First Kashiwazaki International Symposium
on Seismic Safety of Nuclear Installations
SESSION C – SEISMIC MARGIN AND RISK ASSESSMENT
Kashiwazaki, Japan, 25 November 2010

"IAEA Safety Guide (NS-G-2.13) on Evaluation of Seismic Safety for Existing Nuclear Installations"

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The evaluation of the seismic safety of existing nuclear installations:

Where are we now?

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1 - BACKGROUND

Why the seismic safety of an existing nuclear installations should be evaluated?

Firstly, because there is a safety requirement:

- **The "*Safety Requirements on the Safety of Nuclear Power Plants: Operation*" states that systematic safety reassessments of the plant are required to be performed by the operating organization throughout its operational lifetime.**
- **In line with that, recommendations on external hazards analysis in periodic safety reviews include the needs to re-evaluate the seismic safety of existing installations.**
- **Safety culture-continuous improvement- "being alert".**

Why the seismic safety of an existing nuclear installations should be evaluated?

. . . and because:

- Evidence of a seismic hazard at the site that is greater than the design basis earthquake
- Regulatory requirements
- Inadequate seismic design
- Seismic vulnerabilities findings
- Occurrence of seismic events affecting the installation
- New experiences from the occurrence of seismic events
- Need to address beyond design basis external events (including earthquakes)
- A programme for long term operation

How to do it?

- Guidelines for the seismic safety evaluation of existing nuclear installations — mainly nuclear power plants — have been developed and used in many Member States.
- The development and use of guidelines on the seismic safety evaluation of existing nuclear installations started in the USA, at beginning of 1980s, where such guidelines were developed and their application to all existing nuclear power plants was required.
- These methods have been adapted to specific situations and have been applied in the seismic safety evaluation of many nuclear installations in other countries.

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How to do it?

- Since late 80s, the IAEA assisted a number of Member States, mainly those operating VVER type reactors in Eastern European countries.
- From 1987 to 2010, about 116 seismic safety review services were conducted in relation to seismic re-evaluation issues of existing installations.
- Specific technical guidelines were developed for some installations, adapting and applying these methods.
- Using all this experience, an IAEA Safety Report (No 28) was developed and published in 2003.

IAEA TECHNICAL GUIDELINES AND SAFETY REPORT 28

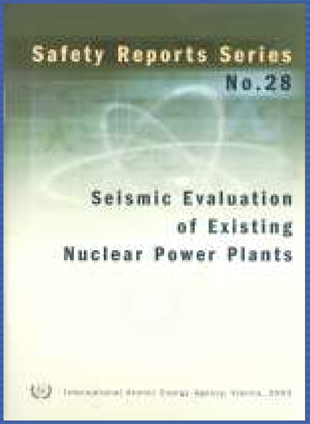
KOZLODUY NPP
- **WANO PROGRAMME MAY 1992**
- **NUCLEAR FACILITIES 1999**

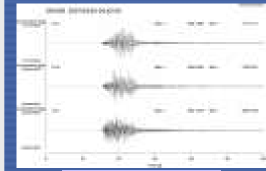
PAKS NPP 1994

ARMENIA NPP 1997

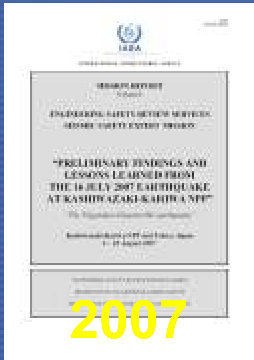
BOHUNICE NPP (V2 Units) 1999

SAFETY REPORT SERIES No 28 (April 2003) :





NEW NEEDS FROM MSs



>16 YEARS

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NEW NEEDS AND LESSONS LEARNED

- Experience gained from the Niigataken Chuetsu-oki earthquake in July 2007, and its effects on the Kashiwazaki-Kariwa NPP (K-K NPP).
- IAEA involvement in the seismic safety review of K-K NPP through 8 missions, from 2007 to 2009, and extrabudgetary activities.
- Main observations and lessons learned were related to:
  - Seismic instrumentation
  - Ageing
  - Sloshing of water in spent fuel pool
  - Seismically induced floods and fires
  - Behaviour of non-safety SSCs
  - Actions to be taken before, during and after earthquake occurrence and need of properly established procedures.

