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Interim Report on Metallic Component Margins Under High Seismic Loads

Survey of Existing Practices and Status of Benchmark Work

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NEA
NUCLEAR ENERGY AGENCY

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Organisation de Coopération et de Développement Économiques
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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was created in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety among NEA member countries. The main tasks of the CSNI are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and reach consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The priority of the CSNI is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs, the committee provides a forum for improving safety-related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA Committee on Nuclear Regulatory Activities (CNRA), which is responsible for the issues concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with the other NEA Standing Technical Committees as well as with key international organisations such as the International Atomic Energy Agency (IAEA), on matters of common interest.

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FOREWORD

This report has been written in the framework of the Working Group on Integrity and Ageing of Components and Structures (IAGE WG) of the NEA, and more precisely with active participation of members of the Seismic sub-group.

This Fukushima based activity (F-CAPS), entitled “Metallic Component Margins under High Seismic Loads (MECOS)”, was approved by the CSNI in June 2012. This activity is being conducted by OECD/NEA and its member countries to address issues arising from the Fukushima Daiichi accident. The approved content of the MECOS work is as follows:

- Review of existing practices to consider seismic hazards in design of systems and components.
- Revisit tests, define typical seismic loads, assess consequences on failure mode and Leak Before Break (LBB).
- Review consequences of potential ageing on these components: e.g. degradations (cracks or local thinning) and reduced material properties.
- Define and perform a benchmark on a typical system for assessing the methods and margins of analysis for high seismic level loads.
- Provide conclusions and recommendations for seismic assessment and complementary R&D of components under high seismic loads.

This interim report of the MECOS project includes the review of reports on seismic tests and analyses from different countries, the survey report, and the status of the benchmark as well as preliminary conclusions of this activity.

OECD/NEA thanks every contributor listed in this status report and specifically the main contributors of this report: Mr. Andrei Blahoainu and Mr. Pierre Labbe.

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Canada:	CNSC and CANDU Energy
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Czech Republic:	NRI REZ
Korea:	KAERI (Korea Atomic Energy Research Institute)
Belgium:	Tractebel Engineering S. A.
UK:	EDF Energy Nuclear Generation Ltd
Sweden:	SSM (Sweden's Radiation Safety Authority)
Japan:	NRA (Nuclear Regulatory Authority - former JNES)
USA:	NRC
Spain:	CSN (Spanish Nuclear Safety Council)

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EXECUTIVE SUMMARY

OECD/NEA/CSNI Working Group on Integrity and Ageing of Components and Structures (WGIAGE) has the main mission to advance the current understanding of those aspects relevant to ensuring the integrity of structures, systems and components under design and beyond design loads, to provide guidance in choosing the optimal ways of dealing with challenges to the integrity of operating as well as new nuclear power plants, and to make use of an integrated approach to design, safety and plant life management.

The activity (CAPS) of the WGIAGE group, entitled "Metallic Component Margins under High Seismic Loads (MECOS)", was initially proposed by the metal sub-group of WGIAGE and approved by the CSNI in June 2012 as a Fukushima activity (F-CAPS). The proposal is aimed to assess the consequences of external hazards on plant safety. The main objectives of the MECOS project were to quantify the existing margins in seismic analysis of safety class components for high seismic loads and assess the existing design practices within a benchmark activity.

The first phase of MECOS work included a survey on the existing seismic regulations and design analysis methods in the member countries. The survey was conducted by means of a questionnaire and a total of 24 questions were asked. The questionnaire consists of three parts: Seismic Input, Seismic Design Basis, and Beyond Seismic Design Basis. The majority of the respondents use the Standard or Modified Shape Spectrum and only a few countries are using the Uniform Seismic Hazard Spectra (UHS) in their seismic design regulations. All of the respondents have minimum seismic demand in their national or adopted standards. The number of defined and used seismic levels for the design of mechanical components is one or two. Almost all of the respondents are using combined testing and analysis methods for seismic qualification and design. Some countries (e.g. Canada, Finland, USA, France, Japan and UK) have specific requirements for seismically designed components to be able to withstand beyond design basis earthquake. If the specific requirements for beyond design basis earthquake exists then design robustness of DBE components are not required.

The second phase of MECOS work included a selection process for the experiments to use for the benchmarking calculations of the three candidate tests and test facilities. These three tests are described briefly in this report. The detailed documentation and recent vintage of the experimental programme by Indian BARC Institute was selected from amongst these three candidates as the benchmark for the MECOS calculations.

The following preliminary conclusions can be made based on the work to date:

a) All the experiments carried out around the world conclude unanimously that there are large margins in the design of piping systems. However,

b) The failure mode addressed by the design criteria (plastic instability) is not the one observed in the experimental campaigns (fatigue-ratcheting).

Preliminary conclusion of MECOS is that the Fukushima accident has not raised any new issues in seismic regulations and in design of components and structures.

1. INTRODUCTION

The main objectives of the MECOS project are to:

- Quantify the existing margins in seismic analysis of safety class components for high seismic loads associated with existing design practices through a benchmark activity
- Propose more realistic analysis for high seismic loading and provide recommendations for possible complementary R&D.

MECOS was initially proposed by the metal sub-group and approved by the CSNI in June 2012. As the project was dormant, it was decided at the WGIAGE meeting in April 2013 that:

- It will be handled directly by the Main Group with a close cooperation between the metal sub-group and the seismic sub-group.
- The work will focus on research and not on regulatory aspects
- A project team composed by nominated representatives from EDF, JNES, CNSC, USNRC and GRS was nominated.

A kick-off meeting was held on June 10^{th} 2013. It was decided that:

- EDF would take the lead on compiling a document summarizing the latest seismic tests on components and piping systems and the analyses performed based on relevant reports provided by USNRC and JNES. On this basis, EDF will identify the best documented tests for the purpose of the benchmark.
- CNSC would develop a survey on the existing seismic design and re-evaluation practices.

According to the Summary report of the 37th WGIAGE Meeting (April 2014), the purpose of this interim report is to provide:

- Review of the seismic tests.
- The survey report
- The status of the benchmark
- Some preliminary conclusions and recommendations for future work.

2. REVIEW OF THE SEISMIC TESTS

A series of 114 reports on seismic tests and analyses of piping systems has been compiled by EDF. The corresponding list is presented in the appendix I. The vast majority of these documents are available on a dedicated website:

https://coopernic-ext.edf.fr/lotus/myquickr/mecos-project/accueil/

Among the series of tests carried out around the world, the most interesting are:

a) the USA Piping and fitting dynamic reliability program;

b) the NUPEC Large-Scale Piping Systems Test Programme;

c) the BARC piping system test;

Short descriptions of these three test programs are presented below.

2.1 The USA Piping and fitting dynamic reliability program

This programme, carried out in USA between 1985 and 1987 was funded by the NRC, the DOE and the EPRI. It consisted of tests of components and tests of piping systems.

Components tests

A series of 40 components, most of them under pressure, were tested on a shaking table (Figure 1). There were elbows, tees, reducers and nozzles, all of them of 6” diameter, covering the schedules 10, 40 and 80. For every component, Safe Shutdown Earthquake (SSE) loading was first calculated according to the nuclear design standards (ASME). Then, beyond-SSE input motions were applied to experimentally determine the available seismic margin. Observed margins were much larger than expected, being typically a factor of 15.

The observed failure mode was fatigue-ratchetting (Figure 2) in place of the expected plastic instability. We write “expected” because the failure mode aimed by piping design codes (ASME in USA, RCC-M in France, KTA in Germany, JEAG in Japan, PNAE in Russia...) is plastic instability and the design criteria are intended to prevent against this failure mode.

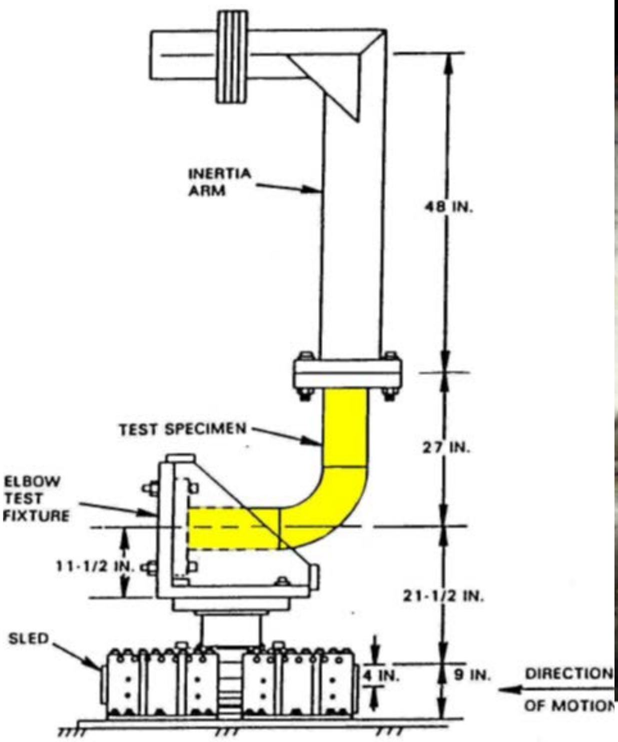

Figure 1: Test setup for components

Figure 2: Ratchetting effect (swelling) observed on a component

System tests

A 6” piping system was also tested. Its 3 supports were placed on 3 different shaking tables (Figure 3) so as to investigate the effects of differential displacements in addition to inertial forces. The conclusions were very similar to those from component tests.

A margin larger than 10 was identified and the observed failure mode was again fatigue-ratchetting (Figure 4).

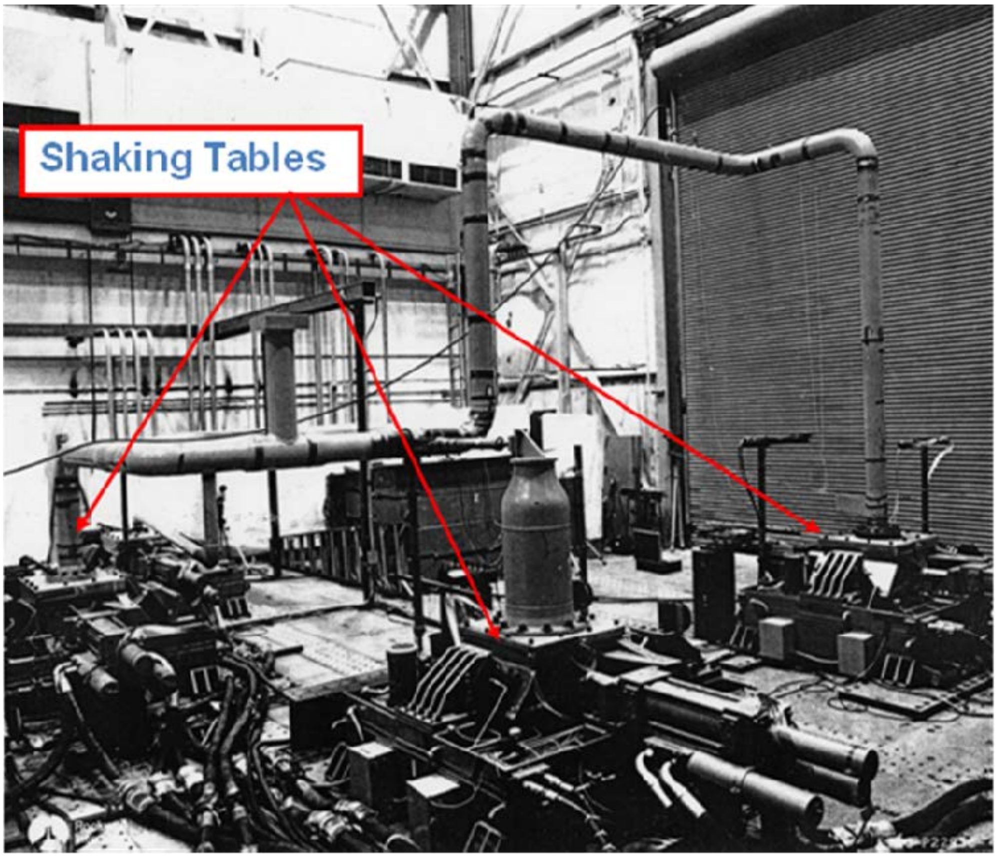

Figure 3: Test setup for piping system

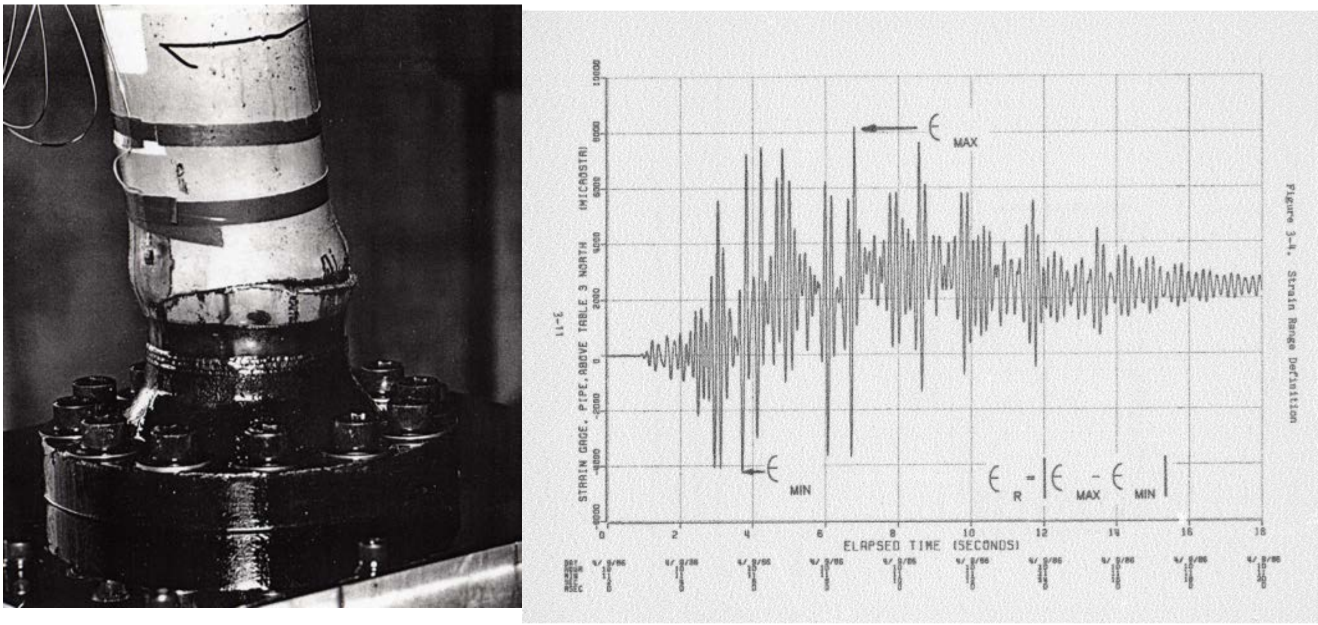

Figure 4: Observed (left) and recorded (right) ratchetting effect

2.2 The NUPEC Large-Scale Piping Systems Test Programme

This programme carried out in Japan was funded by NUPEC. The original documentation is in Japanese but the outlines of the programme are summarized in an NRC document (NUREG/CR-6983) published in 2008. The programme consisted basically of testing a scale 1 pressurized piping system on the large Tadotsu shaking table (Figure 5).

