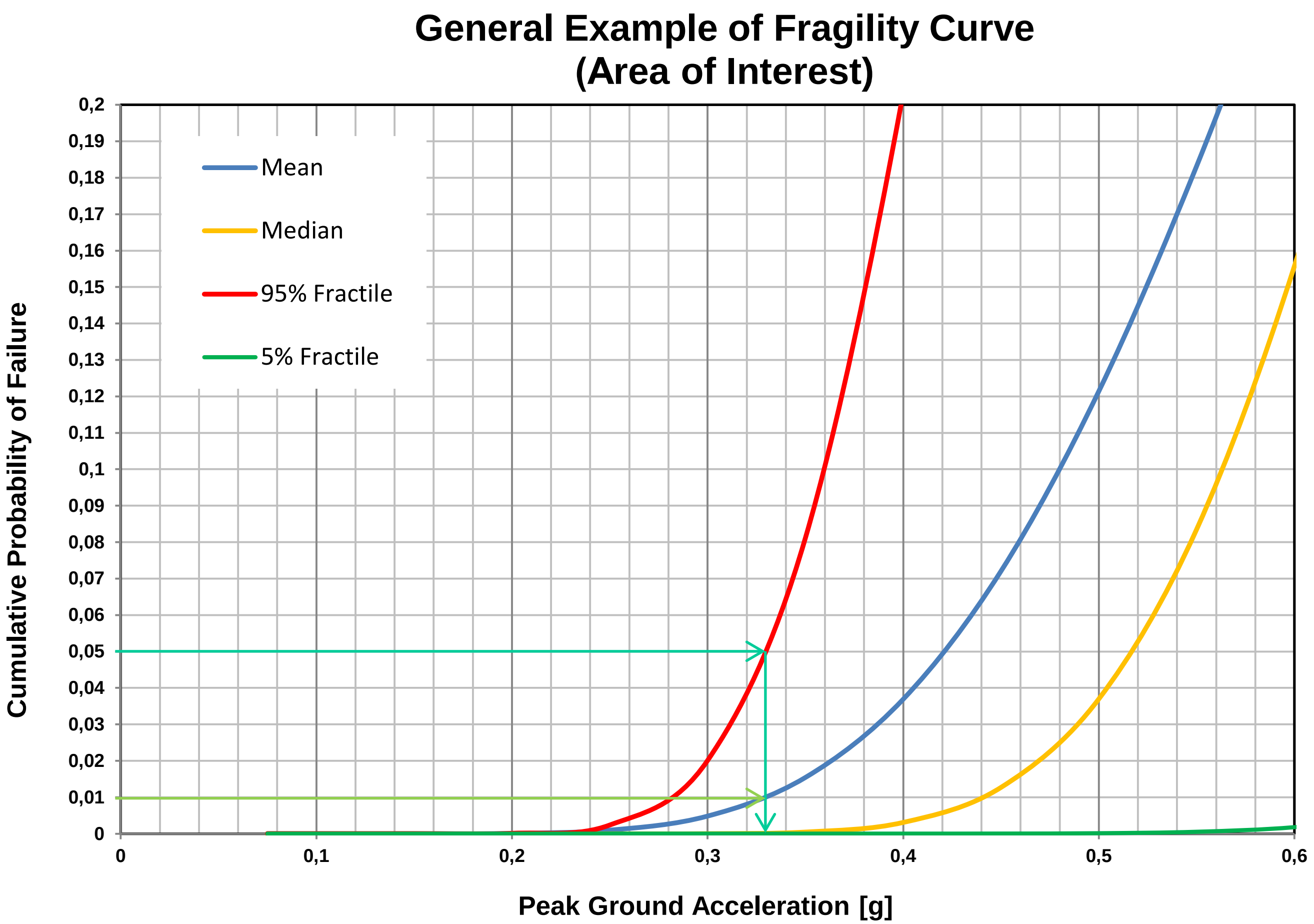
{REFERENCE} - Excerption from: GIP-SQUG

Seismic Capacity - Seismic Resistance

General Example of Fragility Curve