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Comparison of Design/Reevaluated Values for PGA

Name of Installation	Design Value of PGA	Re-evaluated value (Deterministic or corresponding to 10^{-4} annual frequency
Krsko NPP (Slovenia)	0.3g	0.4g
Metzamor NPP (Armenia)	0.1g	0.2g → 0.35g
Mochovce NPP (Slovakia)	< 0.1g	~ 0.2g
Bohunice NPP (Slovakia)	< 0.1g	0.28g

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Comparison of Design/Reevaluated Values for PGA

Name of Installation	Design Value of PGA	Re-evaluated value (Deterministic or corresponding to 10^{-4} annual frequency
Paks NPP (Hungary)	< 0.1g	0.35g → 0.28g
Cernavoda NPP (Romania)	0.2g	> 0.3g
Kozloduy NPP (Bulgaria)	< 0.1g	0.1g → 0.2g
Belene NPP (Bulgaria)	0.1g	0.25g

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Revised New Seismic Hazard at the K-K NPP Site

- The following faults were taken into consideration upon determining the design-basis seismic motion.

Active fault		Length of fault	Scale of earthquake [*1]		Angle of inclination [*2]	Notes
F-B fault		About 34km[*3] (About 27km)	34km	M7.0	Southeastern inclination 35•	As a conservative approach, the total length of the fault was identified as about 34km.
Nagaoka Plain Western Boundary Fault Zone	Kakuda-Yahiko fault	About 54km	91km	M8.1	Western inclination 50•	As a conservative approach, these faults were assumed to move together.
	Kihinomiya fault	About 22km				
	Katagai fault	About 16km				
F-D fault • •		About 30km	55km	M7.7	Southeastern inclination 35•	As a conservative approach, these faults were assumed to move together.
Takada-oki fault		About 25km				

Note 1: With regard to the F-B fault, the scale of magnitude was determined by the scale of the assumed fault surface
• •between the magnitude and the size of the fault surface at the hypocenter of the Niigata-Chuetsu-Oki earthquake. F
• • • •magnitude was determined by the length of ground surface faults using the formula of Matsuda (1975).
Note 2: Angle of inclination: the inclination of fault surface against the horizontal surface.
Note 3: The length of the fault, according to our survey, is 27km, but taking a conservative approach, it is assumed to l

Assessment currently under review

Seismic motion	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Niigataken Chuetsu-oki Earthquake (observed on the foundation of reactor building)	680	606	384	492	442	322	356
Response to the design basis seismic motion Ss (on the foundation of reactor building)	829	739	663	699	543	656	642
The peak value of the design basis seismic motion Ss (on the free surface of base stratum)	2,280				1,156		

The value represents the larger value among horizontal ones (south-north and east-west). (Unit: Gal)

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JAPAN-New Design Basis Ground Motions (under review)

Plant sites	Contributing earthquakes	New DBGM Ss *1	DBGM S2
Tomari	Earthquakes undefined specifically	**550 Gal**	370 Gal
Onagawa	Soutei Miyagiken-oki (M8.2)	**580**	375
Higashidoori	Earthquakes undefined specifically	**450**	375
Fukushima	Earthquake near the site (M7.1)	**600**	370
Tokai	Earthquakes undefined specifically	**600**	380
Hamaoka	Assumed Tokai (M8.0), etc.	**800**	600
Shika	Sasanami-oki Fault (M7.6)	**600**	490
Tsuruga	Urazoko-Uchiikemi Fault (M6.9), etc. →Mera-Kareizaki-Kaburagi F.(M7.8)	**650→800**	532
Mihama	C, Fo-A Fault (M6.9)→B-Fault(M7.7)	**600→750**	405
Ooi	C, Fo-A Fault (M6.9)→Fo-A+Fo-B（M7.4)	**600→700**	405
Takahama	Fo-A Fault (M6.9)	**550**	370
Shimane	Shinji Fault (M7.1)	**600**	456
Ikata	Central Tectonic Structure (M7.6)	**570**	473
Genkai	Takekoba F.（M6.9) → Enhanced uncertainty consideration	**500 →540**	370
Sendai	Gotandagawa F.(M6.9), F-A(M6.9)	**540**	372
Kashiwazaki-Kariwa	F-B Fault (M7.0), Nagaoka-plain-west Fault (M8.1)	**2300 (#1 side) 1209 (#5 side)**	450
Monjyu (Proto Type FBR)	Shiraki-Niu F.(M6.9) , C F.(M6.9)→Small Damping	**600→760**	408
Shimokita Reprocessing F.	Deto-Seiho F.(M6.8), Yokohama F.(M6.8)	**450**	320