Figure 5: The NUPEC piping system on the Tadotsu shaking table

In a first step the SSE of the piping system was calculated according to the Japanese nuclear standards, JEAG, which are very similar to the ASME and RCC-M. Then the principle of the experiment was to apply on the shaking table a seismic input motion corresponding to 8 times the SSE and to repeat it until failure. The failure occurred during the 5th run. The observed failure mode was again fatigue-ratchet

2.3 The BARC piping system test

This programme consists of a series of tests funded by Bhabha Atomic Research Centre, Mumbai, and carried out by the Central Power Research Institute (CPRI) of Bangalore, India. It consists again of a pressurized piping system tested on a shaking table (Figure 6). A difference with the previous tests is that the conclusion about the failure mode was known by the designers of the tests and that they decided to focus on investigating this failure mode instead of trying to identify the available seismic margin for a single seismic event.

The test was conceived in such a way that the SSE of the piping system is 0.5 g. The applied input motion started at 0.25 g and was progressively increased up to 2.0 g. The key point of the experiment was that at each step the input motion was repeated, typically 10 times, according to the programme Presented in the Figure 7. The observed failure mode was the expected fatigue-ratcheting. An interest of the experimental programme is that it that it focuses on the fatigue-ratcheting facet of the failure mode.

The BARC programme also encompasses simple component tests (pressurized straight pipe in cyclic pure bending) as well as other piping configurations. It is still under progress.

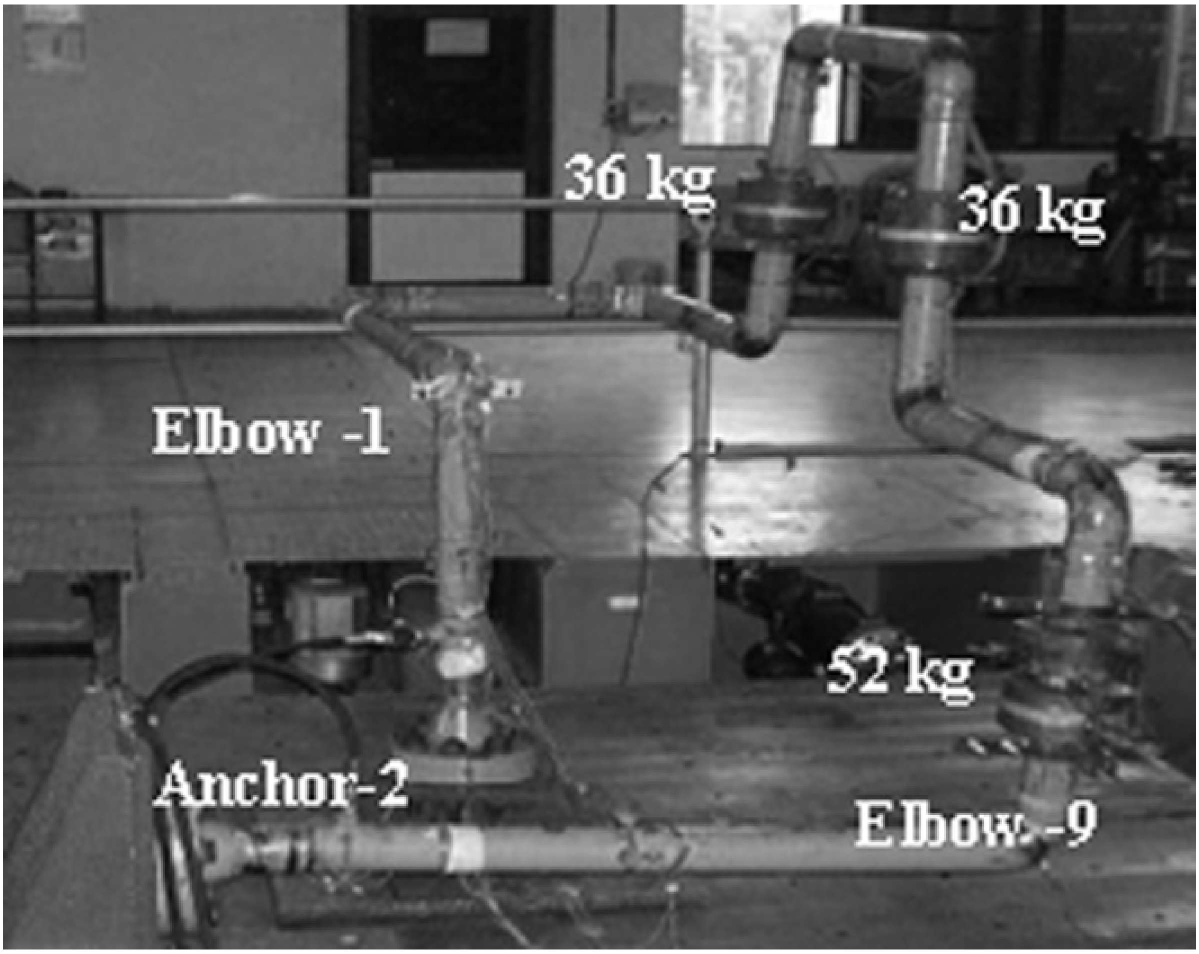

Figure 6: A BARC piping system on the CPRI shaking table

Base excitation (% TRS)	ZPA (g)	Number of base excitation time histories	Maximum primary stress intensity (S_m)
100	0.25	6	1.96
200	0.5	3	2.87
300	0.75	12	3.84
400	1	9	4.82
500	1.25	9	5.81
600	1.5	9	6.81
700	1.75	9	7.8
800	2	3	8.8

Figure 7: The BARC testing programme of the piping system presented in the Figure 6.

3. SURVEY REPORT

The survey was conducted by means of a questionnaire given to the representative of Member States (MS) to complete. A total of 24 questions were asked. The first part of the questionnaire was categorized as Seismic Input [Q1 to Q5]. The second part of the questionnaire dealt with the Seismic Design Basis [Q.6 to Q.19]. The third second section was concerned with Beyond the Seismic Design Basis [Q.20 to Q.24].

Thirteen member States (i.e., Belgium, Canada, Czech Republic, France, Finland, Germany, Japan, Slovenia, South Korea, Spain, Sweden, United Kingdom, and United States of America) responded to the survey.

The survey results are summarized in the order of questions as follows.

Q1: *Do you consider Uniform Seismic Hazard Spectra in the seismic design or you rely on standard design spectrum anchored to specific PGA?*

- Most respondents state that the existing NPPs seismic design is based on Standard/Modified Shape Spectrum anchored to specific PGA (Canada, Finland, Slovenia, Korea, United Kingdom, Belgium, France, Japan, and Czech Republic).
- UHS use on the rise (Canada, Germany, United Kingdom, Sweden, and Japan).

Q2: *What frequency do you associate with PGA?*

- Some respondents state 33 Hz (Canada, Slovenia, Belgium, France, USA and Czech Republic).
- Others use between 33 and 50 Hz (Finland, Korea, Sweden, and Japan)

Q3: *Up to what frequency do you consider the seismic design input?*

- Most respondents use frequency up to 50Hz (Slovenia, Korea, Sweden, UK, Belgium, Japan, and Czech Republic)
- Few use frequency up to 100 Hz (Canada, Finland, Spain and USA)
- Some use frequency up to 90% mass participation (France, Germany).

Q4: *Do you have a minimum seismic design demand defined in your national standard?*

- All respondents have minimum seismic demand in their national standards or adopted standards.
- 0.1g PGA is mostly used except in Germany, Sweden and Japan.

Q5: *How many seismic levels do you define and use in the design of mechanical components?*

- 4 respondents use one level: SSE (Finland, Germany, Sweden and Czech Republic).
- 9 respondents use two levels: DBE and SSE or OBE or half DBE (Canada, Slovenia, Korea, UK, Belgium, Spain, USA, Sweden, France and Japan).

Q6: *Do you have national Codes and Standards for seismic design of mechanical components? If so, please identify them.*

- Most respondents have national seismic design codes, such as, CSA N289, YYL B.7, KTA 2201.4, RCC-M, NRA/JSME/JEAG4601
- The ASME Code as incorporated by 10CFR50.55a is used in USA in design of mechanical components. In addition, 10 CFR Parts 50 and 100, NUREG-0800 and Standard Review Plan (SRP) are in use.
- Some states use US NRC seismic design requirements (USA, Slovenia, Korea, UK, Belgium, Sweden, and Czech Republic).
- Spanish regulation is based on requirements of the country of origin of the nuclear plant project

Q7: *How mechanical components are categorized to identify the expectations regarding the performance from the structural integrity and operability point of view?*

- In all countries mechanical components are categorized and classified for structural integrity and operability.
- Number of the seismic categories (seismic qualification classes) is three in most countries (e.g. Korea, Finland, Spain, Germany ,Belgium and France)
- In USA the Systems, Structures and Components (SSCs) are classified to two categories: Seismic Category I or non- Seismic Category

Q8: *What methods for seismic design do you use?*

- Seismic design by analysis (100%)
- Seismic design by testing (80% except Slovenia and Czech Republic)
- Combination of analysis and testing (Canada).

Q9: *For seismic design of mechanical components which Codes and Standards do you follow?*

For pressure retaining components (e.g. piping, vessels, and tanks):

- Most respondents use ASME code section III for nuclear class components
- Some use their own codes, e.g.; KTA3201.2/ 3204, RCC-M & JSME/JEAG4601 (Germany, France and Japan).

For non-pressure boundary components (e.g. fans, coolers):

- 2 respondents use SQUG GIP guidance (UK, Canada).
- Others use country specific codes & requirements such as KTA3601, AMCA, JEAG/JSME, PNAEG7 & ASCE690 /EUROCODE III (Germany, Slovenia, Belgium, France, Sweden, Japan, and Czech Republic).

For component and piping supports:

- Majority of respondents use ASME code section III sub-section NF
- Three respondents use their own codes such as KTA3205, RCC-M and JEAG/JSME S NC1 (Germany, France and Japan).

Q10: *What acceptance criteria do you use for seismic design (detailed as per item #4 above)?*

- Stress – Exclusively used by most of Member States
- Strain – Also used (Canada, Slovenia, UK, USA, Belgium and Czech Republic)
- Other – Displacement check for operability.

Q11: *Under what conditions is each of the following approach used?*

a) Analysis

- *Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; how do you account for uncertainties in synthesized time histories?*
    - Modal superposition Response Spectrum and linear time history analysis methods are used for complex active SSCs (All respondents)
    - Uncertainties in synthesized Time Histories are accounted by:
        - frequency shifting (Canada)
        - spectrum compatibility (Canada, Germany, Spain and USA)
        - use of multiple TH records (Finland, Germany, Belgium)
        - applying a factor to THs (Slovenia, UK).

- *Equivalent static*
  - For simple systems/single dominant frequency (Canada, UK, USA, Japan, Czech Republic)
  - For Rigid equipment (Finland)
  - Non pressure retaining components or RCC-M Class 2/3 components (Slovenia, France)

b) Testing
- For I&C, mechanical component's strength and functionality/operability check (Canada, Finland, Germany, Slovenia, UK, USA, Belgium, France, Czech Republic)
- For active & small components (Korea, Belgium, Japan)

c) Combination of Analysis and Testing
- When testing alone is impractical (Slovenia)
- For strength and functionality check of essential components like main PHT pump/Diesel generators, valves (Canada, UK, France)
- When requirements of the national standard are fulfilled (USA – standards RG1.20 and NUREG-800)
- Some respondents have no requirements for combined analysis/testing (Germany).

d) Other, please specify (SMA, experience-based, similarity, etc.)
- Seismic design verification of older plants by SMA (Canada, UK, Sweden, Czech Republic)
- Similarity and experience based methods are also used for seismic adequacy (Germany, Slovenia, Belgium, and Japan).

Q12: *Do you consider seismic induced fatigue in seismic design? If so, how?*
- Seismic fatigue is not required to be evaluated by Finland, Sweden and UK
- Germany and Czech Republic perform conditional fatigue evaluations or post seismic inspections
- Maximum fatigue cycles vary from 5 to 25.

Q13: *Do your national code acceptance criteria allow for plasticity in seismic design?*
- Majority of respondent's national codes do not allow plasticity in seismic design
- Limited Plasticity is allowed by Germany, Sweden, France and Japan.
- In USA approval, when plastic analysis is used, is done case-by-case according to ASME code

Q14: *How do you ensure operability of mechanical components during and after an earthquake?*
- Operability is ensured by testing or analysis plus testing combined
- By assigning different seismic category (Canada)
- Reduced stress level limit/elastic behavior (France, Japan).

Q15: *In seismic testing of mechanical components which of the following methods do you use?*
- Single axis test - Used when appropriate. (Finland, USA, Slovenia, UK, Czech Republic)
- Multi-axis random test - Preferred by all other.
- Other, please specify - Bi-axial testing for small components (Canada).

Q16: *When do you consider mechanical components to be inherently seismically rugged?*
- Majority of respondents do not assume mechanical components to be inherently rigid.
- Heavy mass/high fundamental frequency (Canada)
- Component capacity much greater than seismic demand (Belgium, UK).

Q17: *Beyond what frequency a component is defined as seismically rigid?*
- For 40% of the respondents it is 33 Hz. (Canada, Slovenia, Spain, Belgium, Czech Republic)
- 40 and 50Hz is used by some (UK, Finland, Sweden)
- For frequency above 20 Hz, a component is also considered seismically rigid (Japan).

Q18: *What methods and criteria do you use for seismic qualification of the following specific mechanical components?*

- Combined analysis and testing are used for seismic qualification of valves with actuators
- Analysis and testing are used for seismic qualification of emergency power generators (Diesel or turbines)
- Analysis method is used for seismic qualification of large pumps (e.g., main reactor coolant pump).

Q19: *Do you utilize experience-based data and methodologies from actual earthquakes? How and when?*

- For new designs, mostly MSs say “No”, except Germany and UK
- For replacement components, MSs say “Yes” when justified, except Japan. There is no criterion for replacement of components based on actual experience data in Japan.
- Design modification of existing plants, Canada, UK, Belgium, and Sweden say “Yes”)
- For re-evaluation of margins and capacity in existing plants, MSs say “Yes” ,except Japan. In Japan actual experience data of earthquake is not used for seismic design although they are frequently used for design verification.