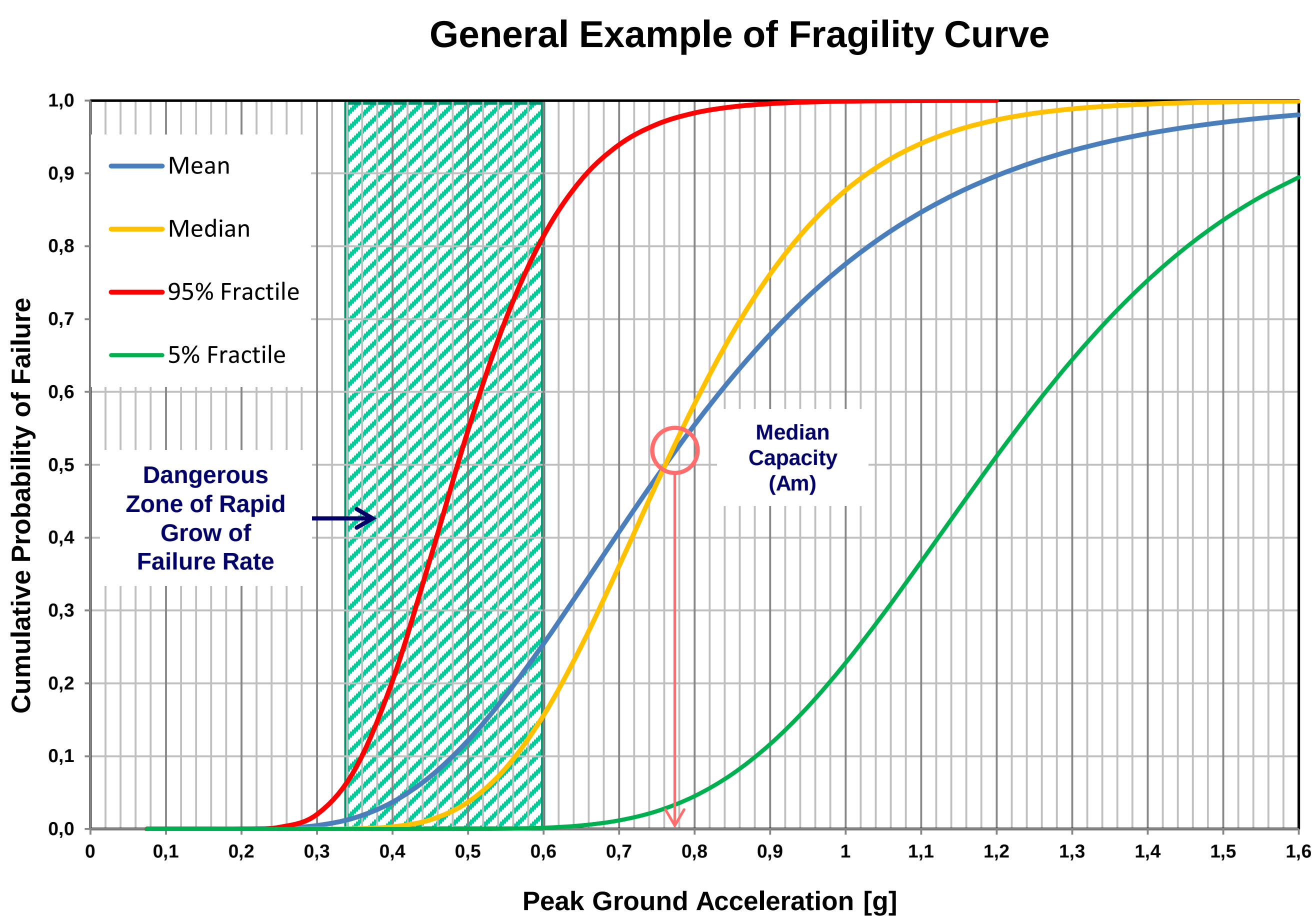


Seismic Capacity - Seismic Resistance

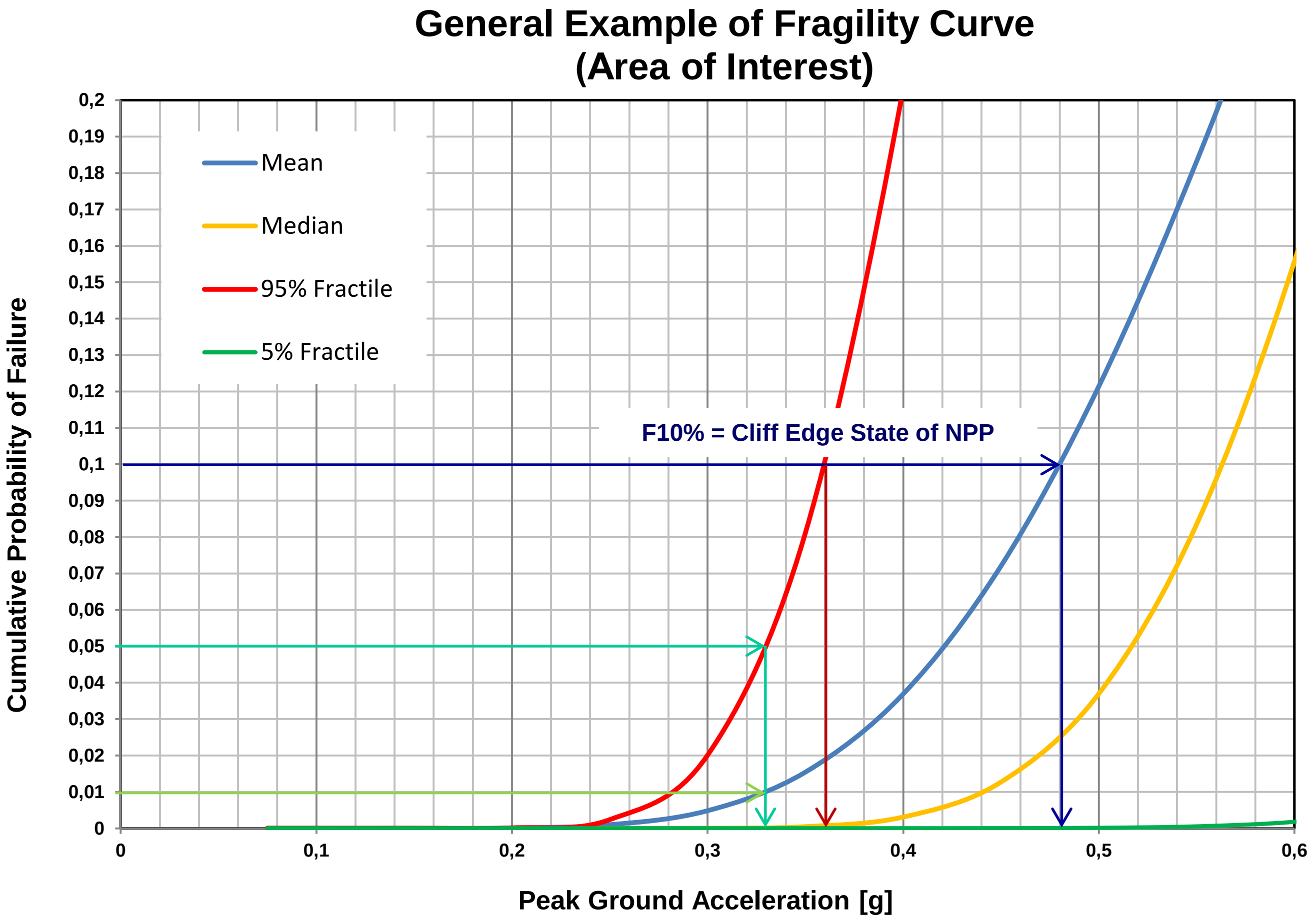


High Confidence of Low Probability Failure (HCLPF) → **95% Confidence of 5% Probability of Failure** → **Mean Confidence and 1% Probability of Failure**