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IAEA SAFETY GUIDE NS-G-2.13

- **As result of all this process, IAEA developed a safety standard –a new safety guide- providing recommendations on meeting the safety requirements and expanding the scope to <u>existing</u> nuclear <u>installations</u>** (e.g. research reactors, nuclear fuel cycle and reprocessing facilities, and independent fuel storage facilities).

- **The new safety guide was published in 2009 after 4 years of development through a formal consensus process with all IAEA Member States.**
  - The Safety Reports No. 28 on Seismic Evaluation of Existing Nuclear Power Plants is still kept providing detailed complementary information, relevant to this Safety Guide. A revision and updating of this Safety Report is under development within the framework of ISSC extrabudgetary programme.

2 - THE IAEA SAFETY GUIDE NS-G-2.

NEW - 2009

IAEA Safety Standards

for protecting people and the environment

Evaluation of Seismic Safety for Existing Nuclear Installations

Safety Guide

No. NS-G-2.13

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Approved for publication by the IAEA Commission on Safety Standards in September 2008.

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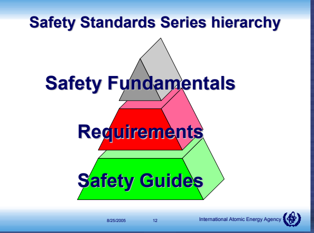


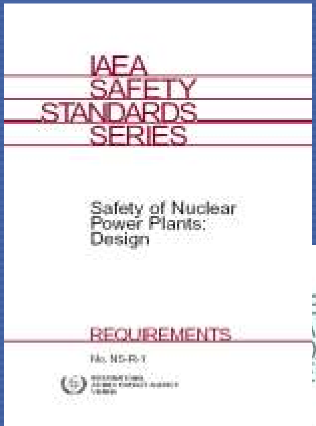
IAEA Safety Standards - Seismic Safety

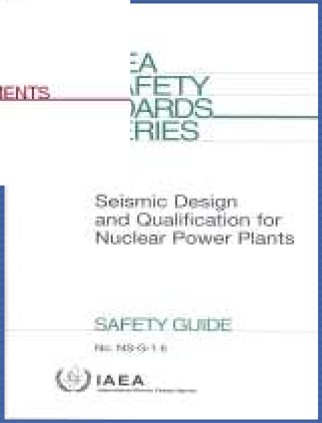
SITE EVALUATION

Seismic Hazard

DESIGN

new installations

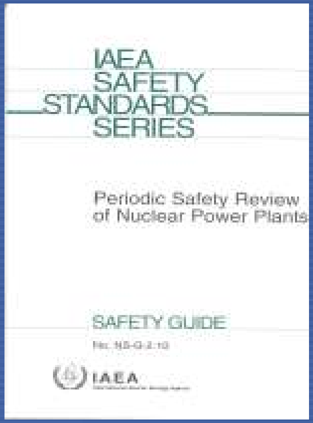




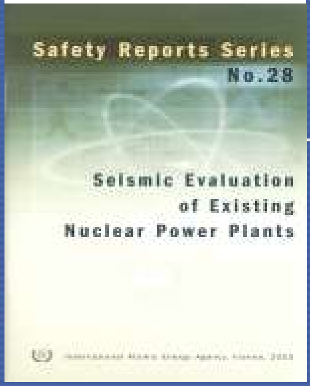
Seismic Design and Qualification

OPERATION

operating/existing installations



Periodic Safety Review



The complete lifetime of the installation

Objectives of the Safety Guide

- To provide recommendations in relation to the seismic safety evaluation of existing nuclear installations.