Q20: *Do you require establishing seismic fragility level? If so, how and for what components? (testing or analysis)*

- No seismic fragility estimation requirements, except Canada, UK
- Some respondents use fragility curves for SPRA. The curves are analysis based (e.g. Finland).
- Some respondents use fragility curves for SPRA. The curves are analysis and/or testing based (e.g. Japan).

Q21: *Do you have requirements/ expectations for seismically designed components to be able to withstand beyond design basis earthquake?*

- BDBE requirements/expectations are specified for Canada, Finland, USA, Spain, UK, France, Japan
- BDBE assessments applied after Fukushima (Stress Test)
- SMA/SPRA is required by some respondents.

Q22: *What kind of margins do you require/expect in the design of SSCs important to safety to withstand beyond design basis earthquake?*

- Majority of respondents do not require any margin above DBE/SSE.
- The margins ranged from 1.5 to 1.67 for Belgium and Canada respectively.
- For NPPs in Japan, evaluated margins ranged from 1.3 to 2.
- In USA and Canada for new plants, it shall be demonstrated that an SSC has seismic capacity greater than the limit for BDBE (1.67 x DBE or 1,5x DBE), and then there is no more margin required on top of the margin one has already demonstrated.

Q23: *How do you quantify the margins beyond design basis earthquake?*

- SMA/SPRA are used to quantify margins over DBE/SSE (Canada, Germany, Finland, Belgium, USA, Spain, France, Japan, and Czech Republic)
- Fragility Analysis (Korea).

Q24: *What methodologies do you use for ensuring capacity of mechanical components beyond design basis earthquake?*

- 70% respondents use *Seismic Margin Assessment*
- 70% respondents use *Seismic PRA*
- 25% respondents use *PSA-based SMA* (Canada, Korea, and UK)
- 40% respondents use *Testing* (Canada, UK, France, and Japan)

- 30% respondents use *Deterministic methods*
- 20% used other methods such as E/Q experience from higher level events (UK), and complementary deterministic methods (Japan).

4. STATUS OF THE BENCHMARK

After reviewing the experimental background possibly available for a benchmark exercise, EDF selected the three experimental programme candidates described in Chapter 2:

a) the USA Piping and fitting dynamic reliability program;

b) the NUPEC Large-Scale Piping Systems Test Programme;

c) the BARC piping system test.

The pro and cons of the 3 programmes were discussed during the last WGIAGE in Paris, April 2014:

- The programme a) is well documented in hard copy documents. However it is expected that retrieving in an appropriate format all the digital records necessary for a benchmark exercise would raise serious difficulties.
- Regarding the Programme b) a key issue is that the original documentation is in Japanese. An important effort of translation was already carried out in the past for issuing the NUREG/CR-6983, which summarizes the main programme outputs. Additionally the successive re-organization of the Japanese Institutions (NUPEC, then JNES, now absorbed by NRA) might generate difficulties in establishing contacts with the Japanese teams that were in charge of this experimental programme ten years ago.
- Advantages of the Programme c) are that
    1. the original documentation is in English, and
    2. the research team is still active on the subject.

  The only difficulty with this programme is that India is not an OECD member country.

Eventually, following the EDF Proposal, IAGE decided to launch the benchmark on the basis of the Indian experimental Programme c). An agreement has been reached to invite the Indian experts to take part in the work and make the test data of BARC available to the NEA members for this project. EDF is now working with BARC on the terms of the benchmark.

The tentative schedule of the benchmark exercise is as follows:

- Benchmark Announcement released by the OECD Secretariat	November 2014
- Web-seminar with all the participants registered in the benchmark	February 2015
- Workshop for sharing first benchmark outputs	November 2015
- Final Workshop	March 2016

5. PRELIMINARY CONCLUSIONS

The activity (CAPS) of the WGIAGE group, entitled “Metallic Component Margins under High Seismic Loads (MECOS)”, was initially proposed by the metal sub-group of WGIAGE and approved by the CSNI in June 2012 as a Fukushima activity (F-CAPS). The proposal is aimed to assess the consequences of external hazard on plant safety. The main objectives of the MECOS project were to quantify the existing margins in seismic analysis of safety class components for high seismic loads and assess the existing design practices within a benchmark activity.

The following conclusions can be made based on the work to date:

- All the experiments carried out around the world conclude unanimously that there are large margins in the design of piping systems. However,

- The failure mode addressed by the design criteria (plastic instability) is not the one observed in the experimental campaigns (fatigue-ratcheting).

These conclusions were already drawn in the past. In this regard, the Fukushima accident has not raised any new issues. It has only triggered a new interest on the subject for the purpose of quantifying the margins available to cope with the effects of beyond design earthquakes.

It is expected that numerical simulations carried out during the benchmark exercise will reasonably reproduce the observed phenomena and will pave the way for a revision of the design engineering practice and provide recommendations.

Preliminary conclusion of MECOS is that the Fukushima accident has not raised any new issues in seismic regulations and in design of components and structures.

APPENDIX I - LIST OF DOCUMENTS COMPILED BY EDF

(*)denotes a reference not available.

Aged Piping Committee of National Research Institute for Earth Science (NIED)

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APPENDIX II - NATIONAL ANSWERS TO THE QUESTIONNAIRE

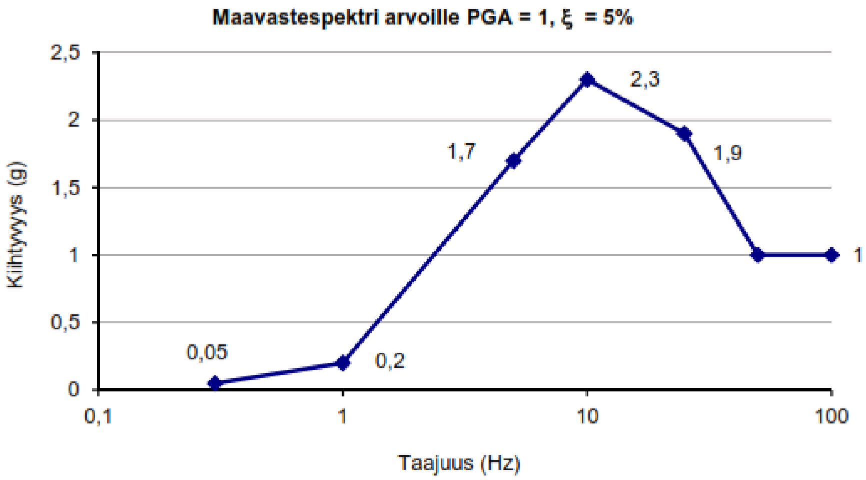
Compilation of NEA/OECD Seismic Survey Responses Submitted by Various States (Questionnaire on Seismic Design of Mechanical Components in Nuclear Power Plants)

Category: Seismic Input

Q. 1:
Do you consider **Uniform Seismic Hazard** Spectra in the seismic design or you rely on standard design spectrum anchored to specific PGA?

CANADA:
Existing nuclear plant's seismic design is based on the Standard Design Spectrum anchored to specific PGA. New build plants in Canada will also consider site specific UHS.

FINLAND:
Spectrum is site specific. An example of acceptable spectrum shape for Southern Finland is given in YVL (Regulatory Guides on nuclear safety) B.7. The shape is given below and it results from hazard calculation separately for a set of frequencies, using the same source model and attenuation model which accepted to be regionally valid. Due to the lack of locally available data the attenuation relationship has been based on records from geologically similar areas to Fennoscandia.



GERMANY:

In general, uniform hazard spectra for an exceedance frequency of 10^{-5}/a (median) are used for seismic design and re-assessments of nuclear installations. The pertinent nuclear safety standard is KTA 2201.1[1] "Design of Nuclear Power Plants against Seismic Events; Part 1: Principles". In the original design of some older plants, modified USNRC-spectra were applied.

SLOVENIA:
The target level of probability for SSE is based on the median values for 10000 years return period. In the original design, the design ground motion complied with Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants". The peak horizontal and vertical

1. Hyperlinks are provided if English versions of the documents are publicly available.

ground accelerations for the SSE are 0.30 g and for the OBE is 0.15 g. The SSE and OBE input ground motion was applied directly to the soil spring model without deconvolution to the foundation level. According to the most recent PSHA study of the NPP Krško site completed in 2004 peak ground acceleration at the surface for 10000 year return period amounts to PGA=0.56 g.

KOREA:
Modified standard design spectrum.

UK:
For new seismic design we use site standard design spectrum and Uniform Seismic Hazard spectra for assessment.

BELGIUM:
Seismic design basis of the Belgian plants is based on standard RG 1.60 spectra anchored to a specific PGA in one site. In the second site, the seismic design basis is based on a site-specific spectral shape anchored on a specific PGA.

SWEDEN:
Uniform seismic hazard spectra typical for Swedish hard rock are applied. The spectral values represent limits of single-degree-of-freedom responses that are expected to be exceeded at the frequency of 10^{-5} per year at site. The peak ground acceleration (PGA) is 0.11 g in the horizontal and 0.09 g in the vertical direction.

FRANCE:
For nuclear applications in France, the regulatory approach for the definition of seismic hazard is provided by RFS 2001-01 (RFS ~ Fundamental Safety Rule).
It is a deterministic approach that gives the site SSE response spectrum, called SMS. For design purposes, enveloping design spectra were used (DBE), anchored to specific PGA depending on the site seismicity.

JAPAN:
As shown in the Figure 1 below, the design basis earthquakes are evaluated and formulated by dividing the mechanism of earthquake occurrences. Uniform hazard spectra are used as a reference for positioning stochastic study of design basis earthquake development results.
Ground motions are formulated for each by dividing the earthquake occurrence types, the first type is earthquakes with specific cause faults and the second type is that of which cause faults cannot be identified. Regarding the first type, three groups, they are crustal earthquakes, inter-plate earthquakes and oceanic intraplate earthquakes, are studied as shown in Figure 1.
For ground motion determined by identifying the source fault, the combination of the two methods is required. One method is spectrum based approach with reference to the seismograms in the past. In this case, the ground motion is calculated from the spectrum. The other is fault model approach in which ground motion is derived directly based on the segmental movements.

PGA is derived using magnitude (M) of assumed fault and epicenter distance (Xeq). (See Sec.2).

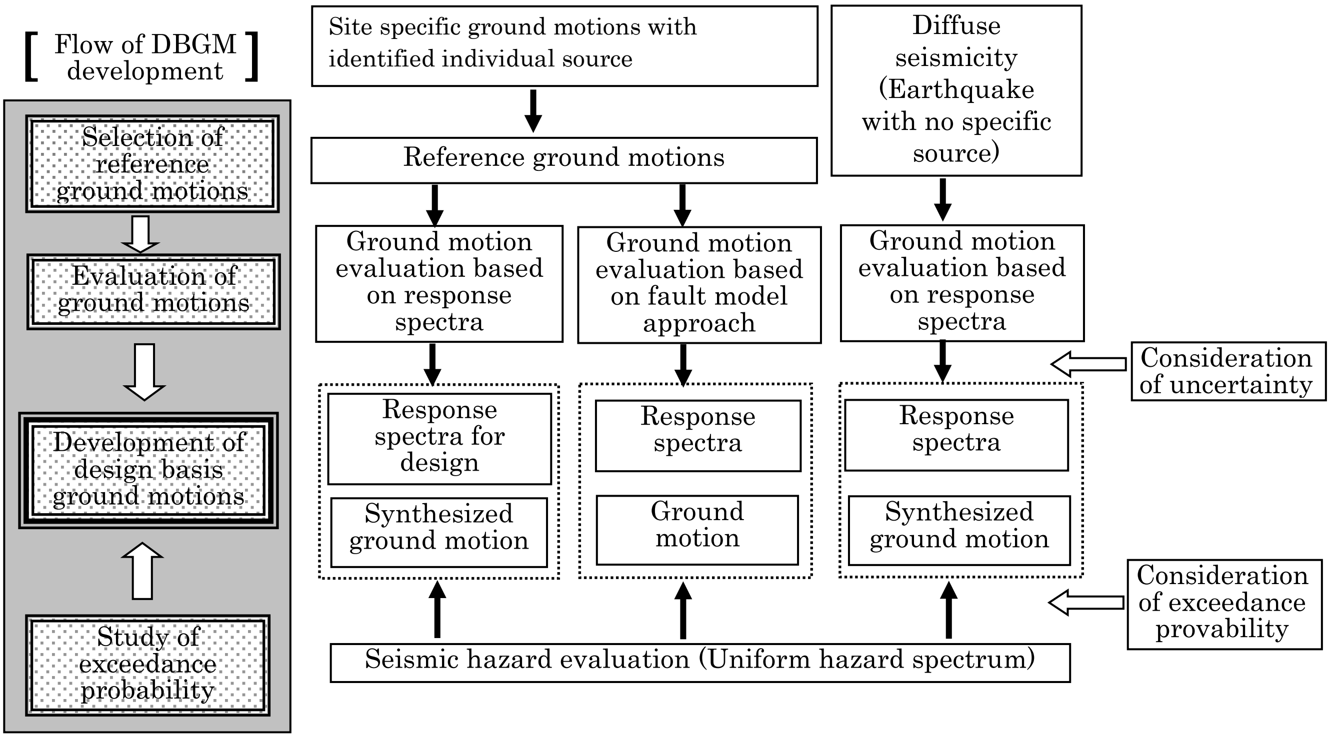


Figure 1: Flow chart for review of the design basis ground motion
(From review guide for DBGM and seismic design by NRAJ)

CZECH REPUBLIC:
Czech Republic is country with very low seismicity. Maximal value of PGA = 0.1g
For NPP Temelín (2xVVER 1000) the following earthquakes have been selected
- San Severo (23.11.1980)
- USA, west part (04.09.1955)
- USA, west part (22.09.1957)
- USA, west part (22.03.1957)

All this ground response spectra (GRS) have been enveloped and anchored to PGA=0.1g.
For NPP Dukovany (4xVVER 440) the standard Newmann GRS spectrum for rock soil has been used and anchored to PGA=0.1g

USA:
For the currently operating reactor fleet a broad-band, standardized response spectrum was anchored to a specified PGA value. The PGA value was usually assumed to occur at ~33 Hz. A variety of spectral shapes were used in the design of the currently operating reactor fleet. The most common standardized response spectral shapes were usually a U.S. NRC Regulatory Guide 1.60 spectrum, or similar to the NRC NUREG/CR-0098 spectrum, or a “Housner”-type for the earliest reactors.

Currently, new reactors are designed according to a certified seismic design response spectrum (CSDRS), which is typically based on a standard design response spectrum anchored to a specific PGA. However, the licensing process for new reactors requires the comparison of the CSDRS with the site-specific performance-based ground motion response spectrum (GMRS) to determine if the CSDRS is adequate for a selected site. The GMRS is obtained by scaling the site-specific, mean uniform hazard response spectrum (10^{-4} annual exceedance frequency) by a design factor defined in ASCE/SEI Standard 43-05 and Regulatory Guide 1.208.