Seismic Capacity - Seismic Resistance



Cliff Edge State



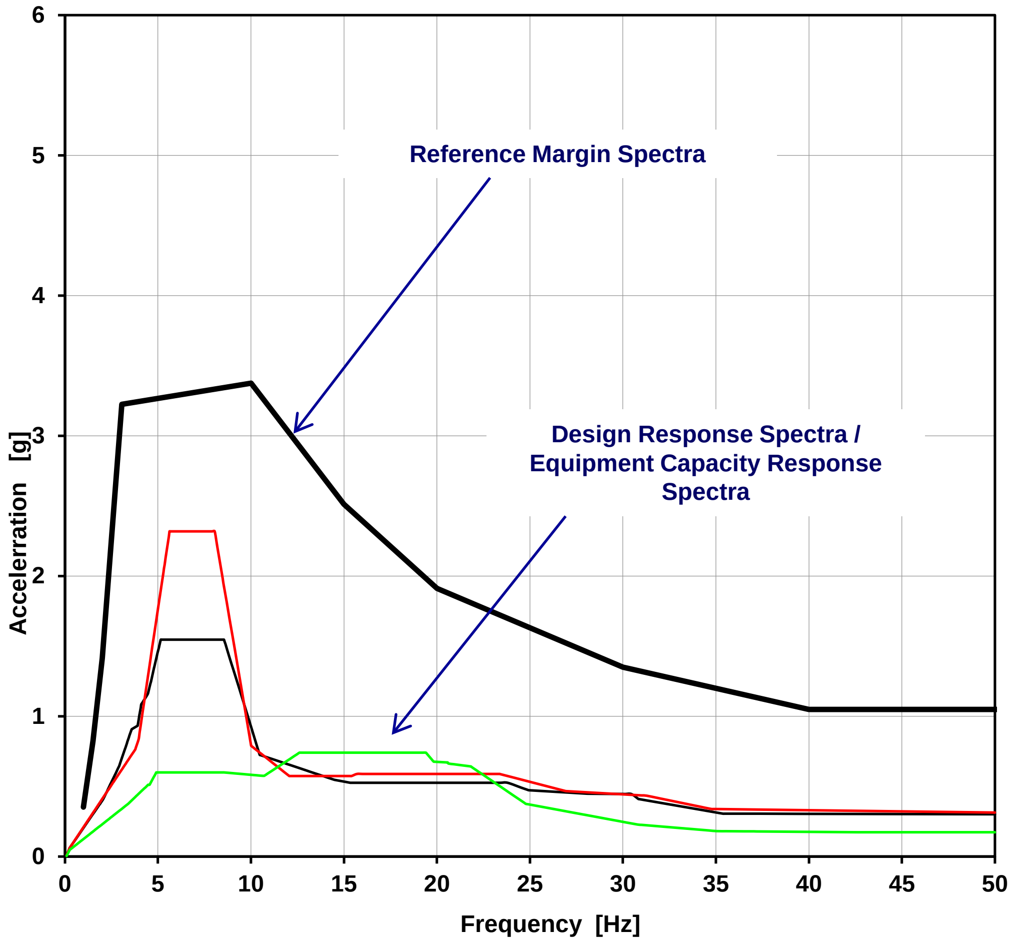
Design/Qualification Rules and Evaluation of Margins

- Application of nuclear standards appropriate margins required by Regulatory body.
- Conservatism of applied evaluation-design method of equipment capacity can be quantified by separation of all variables (loads, capacity, applied method, etc.) and definition their uncertainty and randomness.
- Equipment capacity with no one applied conservatism have a median capacity value **Am**.
- The descriptor expressing the individual margin of the component is HCLPF – High Confidence of Low Probability of Failure.
- Quantification of margins by HCLPF have to follow the rules made. Internationally and seismic engineers recognized technique applicable for determination of HCLPF is CDFM method.
- For equipment generic qualification the HCLPF factor is appropriate to use with Generic Capacity Spectra and

Design/Qualification Rules and Evaluation of Margins

- For equipment generic qualification the HCLPF factor is appropriate to use with Generic Capacity Spectra and Reference Margin Spectra.
- Generic Capacity Spectra is applied for Equipment Qualification. Reference Margin Spectra can be utilized in qualification process but intentionally is applied for final evaluation of safety seismic margin by technique of CDFM method.

Design/Qualification Rules and Evaluation of Margins



Summary of CDFM Method

SUMMARY OF CONSERVATIVE DETERMINISTIC FAILURE MARGIN APPROACH

Load Combination:	Normal + SME
Ground Response Spectrum:	Conservatively specified (84% Non-Exceedance Probability).
Damping	Conservative estimate of median damping
Structural Model:	Best Estimate (Median) + Uncertainty Variation in Frequency
Soil-Structure-Interaction:	Best Estimate (Median) + Parameter Variation
Material Strength:	Code specified minimum strength or 95% exceedance actual strength if test data are available.
Static Strength Equations:	Code ultimate strength (ACI), maximum strength (AISC), Service Level D (ASME), or functional limits. If test data are available to demonstrate excessive conservatism of code equation then use 84% exceedance of test data for strength equation.
Inelastic Energy Absorption:	For non-brittle failure modes and linear analysis, use 80% of computed seismic stress in capacity evaluation to account for ductility benefits, or perform nonlinear analysis and go to 95% exceedance ductility levels.
In-Structure (Floor) Spectra Generation:	Use frequency shifting rather than peak broadening to account for uncertainty plus use median damping.

{REFERENCE} - Excerption from: EPRI NP-6041

Final Remarks

- Design Basis Level for External Events and associated Safety Margins are directly linked with the Performance Goals (CDF/LRF, etc.) needed for checking compliance with the Safety Goals.
- Adequate Safety Margins against External Events need to be demonstrated for safety related SSCs and for the last barrier against large releases.
- External Events with severity greater then design basis may contribute to DBA/BDBA and DEC in terms of unavailability of safety related and mitigation SSCs.
- Beyond Design Basis External Events are associated to Safety Assessment of the design against EE including Safety Margin Assessment.