- It is intended for use by regulatory bodies, responsible for establishing regulatory requirements, and by operating organizations directly responsible for the execution of the seismic safety evaluation and upgrading programmes

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Scope of the Safety Guide

- **It addresses an extended range of <u>existing</u> nuclear <u>installations</u>**
  - **<u>INSTALLATIONS</u> the methodologies developed for nuclear power plants are applicable to other nuclear installations through a graded approach.**
  - **<u>EXISTING NUCLEAR INSTALLATIONS</u> are those installations that are either (a) at the operational stage (including long term operation and extended temporary shutdown periods) or (b) at a pre-operational stage for which the construction of structures, manufacturing, installation and/or assembly of components and systems, and commissioning activities are significantly advanced or fully completed. In existing installations that are at the operational and pre-operational stages, a change of the original design bases may lead to a significant impact on the design and, consequently, to important hardware modifications.**

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Seismic Safety Evaluation Methodologies

- **Two methodologies are discussed in detail in this Safety Guide:**
  - **The deterministic approach: generally represented by the SEISMIC MARGIN ASSESSMENT (SMA); and**
  - **The probabilistic approach: the SEISMIC PROBABILISTIC SAFETY ASSESSMENT (SPSA).**
- **Variations of these approaches, or alternative approaches, may be demonstrated to be acceptable also.**
- A clear distinction should be made between a seismic safety evaluation that does not entail a change in the design basis earthquake (i.e. SL-2) and a seismic safety evaluation where a change in the design basis earthquake is required by the regulatory body.

Seismic Safety Evaluation – "*as-is*" conditions

- **The seismic safety evaluation of existing installations strongly depends on the actual condition of the installation at the time the assessment is performed.**
- **This key condition is denoted the '*as-is*' condition, indicating that an earthquake, when it occurs, affects the installation in its actual condition, and the response and capacity of the installation will depend on its actual physical and operating configuration.**
- **The *as-is* condition of the installation is the baseline for any seismic safety evaluation programme.**
- **It includes the '*as-built*', '*as-operated*', '*as-maintained*' conditions of the installation, and its condition of ageing at the time of the assessment.**

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Objectives of a Seismic Safety Evaluation Programme

It may include to:

- **Demonstrate the Seismic Safety Margin beyond the original design basis, no cliff edge effects;**
- **Identify seismic vulnerabilities and the weak links;**
- **Identify and prioritize the possible upgrades;**
- **Provide input for risk informed decision making;**
- **Assess the seismic risk (expressed in CDF, LERF) and/or plant capacity (expressed in end-state fragility or HCLPF) against regulatory requirements;**
- **Evaluate a group of nuclear installations in a region or a country to determine their relative seismic capacity and/or their risk ranking.**

The agreement of the regulatory body should be obtained to define the objectives of the Programme.

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Outcome (end product) of the Programme

It may include one or more of the following:

- Measure of the seismic capacity of the installation in probabilistic or deterministic terms;
- Identification of structures, systems or components with low seismic capacity and their associate consequences for plant safety, for decision making on upgrading programmes;
- Identification of operational modifications to improve seismic capacity;
- Identification of improvements to housekeeping;
- Identification of actions to be taken before, during and after occurrence of an earthquake affecting the installation.

Formulation of the Programme

- After selecting the evaluation methodology, the programme should be established covering the following aspects:
  - Definition of the seismic input, (i.e. the Review Level Earthquake);
  - Verification of the geological stability of the site with respect to the potential for fault displacement;
  - Acceptance criteria;
  - Seismic behaviour of the installation when subjected to the earthquake hazard;
  - Use of Seismic Experience and Test Data (should be verified to the specificity of the nuclear installation, and SSCs, being evaluated);
  - Plant Walkdowns (the key element of the seismic re-evaluation programme);
  - Ageing considerations;
  - Seismic instrumentation;
  - Criteria for upgrading.

Organization of the Programme

- The successful development and completion of the programme requires the establishment of a dedicated organization with clear responsibilities and with the necessary technical capabilities for undertaking this project.
- A complete and detailed work plan should be prepared for the implementation of the programme.
- The time schedule is strongly influenced by the availability of access to buildings, areas and/or equipment during both the evaluation phase.
- The key starting steps of the programme are:
  - the compilation of the available original seismic design related information and the identification and acquisition of missing as-is information,
  - the determination of the seismic ground motion parameters for the evaluation (i.e. the Review Level Earthquake), and
  - the development of the list of systems, structures and components to be evaluated in accordance with the objectives of the programme and the safety functions and shutdown paths to be ensured.