SPAIN:

The Uniform Seismic Hazard Spectra (USHS) has been considered at the nineties under the IPEEE scope to obtain the Review Level Earthquake exceedance frequency. Currently, the median E-5 USHS shape is considered as a reference level for seismic design. To balance typical USHS low accelerations from PSHA results at low frequencies, the US NRC R.G. 1.60 spectra anchored by the median E-5 PGA value has been adopted for seismic design of the new ATC (temporary spent fuel centralized storage). Additionally, and following AP 1000 design criterion, the mentioned R.G. 1.60 spectra has been amplified at high frequencies to cover the USHS high accelerations resulting from PSHA.

Q. 2:
What frequency do you associate with PGA?

CANADA:
33 Hz in the past. Now a days, it can be up to 100Hz based on when the response acceleration become constant and does not change with change in frequency.

FINLAND:
50 Hz.

GERMANY:
No fixed frequency value is associated with PGA. The PGA value corresponds to the acceleration for frequencies exceeding the upper limit frequency (f_{grenz}) where the site specific response spectrum flattens. For most sites in Germany f_{grenz} is on the order of 20...30 Hz. (Remark: In Germany, the Uniform Hazard Spectra do not primarily refer to a PGA value but to macroseismic intensity.)

SLOVENIA:
PGA is associated with infinite frequency. According to NRG 1.60 spectrum, PGA applies to frequencies larger than 33 Hz.

KOREA:
40Hz

UK:
10-3 and 10-4pa hazard estimates

BELGIUM:
33 Hz

SWEDEN:
50 Hz.

FRANCE:
This frequency is 34 Hz for the SSE (SMS).
Different DBE are used depending on the fleet. The PGA frequency therefore varies from 25Hz to 33Hz, and up to 40Hz for the design of EPR.

JAPAN:
When spectra based approach is used, control points shown in Table 1 are used. These control points are made based on observation records.(From JEAG4601-2008)
At 0.02 second, acceleration is set to match PGA.

Table 1. Control Points of Horizontal Ground Motion at Free Rock Surface

Source Location	M	X_{eq} (km)	Coordinate of control points $_{p}S_{V}$ (cm/s)							
			A	B	C	D	E	F	G	H
			T_A (s)	T_B (s)	T_C (s)	T_D (s)	T_E (s)	T_F (s)	T_G (s)	T_H (s)
			0.02	0.09	0.13	0.30	0.60	1.00	2.00	5.00
Very Near	8.5	40	1.62	18.44	27.32	47.87	68.05	64.66	53.52	40.06
	8	25	1.69	20.05	28.96	48.22	67.80	65.25	52.51	38.35
	7	12	1.40	17.20	24.84	33.86	43.42	36.42	25.15	17.85
	6	6	1.04	12.82	18.51	21.84	23.17	17.41	9.64	3.88
Near	8.5	80	0.73	7.36	11.43	22.92	34.79	32.58	27.60	21.96
	8	50	0.67	7.45	11.17	20.05	28.65	27.06	22.70	17.19
	7	20	0.78	9.44	13.64	19.10	24.83	20.69	14.46	10.37
	6	8	0.77	9.45	13.65	16.23	17.18	12.73	7.16	2.89
Middle	8.5	160	0.26	2.22	3.67	9.45	15.17	14.83	13.64	12.26
	8	100	0.32	3.08	4.86	10.27	16.04	14.96	12.73	10.37
	7	50	0.23	2.65	4.01	6.02	7.64	6.68	4.87	3.64
	6	25	0.21	2.49	3.60	4.54	4.84	3.98	2.07	0.86
Far	8.5	200	0.18	1.44	2.43	6.87	11.17	11.17	10.67	10.04
	8	200	0.10	0.80	1.35	3.82	6.21	6.21	5.93	5.58
	7	125	0.046	0.43	0.70	1.34	1.81	1.59	1.26	1.05
	6	78	0.041	0.45	0.65	0.95	1.03	0.80	0.49	0.22

The value of pSv is the absolute value of the pseudo-velocity response spectrum

CZECH REPUBLIC:
33 Hz

USA:
For the currently operating reactor fleet the frequency assigned to the PGA was typically ~33 Hz. This was used as the anchor point for the standardized response spectral shapes. In current practice for new reactors, PGA is assumed to occur at ~100 Hz or at the frequency where the response spectral values “flatten” (becomes asymptotic to the frequency axis) and are no longer changing with increasing frequency. This flattening may occur at different frequency values in different regions (eastern North America vs. Western North America for example).

SPAIN:
The PGA frequency varies from 25Hz for old designs to 33Hz for newest plants. In the new ATC design, the PGA value is 100Hz.

Q. 3:
Up to what frequency do you consider the seismic design input?

CANADA:
100 Hz is considered adequate.

FINLAND:
100 Hz

GERMANY:
There is no fixed frequency value up to which the seismic input has to be considered. But the nuclear safety standards KTA 2201.3 "Design of Nuclear Power Plants against Seismic Events; Part 3: Building Structures" and KTA 2201.4 "Design of Nuclear Power Plants against Seismic Events; Part 4: Components" require that the contributions of resonance frequencies above the limit frequency are adequately taken into account. It is considered that this requirement is met if the modal masses of all resonance frequencies sums up to at least 90 % of the total mass of the structure or component. If the sum of the modal masses is less than 90 % of the total mass or if the system is significantly inhomogeneous, then the sum of modal contributions must be expanded by the rigid-body contribution.

SLOVENIA:
See answer at the second question for frequency associated with the PGA. Floor response spectra are calculated up to 50 Hz and the corresponding spectral accelerations are used as Zero Period Acceleration (ZPA). For seismic loadings, the equipment is generally assumed to be rigid when its fundamental frequencies are 33 Hz or greater. Rigid equipment may be qualified using ZPA.

KOREA:
50Hz

UK:
We generally consider up to 50Hz for seismic loadings, above 33 Hz or greater we consider the equipment rigid and use the ZPA.

BELGIUM:
50 Hz

SWEDEN:
The applied praxis is to use an appropriate margin above 50 Hz. Normally the margin is not less than 10 Hz.

FRANCE:
It depends on the analysis that is performed for the component.
For a modal analysis, the number of modes included in the analysis have to be checked in order to avoid „missing mass effect". In general, total modal mass considered in the response have to be at least 90% of the total system mass. For some components only the lowest natural frequency is considered to determine the seismic loading.

JAPAN:

The characteristic of DBGM, the frequency content up to 50Hz is defined as the DBGM. However 20Hz or 33Hz is used as a design practice in the facility design

CZECH REPUBLIC:

Up to 33 Hz, missing mass effect is included and total modal mass shall be at least 90% of total system mass

USA:

A maximum frequency of 100 Hz is used for developing design input ground motions. In current practice, floor response spectra are calculated up to a maximum frequency of 100 Hz. Further guidance can be found in the *Interim Staff Guidance On Seismic Issues of High Frequency Ground Motion* (DC/COL-ISG-01) and NUREG-0800 Chapters 3.7 and 3.9.

SPAIN:

There is no default frequency to have to be considered.

In the original design of the NNPP, as a general rule, all modes with frequencies below 33 cps were considered. Missing mass effect was also considered so that the modal participation coefficients reach 90%.

For some subsequent modifications of design, all modes with frequencies below 45 cps were considered. If the modal participation coefficients are less than 90 % of the total mass, then the sum of modal contributions must be expanded by the rigid-body contribution.

Q. 4:
Do you have a minimum seismic design demand defined in your national standard?

CANADA:
Yes. 0.1g is the minimum required PGA for the new plants.

FINLAND:
Design earthquake frequency of occurrence <10^{-5}/year on the median confidence level. Only safe shutdown earthquake (SSE) considered; No operation basis earthquake (OBE). Horizontal PGA at least 0.1*g as described in IAEA NS-G-1.6 and IAEA SSG-9. Vertical as described in SSG-9 and NUREG/CR-6728. The currently operating NPPs are not originally designed for earthquakes. Seismic PRA is required for all NPPs.

GERMANY:
KTA 2201.1 "Design of Nuclear Power Plants against Seismic Events; Part 1: Principles" stipulates that the design basis earthquake shall be specified with a macroseismic intensity of at least I_{EMS} = VI (if the earthquake with an exceedance frequency of 10^{-5}/a determined by the site specific hazard assessment has a lower intensity).

SLOVENIA:
There are no special national standards which cover the seismic input for the NPPs. This area is covered by:

a. Act on Ionising Radiation Protection and Nuclear Safety
b. The Rules on radiation and nuclear safety factors (there is prescribed a Special Safety Analysis which require e.g. field investigations and analysis of characteristics of the site area (e.g. geological, seismological, seismotectonic, geotechnical, hydro-geological, etc.)
c. NPP documents:
   i. Krško USAR, etc.
d. US NRC regulations:
   i. Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants,
   ii. NUREG 0800, standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Rev. 3, March 2007
   iii. NRC RG 1.61, Damping Values for Seismic Design of Nuclear Power Plants, Rev.0, October 1973
   iv. NRC RG 1.61, Damping values for Seismic Design of Nuclear Power Plants, Rev. 1, March 2007
   v. NRC RG 1.22, Rev. 1, February 1978 – Development of Floor Design Response Spectra for Seismic Design of Floor – supported Equipment or components,
   vi. NRC RG 1.92, Rev. 2, July 2006 – Combining Modal Responses and Special Components in Seismic Response Analysis, and

e. ASCE Standard 4-98, Seismic analysis of safety-related nuclear structures and commentary, ASCE 1999.

KOREA:
Yes.

UK:
We generally rely on the agreed (with the Regulator) design basis earthquake at each power station site.) Also take cognizance of IAEA guidance for 0.1g minimum seismic consideration

BELGIUM:
Minimum design basis is a RG 1.60 with a PGA of 0.1g

SWEDEN:
The recommended minimum seismic design demand is governed by the uniform seismic spectra described in question 1.

FRANCE:
The RFS 2001-01 rule provides a minimum design earthquake, called SMF, anchored at 0.1g PGA.

JAPAN:
In addition to dynamic seismic force by the DBGM, static seismic forces are considered multiplying by the following coefficient in accordance with the seismic class.

Buildings and structures
- S class : 3.0
- B class : 1.5
- C class : 1.0

Equipment and piping
- S class : 3.0 x 1.2
- B class : 1.5 x 1.2
- C class : 1.0 x 1.2

CZECH REPUBLIC:
For existing operated NPPs it is PGA=0.1g, se point 1. For planned new units PSHA will be used.

USA:
Title 10 of the Code of Federal Regulations (10CFR) has requirements for minimum seismic demands. In Appendix S to Part 50 of the 10CFR, the horizontal component of the Safe Shutdown Earthquake Ground Motion in the free-field at the foundation level of the structures must be an appropriate response spectrum with a peak ground acceleration of at least 0.1g. Additional guidance relating to this minimum response spectrum is provided in the Standard Review Plan Section 3.7.1 (NUREG-0800) and Interim Staff Guidance 17.

SPAIN:
There are no national standards covering a minimum seismic input for NN.II.; but all plants are required by the CSN to accomplish the PGA value of 0.1 g as a minimum criterion. Design values have a PGA value ≥ 0.1g for newer plants; and older plants designs were revaluated (SEP programme) at a 0.1 g PGA value.

Q. 5:
How many seismic levels do you define and use in the design of mechanical components?

CANADA:
Canadian standards define 3 levels of earthquakes: Site Operating Earthquake (SOE), Design Basis Earthquake (DBE) and Checking Level Earthquake (CLE). Design of mechanical components is usually based on DBE or in limited cases on SOE. CLE is used for seismic capability evaluation.

FINLAND:
Only safe shutdown earthquake (SSE) level is considered.

GERMANY:
Basically, there is just one design basis earthquake, the safe shutdown earthquake, which is termed *Bemessungserdbeben*. This earthquake is used for all design purposes. In addition there is a so called *Inspektionsniveau* (inspection level) that corresponds to earthquake loads of approximately 0.4 times those of the design basis earthquake. But this level has no meaning in the design; it is just intended to trigger specific post-event inspections.

SLOVENIA:
Classification of systems and components by the ANS Safety Classes provides an adequate and proper determination of the applicable seismic design requirements. Two, seismic intensities are used to design mechanical equipment: the OBE demands are used in respect to upset condition, and SSE demands are considered in faulted condition.

KOREA:
2

UK:
As Q# 4 above we use 10-3 second line and 10-4 bottom line levels

BELGIUM:
Two: OBE & SSE

SWEDEN:
Only SSE (Safe shutdown Earthquake) is assumed for Swedish NPPs.

FRANCE:
For design purposes, two levels are considered, depending on design conditions:
- For existing NPP, DBE level (faulted conditions) and half-DBE level (normal and upset conditions);
- For EPR, DBE level (faulted conditions) and Inspection Earthquake level, which is 1/5 DBE (normal and upset conditions).

JAPAN:
There is two-level of design earthquake level in Japan.
One is DBGM Ss for safety function evaluation. The other is Sd for elastic design in which SSCs are required to remain mostly elastic behavior range.
Sd in current seismic design guidelines is not based on seismological background but is set for the design convenience. Because of this, there is no unified ratio of Sd to Ss. The ratio of about 0.8 from 0.5 is being used considering the ratio of elastic behavior limit and function maintain limit.

CZECH REPUBLIC:
Only safe shut down earthquake (SSE) has been assumed for operated NPPs.

USA:

NRC regulations in 10CFR50 Appendix S define two ground motion events: the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE). According to current US NRC guidance in Regulatory Guide (RG) 1.29, Seismic Category I components must be designed to withstand the effects of the SSE.

All other components are designed in accordance with appropriate codes and standards which may require design at a different seismic loading level. RG 1.26 provides additional information.

SPAIN:
Two design levels: SSE and OBE (=1/2 SSE)

Category: Design Basis

Q. 6:
Do you have national Codes and Standards for seismic design of mechanical components? If so, please identify them.

CANADA:
Yes. Canadian Standards Association (CSA) standard N289.3 along with CSA N289.2. Additionally CSA N289.4 provides procedures for seismic qualification by testing.

FINLAND:
No national codes nor standards are approved in Finland. EN 1998 (Eurocode 8) is not approved nationally for seismic design of nuclear facilities in Finland. Finnish regulatory guides (YVL Guides, see https://ohjeisto.stuk.fi/YVL/?en=on) give requirements and list examples of acceptable standards (e.g. ASCE 4-98, ASCE/SEI 43--05, ASME III, ASME QME-1-20, NUREG/CR-6926).

GERMANY:
Components of the (seismic) Classes I and IIa (see question/answer 7) are designed according to nuclear safety standard KTA 2201.4 “Design of Nuclear Power Plants against Seismic Events; Part 4: Components”.

SLOVENIA:
There are no special national codes and standards which cover seismic design of mechanical components. The plant structures, the Engineered Safety Features and other safety related systems and components, are identified and classified in accordance with the requirements of General Design Criterion 2 of Appendix A to Title 10 CFR Part 50, General Design Criteria for Nuclear Power Plants, and Appendix A to Title 10 CFR Part 100, Seismic and Geologic Siting Criteria for Nuclear Power Plants. NRC Regulatory Guide 1.29 designates those structures, systems and components which must be designed to remain functional during the safe shutdown earthquake (SSE) as Seismic Category I.

KOREA:
No

UK:
Eurocode 8 is available but not directly applicable to nuclear facilities. Reference is made to ACI, ASCE and ASME guidance

BELGIUM:
No specific national code for nuclear SSCs. Belgian regulations are based on the NRC requirements

SWEDEN:
In general, applicable American codes and standards are used, e.g. ASME III.

FRANCE:
The French design code RCC-M (French design and construction rules for mechanical components of PWR nuclear islands) primarily applies to safety class mechanical components. It covers the rules applicable to the design and manufacture of pressure boundaries of mechanical components of PWR : reactor fluid systems (primary, secondary and auxiliary systems including vessels, heat exchangers, pumps, valves, piping), and other components which are not subject to pressure (vessel internals, supports for pressure components and storage tanks, low pressure or atmospheric storage tanks). RCC-M includes in the design process seismic loading.

For HVAC, no national codes are required for seismic design. Contractors sometimes partially apply RCC-M for some components (supports, ductworks).

For replacement components, some alternative standards can be used: EN13480 (piping), Eurocode 8 (heat exchangers), sometimes with supplements.

JAPAN:

We have national Codes and Standards for seismic design of mechanical components.

(Governmental Code and Standards)

1) NRA rule No.5, Interpretation of the rule on standard for locations, structures and facilities of nuclear power reactor and its facilities, Enforced on July 8, 2013 (New seismic design reviewing guide is incorporated as a part of this standard) NRA規則第５号「実用発電用原子炉及びその附属施設の位置、構造及び設備の基準に関する規則の解釈」

2) Reviewing guide of NRA, The Guide for the design basis ground motion and seismic design policies
NRA審査ガイド「基準地震動及び耐震設計方針に係るガイド」

3) Reviewing guide of NRA, The Guide for construction application on seismic design NRA審査ガイド「耐震設計に係る工認審査ガイド」

(Society Code)

4) JSME S NC1 – 2005, Codes for Nuclear Power Generation Facilities: Rules on Design and Construction for nuclear power plants
JSME S NC1-2005 発電用原子力設備規格　設計・建設規格、日本機械学会

(Utility side Code and Guide)

5) JEAG 4601- 1984, Seismic design guide for nuclear power plants: Seismic classification, load combination and allowable limit edition
6) JEAG4601-1987, Seismic design guide for nuclear power plants: (Methodologies for ground and active fault survey, analysis of SSCs are described in detail.
This guide was translated in English as **NUREG/CR-6241**)
7) JEAG4601-1991 Supplement edition, Seismic design guide for nuclear power plants: (Methodologies for functional evaluation of active components are described in detail. The type of components described in JEAG4601-1991 is listed in Table 2.)
8) JEAC4601-2008 and JEAG4601-2008, Seismic design guide for nuclear power plants: (These are a code and guide for ground and active fault survey and evaluation revised in accordance with the lessons learned in 2007 Niigata-ken Chuetu-oki Earthquake.)

CZECH REPUBLIC:

We don´t have special national codes and standards. For seismic assessment we use ASME Code Section III, Russian Code PNAEG7-002-86 and Standard Review Plan 0800, Sections 3.7 and 3.8.

USA:

The ASME Code as incorporated by 10CFR50.55a is the acceptable code for design of mechanical components. However, regulations in 10 CFR Parts 50 and 100 provide the criteria for the design basis earthquake that structures, systems, and components important for safe operation and safe shutdown should be designed for. Also, NUREG-0800, The Standard Review Plan (SRP), Chapters 3.2, 3.7, 3.9, and 3.12 provide further guidance for complying with the US NRC regulatory requirements. Alternatively, an applicant/licensee can propose other methods as long as it is demonstrated that the proposed methods provide a level of protection for the public and the environment as high as the methods in the regulatory guides, SRPs, and other regulatory/review documents.

SPAIN:

There are no specific national codes and standards for seismic design of mechanical components. The Spanish regulation is based on requirements of the country of origin of the project: The USNRC requirements for PWR (Westinghouse) or BWR (General Electric) designs, and the nuclear safety standard KTA 2201.4 "Design of Nuclear Power Plants against Seismic Events" for Trillo (KWU) plant.

Q. 7:
How mechanical components are categorized to identify the expectations regarding the performance from the structural integrity and operability point of view?

CANADA:
Seismic Category A for structural and pressure boundary integrity and Category B for functionality during and after an earthquake.

FINLAND:
Instructions for seismic classification of SSC is given in YVL B.2.

GERMANY:
The seismic classification for structures, systems, and components (SSC) is specified in nuclear safety standard KTA 2201.1 “Design of Nuclear Power Plants against Seismic Events; Part 1: Principles”. For Class I components and civil structures it shall be verified that they will be able to fulfill their respective safety related tasks (load-carrying capacity, integrity, and functional capability) in case of an earthquake. For Class IIa components and civil structures it shall be verified that they will not impair Class I SSCs during an earthquake in such a way that they would not be able to fulfill their safety related functions.

SLOVENIA:
Mechanical components and systems are classified according to ANSI N18.2-1973 Safety Classes. Components and systems having the ANSI Safety Class 1, 2 or 3 designations are Seismic Category I. All Seismic Category I structures, systems and components must withstand the effects of the SSE and assure its integrity. The operability of Category I mechanical equipment must be demonstrated if the equipment is determined to be active, i.e. mechanical operation is relied on to perform a safety function.

KOREA:
Seismic category I, II and III

UK:
Functionality requirements are identified to support the nuclear safety case e.g. post seismic claims etc

BELGIUM:
- Passive component
- Active component for witch the function can be showed using structural criteria
- Active electro-mechanical complex component for witch the function can be showed by shaker table test

SWEDEN:
The mechanical components are assigned into five different quality classes. The quality classification is determined while taking into account the significance of the components’ structural integrity for facility safety during all events specified in event classification system.

The acceptance criteria for mechanical components which are specified in the
design specifications for pressure retaining and load bearing components (KFM), take also into consideration if active function is required for a specific load case in the KFM.

FRANCE:
Mechanical components are categorized in different classes, taking into account the safety related function of the equipment and, where appropriate, the radioactive inventory or the operating conditions. If mechanical components fulfill a safety function, they are "safety classified". They are

then divided into three safety classes. These safety classes lead to quality levels for design and manufacturing of mechanical components.

The loadings considered for the design of the component are the result of the plant conditions. The criteria level to be applied to the component is dependent on the role which the component is required to play during and/or after these conditions.

Stability, integrity:

Applying Level C or Level D criteria is considered sufficient to demonstrate the stability and integrity of mechanical components in emergency or faulted conditions respectively.

Functional capability:

Functional capability corresponds to the ability of the system to transmit the required fluid flow. No significant restriction of flow passage is consequently required, which implies the verification that there is no risk of excessive deformation.

Operability:

The operability is related to active components, e.g. valves, pumps and others which require functional movement in order to fulfill their functional requirement.

JAPAN:

Regarding the structural integrity, seismic analysis is implemented based on the methodologies shown in JEAG4601-1987 and integrity evaluation is implemented based on the load combination and allowable limit described in JEAG4601-1984. The detail stress evaluation method, stress values such as minimum tensile and yield stresses of materials, inspection methods are described in the rule JSME S NC1-2005 “Rules on Design and Construction for Nuclear Power Plants” of the Japan Society of Mechanical Engineers.

Regarding active components such as electric panels, pumps and valves, the functionability is evaluated by vibration test base, i.e. comparing calculated acceleration with test certified acceleration. All components seismically important were tested as shown in Figure 2. Seismic analysis models for component types are also verified through these tests. Partial tests for seismically critical portions such as bearing were also implemented in these tests to expand applicable limit. The history of active component evaluation methodologies are also shown in Figure 2.

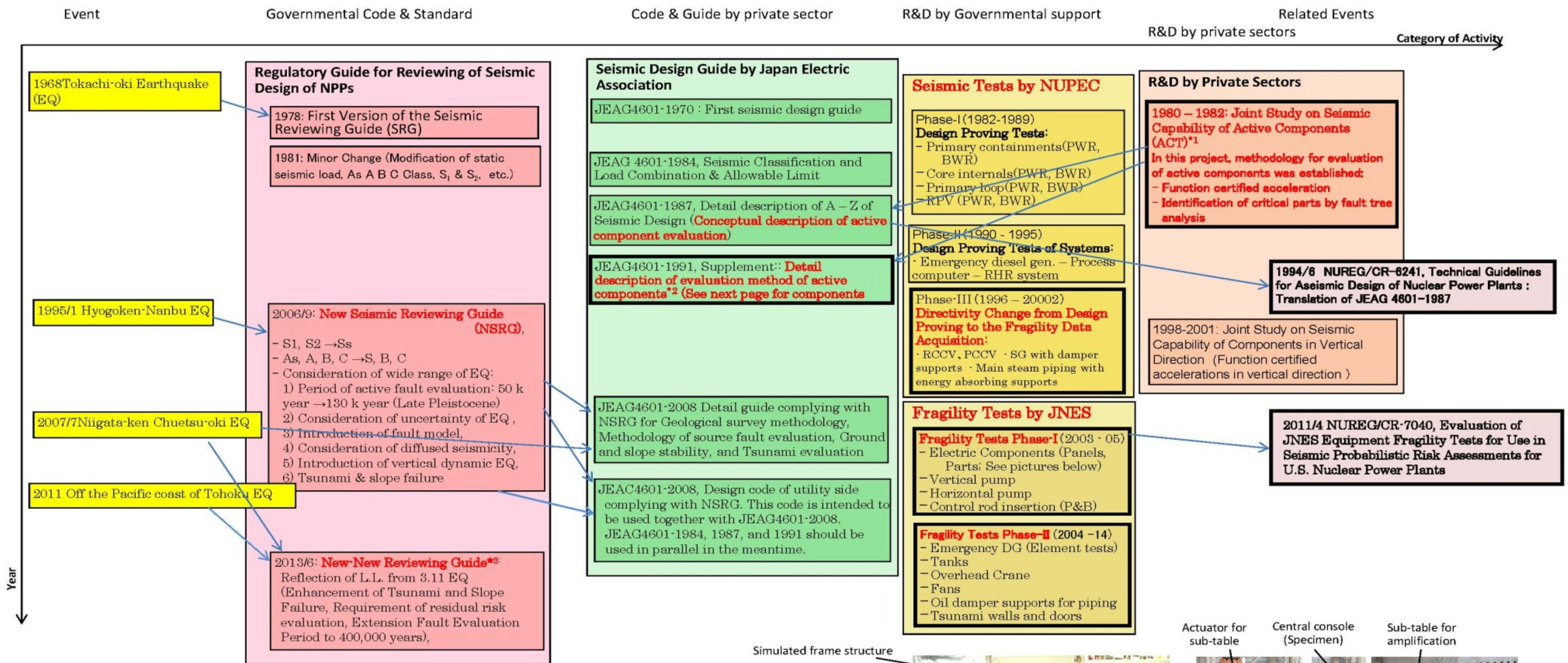
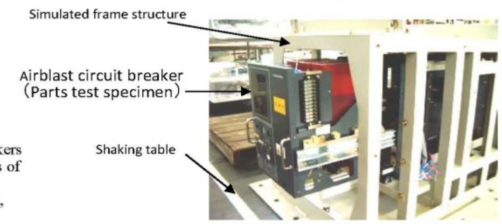
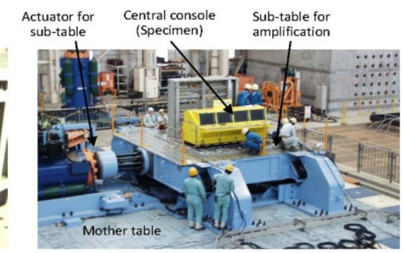


Figure 2 History of Development of Functional Evaluation Methodology



Picture of an airblast circuit breaker parts test with strengthened support structure
(From a fragility test report by JNES)



Picture of high acceleration test of a central console of NPP using sub-table on a large shaking table of Tadotsu for vibration amplification.
(From a fragility test report by JNES)

Note:

*1: Active component tests (ACT) program was a very big project with participation of all NPP makers and utilities to shear vast amount of tests. Many professors participated in the review committees of test program, results and evaluations.
Test program and evaluation results were presented in SMiRT 8, Brussels 1985 as K14/1, K14/2, K14/3 and K14/4.

*2: Methodologies of seismic capability evaluations of active components developed mainly by ACT were summarized in JEAG4601-1991.

*3: **New-new seismic design reviewing guide is incorporated as a part of NRA rule No.5,** Interpretation of the rule on standard for locations, structures and facilities of nuclear power reactor and its facilities, Enforced on July 8, 2013

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Table 2. Components of which evaluation methodologies and function certified acceleration are described in JEAG4601-1991

Name of Components	Type of components	Applicable Range of Evaluation	Note
Vertical Pump	Pit Barrel Type	Up to 1,800m³/h	Flow Capacity
	Mixed Flow Type	Up to 7,600m³/h	
	Single Stage Floor Type	Up to 1,900m³/h	
Horizontal Pump	Single Stage Centrifugal Pump	Up to 2,400m³/h	Flow Capacity
	Multi Stage Centrifugal Pump	Up to 700m³/h	
Turbine for Pump Drive	For RCIC Pump	Negligible Difference with Plant Power Output	—
	For HPCI Pump		
	For AFW Pump	Up to 250 m³/min	Flow Capacity
Electric Motor	Horizontal Axis with Plain Bearing	Up to 1,400kW	Output
	Horizontal Axis with Rolling Bearing	Up to 900kW	
	Vertical Axis with Plain Bearing	Up to 2,700kW	
	Vertical Axis with Rolling Bearing	Up to 1,300kW	
Fan	Centrifugal Direct Drive Fan	Up to 2,500m³/min	Flow Capacity
	Axial Flow Fan	Up to 2,900m³/min	
	Centrifugal Coupling Drive Fan	Up to 2,900m³/min	
Air Dumper	Air Operated Dumper	Up to 1,800mm	Vane Length
	Motor Operated Dumper	Up to 1,700mm	
Emergency Diesel Generator	Diesel Engine	Up to 15,500kW	Generator Capacity
	Governor	UG Type, EGP Type	Type
Chiller Unit	Reciprocating Chiller	Up to 100USRT	Capacity：1 USRT=302kcal/h
	Screw Type Chiller	Up to 150USRT	
	Centrifugal Chiller	Up to 600USRT	
Air Compressor for Instrumentation	V Shape Twin-cylinder	Up to 200kW	Output
	Vertical Single Cylinder	Up to 100kW	
Piston Pump	Horizontal Type	Similar Flow Rate and Discharge Pressure	—
	Vertical Type		
Valve	Glove Valve	Up to 500A	Valve Size
	Gate Valve	Up to 650A	
	Butterfly Valve	Up to 1800A	
	Check Valve	Up to 850A	
	Rubber Diaphragm Valve	Up to 100A	
	MSIV	Up to 850A	
	Electro-magnetic Valve for MSIV	Up to 25A	
	Safety Valve	Up to 200A	
	Scram Valve for CRD	Up to 50A	

CZECH REPUBLIC:

Mechanical components are categorized as follows

- seismic category I with subcategories Ia, Ib and Ic
- seismic category II

USA:

Systems, Structures and Components (SSCs) are classified as Seismic Category I or non- Seismic Category I. The expectation for the Seismic Category I SSCs is that these are designed to withstand the design basis earthquake so these can support and maintain safe shutdown conditions. The expectation for the non-Seismic Category I is that their failure will not compromise the Seismic Category I SSCs or their safety function. Guidance on seismic classification of SSCs is provided in Regulatory Guide 1.29. Also, Regulatory Guide 1.26 provides the quality classification for SSCs to be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. The quality classification also provides performance and integrity expectation for SSCs important for safety.