SMA and SPSA METHODOLOGIES

SMA STEPS:

- Selection of the assessment team
- Selection of the review level earthquake
- Plant familiarization and data collection
- Selection of success path(s) and SSEL
- Determination of the seismic response
- Plant walkdown for seismic capability
- HCLPF determination for selected SSCs
- HCLPF calculations for the installation
- Enhancements to the programme (e.g. seismic induced fire and flood, detailed relay reviews)
- Peer review
- Documentation.
- Detailed Methodology is described in US-DOE EH 545 and/or EPRI NP 6041
- SMA Methodology will be detailed in the new SR that will replace Safety Report Series 28

SPSA STEPS:

- Selection of the assessment team
- Seismic hazard assessment
- Plant familiarization and data collection
- Systems and accident sequence analysis
- Determination of the seismic response
- Human reliability analysis for seismic events
- Plant Walkdowns for seismic capability
- Fragility calculations for selected SSCs
- Risk quantification for the installation
- Enhancements to the programme (e.g. seismic induced fire and flood, detailed relay reviews)
- Peer review
- Documentation
- Detailed methodology described in US-EPRI Implementation Guide 1002989
- SPSA Methodology will be detailed in the new SR that will replace Safety Report Series 28

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Common Elements of SMA and SPSA Methodologies

- **Plant waldown and screening procedure**
- **Evaluation of soil capacity**
- **Structure Response (including in-structure response spectra)**
- **Equipment – Structure interface (anchorage)**
- **Identification and review of electrical devices (e.g. essential relays and relay chatter evaluation)**
- **Evaluation of distribution systems**
- **Evaluation of reactor system**
- **Identification of seismic interactions**
- **Seismic induced fire and flood**

PLANT WALKDOWNS

- Plant walkdowns are one of the most significant activities of the seismic safety evaluation programme of existing installations.
- Walkdown and Screening include:
  - Preparatory activities for the walkdown
  - Preliminary walkdown of the selected SSCs;
    - Identify, classify and screen in those items requiring a detailed HCLPF evaluation.
    - Collect more information on those items which will require more detailed seismic assessment.
  - Detailed walkdowns:
    - Collect data for filling the detailed information contain on the SEWS. This walkdown includes preparation of a SEWS for each SSC not screened out in preliminary walkdown.
  - Documentation.

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SMA SEISMIC CAPACITY

- Conservative Deterministic Failure Margin approach (CDFM):
  - RLE 84 percentiles NEP
  - Load combination: Normal + RLE
  - Damping: conservative estimate of median damping
  - Structural Model: Best estimated + variability in Frequency
  - SSI: Best Estimated (Median) + SSI parameter variation
  - Material Strength: Minimum Code Strength or 95% NEP
  - Capacity Equations: Code ultimate strength (ACI), maximum strength (AISC), Service level D (ASME) or functional limits.
  - Inelastic Energy Absorption: for linear analysis
  - In-structure FRS generation: use frequency shifting rather than peak broadening to account for uncertainty
  - Local ductility factors may be used if justified