SPAIN:

Mechanical components are categorized in accordance with the criteria of ANSI N18.2 Safety Classes and USNRC RG 1.29. Components categorized as ANSI Safety Class 1, 2 or 3 have, generally, Seismic Category I (SC I).

The seismic qualification must assure that the equipment will maintain its ability to perform the required safety functions during and after a seismic event, and will keep this state until the time corresponding to the end of its qualified life time of operation.

Seismic Category I structures, systems and components shall withstand the effects of the SSE and ensure its integrity, and, in the case of active components, they must demonstrate operability.

The SSCs not included in the aforementioned category are known as Seismic Category II (SC II) and have been designed in accordance with the Spanish seismic resistance standard; with the exception of those SSCs, known as SC II/I or SC IIA and designed to withstand the SSE, whose eventual failure in response to a seismic action might affect the function of any SSC binned as SC I.

Q. 8:
What methods for seismic design do you use?

CANADA:
Seismic design by analysis, testing and in some cases where justified the combination of analysis and testing is used.

FINLAND:
Usually linear elastic based on 3D modeling of buildings, mechanical components and systems. Both modal response spectrum and time history analysis are allowed. Shaking table validation for electric and automation systems.

GERMANY:
The seismic safety of SSCs is verified analytically, experimentally, or by analogy or plausibility considerations. Specific requirements for the verification of building structures are stipulated in KTA 2201.3 "Design of Nuclear Power Plants against Seismic Events; Part 3: Building Structures" and requirements for components in KTA 2201.4 "Design of Nuclear Power Plants against Seismic Events; Part 4: Components".
Basically, dynamic methods (i.e. response spectra analysis, linear and non-linear time history analysis) are used. But simplified methods (e.g., quasi-static methods) are also permissible. The analytic results have to be evaluated with respect to the effects of uncertain input data. If necessary this might involve performing sensitivity analyses. This applies, in particular, to non-linear analyses.

SLOVENIA:
Dynamic analyses of structures systems and components are performed using a modal analysis plus either the response spectrum analysis or integration of the uncoupled modal equations.

KOREA:
Elastic design.

UK:
We use analysis, comparison with equivalent plant in the USA EPRI experience database or in some cases, by shaker table testing the components.

BELGIUM:
Acceptable methods described in NURG 800, ASCE 4, US NRC regulations.

SWEDEN:
In general new components are qualified by calculations and/or tests in accordance with the requirements in the Technical Requirements for Mechanical Equipment (TBM) prepared by the Swedish nuclear power utilities. In TBM applicable codes and standards are referred.

FRANCE:
No Response provided for this question!

JAPAN:
Methodologies for seismic design and evaluation are described in JEAG4601-1984, 1987 and 1991 (See Figure 2).

CZECH REPUBLIC:
Dynamic analysis is applied using model analysis and response spectrum method.

USA:

Section IV(a)(1)(iii) of Appendix S to 10 CFR Part 50 requires the safety functions of SSCs to be assured during and after the vibratory ground motion associated with the SSC ground motion through design, testing or qualification methods.

SPAIN:

The seismic design of mechanical or electrical components were designed by analysis, testing and in some cases a combination of both. The functions of retention position and leak tightness required to mechanical equipment generally were evaluated by aforementioned analysis. The operability function was evaluated by analysis with very limited extent.

For analysis design, typically dynamic methods (response spectrum, and linear/nonlinear time history analysis) were followed. With some constraints, simplified methods (equivalent static methods) were also admitted.

Q. 9:
For seismic design of mechanical components which Codes and Standards do you follow?
(a) Pressure retaining components (e.g. piping, vessels, and tanks)?
(b) Non-pressure boundary components (e.g. fans, coolers)?
(c) Component and piping supports?

CANADA:

a. CSA N285 which in turn calls for ASME Code Section III for nuclear class components. ASME Code section VIII and ASME B31.1 for non-nuclear components.
b. If operability demonstration is required, these components are qualified by analysis or testing. The seismic adequacy evaluation can also be performed by comparison against the SQUG 'Bounding Spectrum' or the 'Generic Equipment Ruggedness Spectra'.
c. CSA N285 and ASME code Section III, sub section NF for nuclear class components.

FINLAND:

a. ASME III and other similar design codes like RCC-M.
b. ASME QME-1-20 is approved, also for active parts of pressure boundary systems and components.
c. ASME III Subsection NF is applicable to pressure boundary component supports. Also App. F rules are useful for avoiding damage chains due to failure of supports.

GERMANY:

Components of the (seismic) Classes I and IIa (see question/answer 7) are designed according to nuclear safety standard KTA 2201.4 "Design of Nuclear Power Plants against Seismic Events; Part 4: Components". In addition the design has to comply with the component-specific nuclear safety standards, e.g.

a)

- KTA 3201.2 "Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 2: Design and Analysis"
- KTA 3204 "Reactor Pressure Vessel Internals"
- KTA 3211.1 " Pressure and Activity Retaining Components of Systems Outside the Primary Circuit; Part 2: Design and Analysis"

b)

- KTA 3601 "Ventilation Systems in Nuclear PowerPlants"
- For many non-pressure boundary components the specifications in the license are based on conventional standards and amended by additional requirements.

c)

- KTA 3205.1 "Component Support Structures with Non-integral Connections; Part 1: Component Support Structures with Non-integral Connections for Components of the Reactor Coolant Pressure Boundary of Light Water Reactors"
- KTA 3205.2 "Component Support Structures with Non-integral Connections; Part 2: Component Support Structures with Non-Integral Connections for Pressure and Activity-Retaining Components in Systems Outside the Primary Circuit"

SLOVENIA:

a. Pressure retaining components (e.g. piping, vessels, and tanks)?
The Class I piping systems are analyzed to the rules of the ASME Code, Section III, NB 3650.
Design of ASME Code Class I piping is intended to comply with NB-3600 of ASME Section III. The Class I pressure vessels are qualified according to ASME Section III, NB-3200 and NB-3300. Similar, the Class II vessels are analysed with respect to NC-3200 and NC-3300 and piping with respect to NC-3650.

b. Non-pressure boundary components (e.g. fans, coolers)?
AMCA 210-67, AMCA Standards Handbook 99-67, NEMA MG1-67, AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, Editions 7th , 9th and 13th.

c. Component and piping supports?
In general, rules of ASME Sect III – NF are followed. Specifically, piping stresses induced by relative movements of anchors during an earthquake are compared in accordance with Eq. (10) or (11) of NC-3652 of ASME Section III. The effect of differential seismic movement of piping supports is included in the piping analysis according to the rules of the ASME Boiler and Pressure Vessel Code, Section III, Paragraph NB 3653.

KOREA:
Us NRC 10CFR50 app. A (General Design Criteria)

UK:
a. Pressure retaining components (e.g. piping, vessels, and tanks)? EPRI NP 6041 Appendix H guidance for tanks
b. Non-pressure boundary components (e.g. fans, coolers)? SQUG GIP guidance
c. Component and piping supports? ASME guidance and SQUG GIP

BELGIUM:
a. Pressure retaining components (e.g. piping, vessels, and tanks)? ASME III Subsection AB/NC/ND

b. Non-pressure boundary components (e.g. fans, coolers)? ASCE 690 or EUROCODE III with certain adaptations

c. Component and piping supports? ASME III – Subsection NF (for class 1,2 & 3 ASME Class Pressure vessels & piping) - ASCE 690 or EUROCODE III with certain adaptations for other components

SWEDEN:
a. Pressure retaining components (e.g. piping, vessels, and tanks)?
The applied Codes and Standards depend on the quality class. In general the following is applied:
Quality class 1: Applicable parts of ASME III.
Quality class 2: Applicable parts of ASME III.
Quality class 3: Applicable parts of ASME III.
Quality class 4: Applicable parts of ASME III or The Swedish Work Environment Authority, applying for pressurized equipment AFS 1999:4, AFS 1993:41, (revised in AFS 1994:53) and AFS 2005:2.

b. Non-pressure boundary components (e.g. fans, coolers)?
For new components applied method may vary case by case depending on manufacturer/supplier and type of components. The manufacturer/supplier shall provide documentation that verifies seismic adequacy of the component.

c. Component and piping supports?
Applicable parts of ASME III for quality class 1, 2 and 3.
For quality class 4, applicable parts of ASME III or The Swedish Work Environment Authority, applying for pressurized equipment AFS 1999:4, AFS 1993:41, (revised in AFS 1994:53) and AFS 2005:2

FRANCE:

a. Pressure retaining components (e.g. piping, vessels, and tanks)?
Mainly RCC-M, Volume B, C, D.

b. Non-pressure boundary components (e.g. fans, coolers)?
EDF specific requirements are defined for non-pressure boundary components.

c. Component and piping supports?
Mainly RCC-M, Volume H. The design rules for supports or support components which are embedded in concrete are dealt with in the ETC-C.

JAPAN:

a. Pressure retaining components (e.g. piping, vessels, and tanks)?
JEAG4601-1984 and JSME S NC1-2005[*1]

*1: Code for Nuclear Power Generation Facilities – Rules on Design and Construction for Nuclear Power Plants - , Japan Society of Mechanical engineers, Sept.,2005

b. Non-pressure boundary components (e.g. fans, coolers)?
Question is not clear but if it means active components, they are evaluated by JEAG4601-1984 and JSME S NC1-2005 and JEAG4601-1991

c. Component and piping supports?
JEAG4601-1984 and JSME S NC1-2005

CZECH REPUBLIC:

a) ASME Code Section III for methodology, allowable stresses according Russian standard PNAEG7-002-86
b) if operability demonstration is required, for allowable stresses is used Russian standard PNAEG7-002-86
c) ASME code Section III, subsection NF

USA:

a) For Pressure Retaining Components: Following RG 1.26, the acceptable code for Component Quality Groups A (Class 1), B (Class 2), and C (Class 3) is the ASME Code Section III, with the exceptions and additions noted in RG 1.26. For Component Quality Group D, acceptable codes include the ASME Code Section VIII, ASME B31.1/31.3, API-620, API-650, and AWWA D-100. Applicability of these codes depends on the pressure rating and service. Additional details can be found in Table 1 of RG 1.26.

b) Non-Pressure Boundary: It depends on the equipment, its service (safety related or non-safety related), its location relative to safety related equipment. In general industry standards but that could be augmented/by ASME QME-1 or IEEE-344 depending on the details of the equipment

c) Component and Piping Supports: ASME Section III Subsection NF or ASME Section VIII depending on the application (see a).

US federal regulations state that systems and components in a nuclear power plant must meet requirements in the ASME Code as indicated in 10 CFR 50.55a. Additional guidance for specific code cases are provided in the RGs 1.84 and 1.192. RGs provide the staff position on an acceptable method to comply with regulatory requirements. Applicants/Licensees may use alternate methods to those listed in the RGs. However, the alternate methods must be demonstrated to provide as much protection to the health and safety of the public and the environment as the proposed method in the RGs.

SPAIN:

a) The ASME Code Section III, for nuclear class components.

b) The IEEE-344 and USNRC RG. 1.100, for nuclear class components. For Trillo plant: KTA 3601 “Ventilation Systems in Nuclear Power Plants”.

c) The ASME code Section III, subsection NF.

Q. 10:
What acceptance criteria do you use for seismic design (detailed as per Q #4 above)?
a. Stress
b. Strain
c. Other

CANADA:
(a) Stress and in cases where operability demonstration is required displacement and strains are also considered

FINLAND:
(a) Stress. In addition, displacements shall be such that damage to nearby SSC is prevented.

GERMANY:
In Germany, qualification/verification is typically done on the basis of stresses. For pressure retaining components and non-pressure boundary components the design basis earthquake is generally associated with load level D (the German classification scheme is similar to the ASME classification). Load level C may be required if the integrity of a component, in particular the integrity of pipe connections, cannot be ensured in load level D. If operability of a component is required, either corresponding verification has to be provided or the load level has to be restricted to B. (Safety Requirements for Nuclear Power Plants, Annex 2)

SLOVENIA:
a. Stress
Stress criteria for seismic design of mechanical components are given in ASME Code, Section III, Subsections NB, NC and NF for the Class 1 components, the Class 2 components and their supports, respectively. The stress criteria for concrete structures are based on strength design concept of ACI 318.

b. Strain
For mechanical components and civil structures any deformation or deflection limits prescribed by the design specifications and/or above standards are considered.

c. Other : N/A

KOREA:
a.

UK:
a. Stress – for design, limit stress to linear elastic range.
b. Strain – displacement limits for piping
c. Other – assessment may consider non-linear behaviour ie non-collapse performance criteria
Both Stress and strain and in some cases fatigue life cycling

BELGIUM:
Seismic design of components is typically based on stress. Strain & Displacement are used in specific cases for instance, the qualification of active components for which the operability can be demonstrated by analysis.

SWEDEN:
Acceptance criteria are specified in KFM in accordance with guidelines specified in ASME III.

FRANCE:

The acceptance criteria is generally a stress criteria, based on an elastic approach. No strain criteria is defined in RCC-M for seismic design.

JAPAN:

Regarding structural components, they are basically evaluated by stress. Load combinations and allowable limits are described in JEGA4601-1984.

Regarding active components, response acceleration is often used as explained in the Questionnaire 7.