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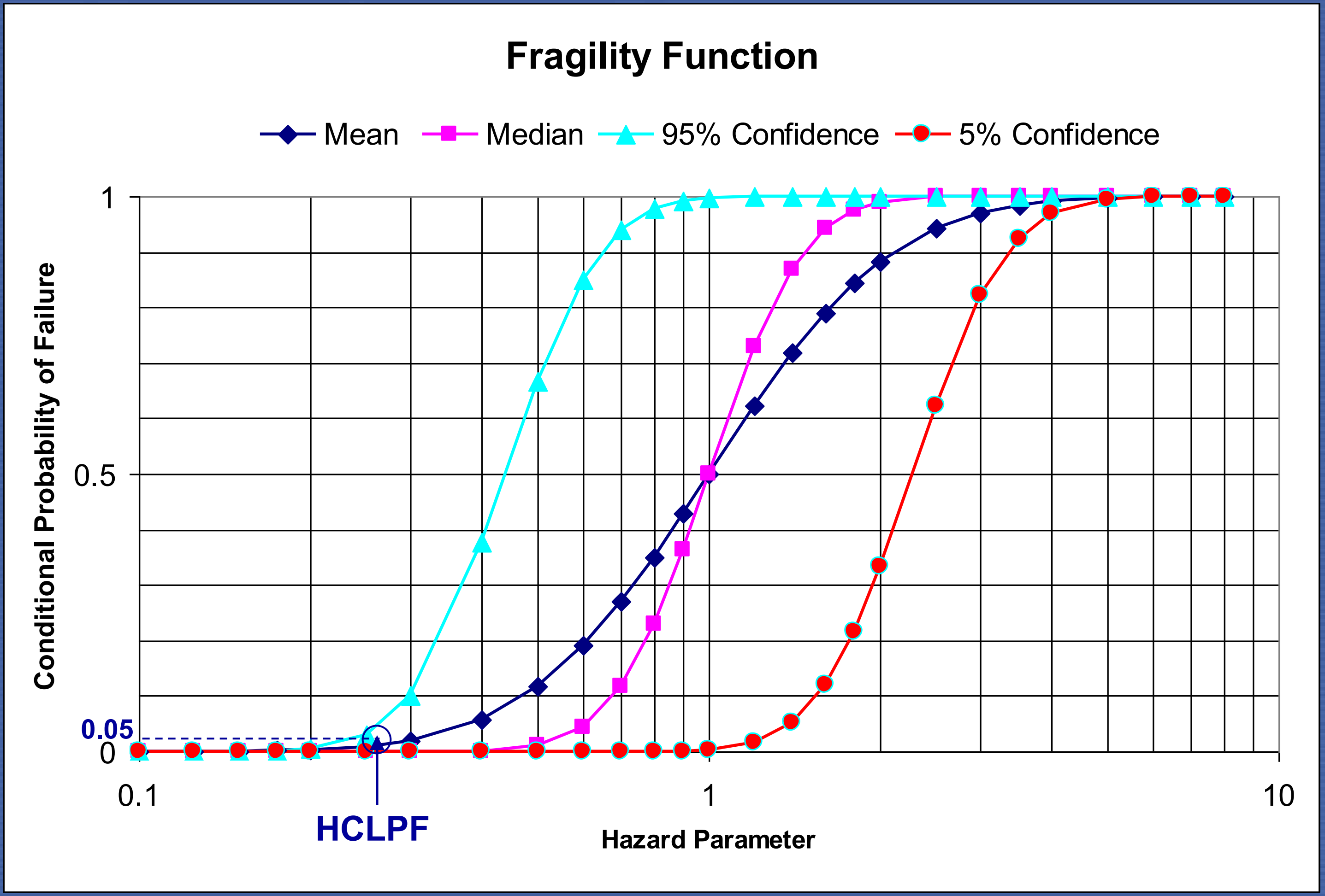
Common Elements of SMA and SPSA Methodologies



Management System for Seismic Safety Evaluation

- **CONFIGURATION MANAGEMENT:**
  - **The operator should implement a configuration management programme to ensure that, in the future, the design and construction of modifications to SSCs, the replacement of SSCs, maintenance programmes and procedures, and operating procedures do not invalidate the results of the implemented programme of seismic safety evaluation.**

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CONCLUDING REMARKS

- **The seismic safety of a nuclear installation shall be reassessed during the operational lifetime as part of the periodic safety reviews. Safety culture, continuous improvement process, being always alert…**
- **Experience from the occurrence of actual earthquakes or new estimate showed a higher seismic hazard than the one considered at the time of the original designs**
- **Comprehensive and systematic methodologies were developed and used during last 30 years for conducting such re-evaluations, using realistic assumptions and behaviour criteria**
- **A new and updated IAEA safety guide is now available reflecting international consensus and recognition of such needs and tools, while more detailed guidance is under preparation (Safety Reports)**
- **Many nuclear plants have been seismically re-evaluated in many countries resulting in increasing seismic safety**

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Thank you for your attention

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