CZECH REPUBLIC:

As a acceptance criterion we use stresses according Russian standard PNAEG7-002-86. If needed, displacements are used.

USA:

For Mechanical components:

a) Stress: Acceptable as described in ASME Section III Subsections NB, NC, ND and NF; or ASME QME-1 or IEEE-344.
b) Strain: Acceptable only where recognized by ASME and accepted by the NRC.
c) Other: Other methods are reviewed on a case-by-case basis.

SPAIN:

The acceptance criteria are specified in accordance with guidelines specified in ASME III, and they are usually stress criteria. In specific cases, where qualification is done by analysis and operability demonstration is required, strains and displacements are also considered. If a support component deformation can be expected to affect the operational readiness requirements of the supported component, then deformation limits should also be specified.

Q. 11:
Under what conditions is each of the following approach used?
a. Analysis
- Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories?
- Equivalent static:

b. Testing?
c. Combination of Analysis and Testing
d. Other, please specify (SMA, experience-based, similarity, etc.)

CANADA:

a. Analysis - Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories?
For complex multi degree of freedom systems. Synthesized time histories shall be spectrum compatible and envelop the spectrum and account for the frequency shift by +/- 15%.
- Equivalent static: For very simple systems with a single dominant frequency.
b. Testing: Mostly for I&C component's strength and functionality check. Also used to test strength/functionality of mechanical components as well.
c. Combination of Analysis and Testing: For strength/functionality of mechanical components such as main PHT pump and diesel generators etc.
d. Other, please specify (SMA, experience-based, similarity, etc.): SMA was used for seismic qualification for plants which were not designed by carrying out standard dynamic analyses to meet ASME code requirements (e.g., Pickering A and Bruce A). Experience-based, similarity methods are used for standard off- the shelf items. SMA is also used for seismic margin assessment.

FINLAND:

a. Analysis for large SSC's with well understood mechanical failure modes (i.e. assessed by structural integrity alone). Most commonly used analysis method is response spectrum modal superposition. Linear time-history method is also used. Uncertainties handled by checking independence of records (ASCE 4-98 Clause 2.2.(d), or IEEE 344-2004, Clause 8.6.6.2) and recommending 3 record sets analysis case. Equivalent static method may be used for rigid equipment (e.g. as defined in IEEE 344).
b. Seismically classified electrical and automation equipment and some valves are tested.
c. Combination of analysis and testing are used for instance in cases where shaking table qualification of the sole component, without its supporting structure, is meaningful.

GERMANY:

According to KTA 2201.1 "Design of Nuclear Power Plants against Seismic Events; Part 1: Principles" the earthquake safety of SSC can be verified analytically, experimentally, or by analogy or plausibility considerations. It is not specified under what conditions each of the approaches may be used. Basically, the decision is up to the applicant. Whether the chosen approach is acceptable for the SSC under consideration or not, is decided by the regulatory authority (if necessary after consulting their TSO). In the following some general requirements (mainly from KTA 2201.1) are presented. More detailed requirements can be found in KTA 2201.3 "Design of Nuclear Power Plants against Seismic Events; Part 3: Building Structures" and KTA 2201.4 "Design of Nuclear Power Plants against Seismic Events; Part 4: Components".

a)
- Basically, dynamic methods (i.e. response spectra analysis, linear and non-linear time history analysis) shall be used. But simplified methods (e.g., quasi-static methods) are also permissible.

- Quasi-static method may be used for systems with a homogeneous distribution of stiffness and mass. Secondary spectra shall be applied to the design of support structures of subsystems. The subsystem (supported system) itself shall be designed based on tertiary spectra. The system responses (stresses) may be calculated by a static analysis. In this context, substitute accelerations shall be defined that result in quasi-static actions in proportion to the mass distribution.
- If linear modal superposition is used, the phases of the superposed modes shall be taken into account. In the case of modal response spectrum methods, the phases should be taken into account by applying the complete quadratic combination (CQC). (However, in well-founded cases it is permissible to use other types of superposition, e.g. square root of the sum of squares).
- For the determination of floor response spectra, the frequency increment in each octave shall normally be no larger than 1/50 of the lower limit of the octave, however, no smaller than 0.02 Hz.
- The analytic results shall be evaluated with regard to the influence of uncertain input data. If necessary this might involve performing sensitivity analyses. This applies, especially, to non-linear analyses.
- Normally artificial acceleration time histories shall be used that are compatible with the ground acceleration response spectrum. Alternatively, the registered acceleration time histories may be used. Artificial time histories may be assumed as being statistically independent if the absolute value of the correlation coefficient of each of two time series is smaller than 0.3 and the mean absolute value of all correlation coefficients is smaller than 0.2. Time histories shall be considered as compatible with the ground acceleration response spectrum if the amplitudes of no more than 10 % of the control frequencies of the response spectrum calculated for a damping ratio of D = 0.05 are lower than 10 % of the amplitudes of the goal spectrum.
- Registered acceleration time histories may be used as an alternative to artificial time histories; however, at least 5 time series shall be applied. The response spectra from these time histories shall be compatible with the ground acceleration response spectrum in the frequency range decisive for the analyzed structure. In the case of linear analyses, the averaged results of these analytical procedures may be applied.

b)

- The objective of the test shall be defined in accordance with the respective safety-related tasks of the SSC. It has to be ensured that all relevant limit values derived from the objective can be determined during the test.
- Specific requirements regarding testing are stipulated in Section 5 (approx. five pages) of KTA 2201.4.

c)

- There are no specific requirements for the combination of analysis and tests.

d)

- Besides analysis and testing, verification by analogy or plausibility considerations is allowed. Detailed requirements in this regard are stipulated in KTA 2201.4, Section 5 and 6.
- Verification by analogy:
    - Verification by analogy shall be based on the following reference results: a) results from analytical or experimental verifications that were performed on similar, type-identical components, b) the quantitatively documented results for the respective component with regard to its behavior under other actions, provided these results are suited to make comparisons.
    - The available reference results shall be evaluated with regard to transferability and it shall be quantitatively substantiated that this procedure ensures that the respective component will fulfill its safety-related task.

  - Dynamic system characteristics may be used as reference if the static system characteristics are comparable and any changes with respect to mass distribution are evaluated.
- Verification by plausibility considerations:
  - Verification by plausibility considerations shall be based on factual experience as follows: a) Experience regarding the behavior of similar, type-identical components in nuclear or non-nuclear facilities during earthquakes that have actually occurred. b) Experience from earthquake verifications for similar, type-identical components that enable an evaluation of the design of other components with regard to earthquake safety.
  - The factual experience shall be evaluated with regard to transferability of actions and capacities. On this basis it shall be substantiated that it is plausible that the respective component will be able to fulfill its safety-related task.
  - To gain the required factual experience, it is necessary to peruse the design documents and to perform walkdowns. The observations made in this context shall be documented. Normally, the walkdowns shall be performed in the actual power plant. But if a CAD model is available, they can also be performed as a virtual walkdown, provided that the CAD model and all data relevant to the evaluation are current and of sufficient quality.

SLOVENIA:

a. Analysis

- Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories?

In general, seismic category I structures are dynamically analysed for SSE and OBE earthquake conditions using a modal analysis time history method. The Reactor Coolant Loop Piping is analysed using the time-history method on the coupled building/loop system model by applying 6-component time-history accelerations (3 translational, and 3 rotational accelerations) at the base of the coupled system model. The seismic response of components, obtained from the synthesized time histories is multiplied by a factor of 1.2. In such a way it is considered that uncertainties are accounted for. The torsional effects are taken into account by lumping masses at the centres of gravity and eccentric masses. The uncertainties in floor response spectra calculation are approximately taken into account by broadening of floor spectra by ± 15%.

- Equivalent static

The equivalent static approach is used for the seismic qualification of various non-pressure retaining components, i.e. racks, platforms, supports of air conditioning equipment, filters, etc.

The magnitude of the seismic acceleration used for determination of equivalent static load is established on the basis of the expected dynamic response characteristics of the component.
Components, which can be characterized as a single-degree-of-freedom system, are considered to have a modal participation factor of one. Seismic acceleration coefficients for multi-degree-of-freedom systems which may be in the resonance region of the amplified response spectra curves are increased by 50 percent (multiplied by 1.5) to account conservatively for the increased modal participation.

Also, the effect of differential seismic movement of components interconnected between floors is considered statically in the integrated system analysis and in the detailed component analysis.

b. Testing

The following are general conditions that are followed, when equipment is qualified through testing: tests are performed by subjecting the tested equipment to a vibratory motion, which simulates that motion to be experienced at the equipment mounting during OBE and SSE; active equipment is tested in an operating condition; the equipment is mounted for the test in a manner that simulates the intended service mounting; the test shall demonstrate the ability of the equipment to perform its intended function.

c. Combination of Analysis and Testing
Combination of analysis and testing is used when testing exclusively becomes impractical, for example, to determine motions at the mountings in the form of the response spectra or time histories for the analysis of attached devices.

d. Other, please specify (SMA, experience-based, similarity, etc.)
Equipment types which are similar to those previously qualified are candidates for review and qualification by the concept of similarity. Dynamic similarity is reviewed in a manner that addresses: physical system similarity, similarity of excitation, dynamic response similarity, and similar operability.

KOREA:

a. Analysis passive component
Dynamic: Power spectral density

c. Testing? Active component

UK:

a. Analysis
- Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories? Generally used in more complicated plant and/or structures where uncertainties lie in probable behavior and cater for uncertainties by ensuring large factors of safety.

- Equivalent static - simple structures where adequate margins exist

b. Testing?
Small components with no previous seismic qualification or details in experience database.

c. Combination of Analysis and Testing - As above to confirm behavior of essential components.

d. Other, please specify (SMA, experience-based, similarity, etc.) - as noted previously.

BELGIUM:

a. Analysis
- Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories? Using more than one set of THS

- Equivalent static
Those methods are used for passive component or active component if functionality can be showed by structural considerations… (e.g . ASME QME 1)

b. Testing?
Used for active complex components e;g. electrical assemblies & devices

c. Combination of Analysis and Testing

d. Other, please specify (SMA, experience-based, similarity, etc.)
The SQUG-GIP was used for seismic adequacy of the the GIP 22 classes of components for seismic revaluation of one of the Belgian site

SWEDEN:

a. Analysis
- Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories?
- Equivalent static

In general analysis is applied for new components.

b. Testing?

In general testing is applied for new components.

c. Combination of Analysis and Testing

In general a combination of analysis and testing is applied for new components.

d. Other, please specify (SMA, experience-based, similarity, etc.)

The methods applied for Swedish NPPs are according to EPRI NP-6041-SL"A Methodology for Assessment of Nuclear Power Plant Seismic Margin" or according to SQUG Generic implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment.

SMA or GIP methodologies can be used for existing components. However, also analysis may be used for existing components.

FRANCE:

a. Design by analysis is the approach used for passive components. Transient linear and non-linear analysis using time histories are very rarely used in the design process. Equivalent static analysis can be used for some components that belong to RCC-M class 2 or 3.
b. Testing procedures will be used to demonstrate operability if the component is mechanically or structurally complex such that its response cannot be adequately predicted analytically.
c. A combination of analysis and testing is used for valves for example.

JAPAN:

a. Analysis
- Dynamic: Response spectrum Modal superposition; Linear and non-linear analysis using time histories; How do you account for uncertainties in synthesized time histories?
- Equivalent static

Analysis methods shown below are used:

Piping : Normally Response spectrum Modal superposition is used for design analysis. Time history direct integration is sometimes used when evaluating beyond DBE.

Building: Time history analysis. Uncertainty of time history is covered by using several synthesized wave if necessary.

Equipment: Equivalent static analysis is sometimes used because equipment tend to be analyzed using very simple model like one degree of freedom

b. Testing?

Active components are normally evaluated using test data as shown in Figure 2.

c. Combination of Analysis and Testing

Some active components in which new parts are installed may be evaluated by combination method, i.e. Please image electric panel in which non-tested parts are installed. You can calculate panel response and combining newly gained test data of new parts, you can evaluate the panel as total.

d. Other, please specify (SMA, experience-based, similarity, etc.)
Similarity is an important view point if we want to expand applicability of test result. The range of similarity you can apply test result or test verified model or function confirmed acceleration to other similar equipment was reviewed in the review committee in the Active Component Test Project. Applicable range of test base active component evaluation is described in JEAG4601Suppliment-1991 for each type of equipment.

CZECH REPUBLIC:

a) analysis: Response spectrum modal superposition, linear analysis using time histories. Uncertainties in synthetized time histories are evaluated according RG 1.92

Equivalent static: for very simple components or systems

b) testing: in the casa of equipment qualification (EQ)
c) combination of analysis and testing: only for EQ
d) SMA is used for seismic reassessment of older NPPs

USA:

Any method can be used if it can be and is properly justified.

a. Analysis

- Dynamic: When using either the response spectrum method or the modal superposition time history method, responses associated with high frequency modes should be included in the total dynamic solution using the guidance and methods described in Regulatory Guide (RG) 1.92, Regulatory Positions C.1.4 and C.1.5. Uncertainties in synthesized time histories are accounted for by keeping frequency intervals sufficiently small and by maintaining the response spectrum sufficiently close to the target spectrum. Also, peaks on floor response spectra are broaden as indicated in RG 1.122. Further guidance can be found in NUREG-0800 Chapters 3.7.2 and 3.9.2.

- Equivalent static: Equivalent static methods are acceptable if a system can be realistically represented by a simple model, if relative motion between all points is accounted for, and if a factor of 1.5 is applied to the peak spectral acceleration of the applicable ground or floor response spectrum. A factor less than 1.5 may be used, if adequate justification is provided. Further guidance can be found in NUREG-0800 Chapter 3.9.2.

b. Testing: Piping vibration, safety relief valve vibration, thermal expansion, and dynamic effect testing should be conducted during startup testing. The purpose of these tests is to confirm that these piping systems, restraints, components, and supports have been adequately designed to withstand flow-induced dynamic loadings under the steady-state and operational transient conditions anticipated during service and to confirm that normal thermal motion is not restrained. Further guidance can be found in NUREG-0800 Chapter 3.9.2.

c. Combination of Analysis and Testing: Combination of analysis and testing can be used if guidance in RG 1.20 and acceptance criteria #3 on NUREG-0800 Chapter 3.9.2 is followed. Based on data obtained from plant or scale model tests, forcing functions should be formulated to include the effects of complex flow path configurations and wide variations of pressure distributions. Further guidance can be found in NUREG-0800 Chapter 3.9.2.

d. Other, please specify (SMA, experience-based, similarity, etc.): Other methods are reviewed on a case-by-case basis.

SPAIN:

a). Dynamic analysis: Response spectrum modal superposition; and linear and non-linear analysis by time histories. In general, were applied for complex multi degree of freedom systems: response spectra analysis applies to linear systems, where linear dynamic behavior is assumed; and time-history analysis applies to complex systems were linear and non-linear dynamic behavior is assumed. The uncertainties in synthesized time histories for floor response spectra calculation, are taken into account by floor spectra broadening according to USNRC RG 1.122.

Static analysis: applies for stiff components with natural frequency above 33 Hz.

Equivalent static analysis: applies for simple components, using very simple model like one degree of freedom

b). Testing: Applied for active complex components in seismic qualification of equipment

c). Combination of analysis and testing: In general is applied for large components with fixed and mobiles parts, or for separately seismic qualification of panels and devices.

d). Experiences: in according IEEE-344-87; SMA applied in seismic IPEEE according to EPRI NP-6041-SL, or SQUG (GIP) for Seismic Verification of older NPPs.

Q. 12:
Do you consider seismic induced fatigue in seismic design? If so, how?

CANADA:
Yes. Only when Primary + Secondary stress due to DBE exceeds 3Sm or shakedown limit. Seismic fatigue usage factor is added to transient fatigue usage factor for ASME code compliance for nuclear class 1 components. Maximum 25 cycles at peak acceleration are considered adequate for seismic fatigue usage factor calculation.

FINLAND:
For equipment qualification, procedures of IEEE 344 Clause 8.1.5 was recommended (to component suppliers), in the context outside Finland (where OBE definition existed). Equivalent effect of five OBEs was used for seismic induced fatigue. Seismic induced fatigue is not considered for locations in Finland.

GERMANY:
Seismicity in Germany can be classified as low to moderate. Therefore, earthquakes which are likely to happen during the lifetime of the German NPPs can be expected to have very low accelerations and a very limited number of cycles. Consequently, seismic induced fatigue is not a major issue. Nevertheless, nuclear safety standard KTA 2201.6 "Design of Nuclear Power Plants against Seismic Events; Part 6: Post-Seismic Measures" stipulates that inspections have to be performed in case an earthquake affects the plant, in particular if the so called Inspektionsniveau (inspection level, c.f. question/answer 5) is exceeded. If the seismic loads reach a level of 0.6-times the loads of the design basis earthquake, the plant has to be shut down and the inspections have to be supplemented by verification calculations for critical components. This graded approach ensures that potential relevant effects of an earthquake (including fatigue) don't go unnoticed. Ageing effects in general are dealt with in nuclear safety standard KTA 1403 "Ageing Management in Nuclear Power Plants"

SLOVENIA:
The effects of cyclic loadings are taken into account. Five OBE occurrences in the life of the plant are assumed. USAR defines that ten maximum stress cycles for flexible equipment (natural frequencies less than 33 Hz) and five maximum stress cycles for rigid equipment (natural frequencies greater than 33 Hz) for each OBE occurrence should be used for fatigue evaluation of systems and components.

KOREA:
Yes, 20 cycle of SSE stress level.

UK:
No, due to low number of cycles considered for short duration UK earthquakes.

BELGIUM:
For the ASME class 1 components a normalized number of stress cycles corresponding to 5 OBE occurrences is assumed for fatigue evaluation

SWEDEN:
No.

FRANCE:
Seismic induced fatigue has to be considered for RCC-M class 1 components (the code class may be different from the safety class, and is given in the equipment specification), and only for normal and upset conditions. It is considered 30 occurrences of Inspection Earthquake (IE), with 20 cycles in each IE.
These rules may also be applied for some class 2 equipment (heat exchangers, for instance).

JAPAN:

Evaluation of seismically induced fatigue is required for Class 1, Class 2 and Class 3 components. Requirements are described in JEAG4601/Suppliment-1984. the description for Class 1 piping is shown below as an example.

Fatigue evaluation is required for allowable stress condition III_AS and IV_AS as shown in Table 3.

Table 3 Allowable stress of Class 1 Piping (From JEAG4601 Supplement-1984)

Stress category / Allowable stress condition	General primary membrane stress	Local primary membrane stress	Primary + Secondary stress	Primary + Secondary + Peak stress
Design	S_m	$1.5\ S_m$	—	—
I_A	—	—	$3\ S_m$ (1)	At the load combination for operating condition I and II, the cumulative fatigue factor should be 1.0 or less.
II_A	—	—		
III_A	$(1.5\ S_m)$ (2)	$2.25\ S_m$	—	—
IV_A	$(2\ S_m)$ (2)	$3\ S_m$	—	—
III_AS	$1.5\ S_m$ (4)	$2.25\ S_m$ (5) ただし，ねじりによる応力が0.55 S_mを超える場合は，曲げとねじりによる応力について1.8 S_mとする。	$3\ S_m$ (3)(5) （S_1又はS_2地震動のみによる応力振幅について評価する。）	The cumulative fatigue factor analysis should be carried out for only ground motion Ss or S_d, and the sum of the cumulative fatigue factor with that in operating condition I and II should be 1.0 or less.
IV_AS	$2\ S_m$ (4)	$3\ S_m$ (5) ただし，ねじりによる応力が0.73 S_mを超える場合は，曲げとねじりによる応力について2.4 S_m とする。		

Note: S_1 should be read as S_d, S_2 should be read as Ss.

Where:

III_AS is allowable stress condition under the operating condition III+ Seismic Load,
IV_AS is allowable stress condition under the operating condition IV + Seismic Load.

CZECH REPUBLIC:

Russian standard PNAEG7-002-86 require seismic induced fatigue only is the case if cumulative damage factor is higher that 0.8

USA:

Seismic induced fatigue is associated with earthquake stress cycles. Guidance for determining the number of earthquake cycles for use in fatigue calculations should be the same as the guidance provided in Staff Requirement Memorandum (SRM) for SECY-93-087 dated July 21, 1993 for piping systems (Agencywide

Document Access and Management System (ADAMS) Accession Number ML003708056). The number of earthquake cycles to consider is two SSE events with 10 maximum stress cycles per event. This is considered to be equivalent to the cyclic load basis of one SSE and five OBEs. Alternatively, the number of fractional vibratory cycles equivalent to that of 20 full SSE vibratory cycles may be used (but with an amplitude not less than one-third of the maximum SSE amplitude) when derived in accordance with Institute of Electrical and Electronics Engineers (IEEE) Standard 344-1987, Appendix D.

SPAIN:

The effects of cyclic loadings are taken into account. Five OBE and one SSE occurrences are assumed during the time life of plant operation.

Procedures of IEEE 344 are applied to equipment qualification; and preceding SSE occurrence, equivalent effect of five OBEs is used for seismic induced fatigue as vibrational aging.

Q. 13:
Do your national code acceptance criteria allow for plasticity in seismic design?

CANADA:
CSA standard N289.3 does not allow for gross plasticity in seismic design.

FINLAND:
This depends on how the seismic loading is categorized for the component. Category D is permissible in case that just integrity is required, and implies gross plastic deformation which may necessitate component removal from service. In contrast, category B is required to exclude plastic deformation in components with active safety functions, calling for movement of their internals. The implementation of load categorization shall be submitted for regulatory approval.

GERMANY:
In general, ductility is not part of the seismic design concept. Limited plastifications at geometrical discontinuities are acceptable in case of the design basis earthquake (i.e. in this case SSCs are not expected to remain completely in the elastic range). But it has to be verified that these plastifications do not impair the integrity/functionality of (seismic) Class I SSCs (c.f. question/answer 7).

SLOVENIA:
No, a general elastic behaviour of the structure under the safe shutdown earthquake loading condition must be ensured. On the other hand, many components can experience significant permanent deformation without loss of function. Piping and vessels are examples of the latter where the principal requirement is that they retain their contents and allow fluid flow.

KOREA:
No.

UK:
N/A

BELGIUM:
No incursion on plasticity domain allowed.

SWEDEN:
Yes, but not in case active function is required.

FRANCE:
RCC-M Level D criteria allow for plasticity. These criteria can be used when only stability and/or integrity are required during or after a DBE.

JAPAN:
We have two level earthquakes for design as described before.
For Ss, plastic deformation is allowed if required function is maintained. But to keep response level in elastic behavior is found especially in case of active components such as electric panels for simple and solid design.

CZECH REPUBLIC:
No.

USA:

Acceptable standards and codes endorsed in regulatory guidance use elastic methods of analysis for design-basis conditions without reductions for seismic forces associated with ductility-based design and without allowance for response in the plastic range (except for localized plasticity). However, the ASME Code provides guidance if plastic analysis is used and its acceptability is reviewed on a case-by-case basis.

SPAIN:

In seismic design, all SSCs of Seismic Category I must withstand the effects of the SSE and assure their elastic behaviour.

Q. 14:
How do you ensure operability of mechanical components during and after an earthquake?

CANADA:
By assigning a seismic Category of ‘B’ to such components and qualifying these components by testing.

FINLAND:
Design and testing up to the SSE. Seismic PRA and Design Extension Condition analyses reduce the risks of cliff-edge effects. The safety of a NPP is improved throughout the life-time of the NPP. Seismic PRA is used to identify improvements for the safety of the NPP. Seismic PRA and improvements made based on the findings found from the seismic PRA are important especially for the old NPPs that are not designed for earthquakes.

In seismic design by analysis, the load and service limit categorization as per the applicable code is the main approach to ensure integrity, operability and functional capability. A detailed description on this is given in the Finnish response to a dedicated CAPS proposed within Metal Sub-group several years ago, see STUK question #8 on the WGIAGE web site.

GERMANY:
SSCs in (seismic) Class I have to be designed such that they are able to fulfill their safety related tasks in case of the design basis earthquake. Typical safety related tasks are: load-carrying capacity (stability), integrity, and functional capability. Functional capability is the capacity of a system or component to fulfill the designated tasks by way of its respective mechanical or electrical function. Active and passive functional capabilities have to be differentiated. Active functional capability of a component ensures that the specified movements (relative movements between individual parts) can be performed (closing of clearances, creating or changing of friction forces) and that the electrical functions are maintained. A passive functional capability of a component means that permissible deformations and movements are not exceeded. KTA 2201.4 “Design of Nuclear Power Plants against Seismic Events; Part 4: Components” provides details on how this requirement can be fulfilled.

SLOVENIA:
The operability of Category I mechanical equipment must be demonstrated if the equipment is determined to be active, i.e., mechanical operation is relied on to perform a safety function. The operability of active Class 2 and 3 pumps, active Class 1, 2 or 3 valves, and their respective drives, operators and vital auxiliary equipment is shown by satisfying the criteria given in *Pump and Valve Qualification for Operability Program*. Other active mechanical equipment is shown operable by either inspection, testing, analysis or a combination of testing and analysis. The operability programs implemented on this other active equipment is similar to the program mentioned above.

KOREA:
By seismic qualification test.

UK:
By pre-qualification which may include physical testing and operating procedures post-seismic to assess damage

BELGIUM:
By testing or by structural considerations in certain circumstances.

SWEDEN:
By taking into consideration if active function is required for a specific load case in the KFM, see further Question 7.

FRANCE:
A stress criteria level B (stress below elastic limit with a safety coefficient) is defined in RCC-M for operability.
For valves, a combination of analysis and testing is used.
For some other active mechanical components like pumps, deformations are also compared to allowable clearances.

JAPAN:
Operability is ensured if experienced earthquake response is under Sd design level i.e. in the range of elastic behavior.

CZECH REPUBLIC:
Seismic subcategory Ia: total integrity required
Seismic subcategory Ib: only mechanical integrity is required
Seismic subcategory Ic: seismic interactions with components is prohibited, partial failures in operability or mechanical integrity are possible

USA:
To provide assurance that mechanical components will perform during and after an earthquake, RG 1.100 provides acceptable guidance for seismic qualification of active mechanical components, such as ASME QME-1 or IEEE-344. Furthermore, RGs 1.166 and 1.167 refer to EPRI-6695, with exceptions noted in RG's, as an acceptable guidance for licensees to establish post-earthquake action plans to assess the plant's condition, including short and long-term evaluations, surveillance tests for components, inspections, and other measures to provide assurance that the SSCs are on acceptable conditions for safe performance after an earthquake.

SPAIN:
Mechanical equipment operability of Seismic Category I must be demonstrated if the equipment is determined to be active.
Qualified equipment must be capable of performing its safety function(s) during and/or after an earthquake.
The justification for operability is done depending on followed qualification method.
For components qualified by analysis, operability only can be demonstrated when it just depends on the structural integrity, as in passive components case. For active components, using analysis to evaluate operability is limited to check that maximum strains and displacements meet design requirements, and ensure their safety functions.
In other cases, justification for operability is done when components are qualified by testing, by monitoring the behaviour during the dynamic test, and by functional tests.

Q. 15:
In seismic testing of mechanical components which of the following methods do you use?
a. Single axis test
b. Multi-axis random test
c. Other, please specify

CANADA:
a. Single axis test - No
b. Multi-axis random test - Preferred
c. Other, please specify - Bi-axial testing is also utilized for small components.

FINLAND:
Both single axis test and multi-axis random test. Single axis testing was used with appropriate factors to increase uni-axial shaking intensity, in order to account for multi-directionality of the vibration. The factors are based on same testing standards as corresponding design standards, like IEC/IEEE.

GERMANY:
Basically, the excitations shall be applied simultaneously in all three spatial directions. An individualization of the sequence of the individual direction-related loads is permissible, provided, a) the verification objective allows for the superposition of the corresponding reactions of the test object, or b) it is shown that the behavior of the test object (eigenfrequencies, stiffness) or that the required response spectra (frequency ranges with large resonance peaks) are independent of each other with respect to the individual axes, or c) the multi-axial character of the seismic excitation is taken into account by means of a correspondingly higher test excitation. In the case of multi-axial test excitations with a fixed phase assignment, the in-phase and 180°-phase-offset excitation signals shall normally be combined.

SLOVENIA:
If the degree of coupling in the equipment is small, then single axis testing is justified. Multi-axis testing is required if there is considerable cross coupling; however, if the degree of coupling can be determined, then single axis testing can be used with the input sufficiently increased to include the effect of coupling on the response of the equipment.

KOREA:
b.

UK:
a. Single axis test - yes
b. Multi-axis random test - yes
c. Other, please specify

BELGIUM:
Multi-axis random tests are usually performed – Single axis is also used in specific cases…

SWEDEN:
The testing is normally performed in accordance IEEE 344-1987, therefore multi-axis is normally used.

FRANCE:
For active components, multi-axis tests are generally used.

JAPAN:
In most cases, multi-axis random excitation tests are applied.

By superimposing the design spectra of the plants in Japan, artificial time histories to envelope the spectra are made as input wave for shaking test.

CZECH REPUBLIC:
We have only shaking tables for single axis test.

USA:

a) Single – yes.
b) Multi-axis – yes.
c) Other – As required to obtain conservative (but not overly so) test situation (per IEEE-344 2013) or ASME QME-1, if accepted by the NRC as documented in Regulatory Guide 1.100, NUREG-0800, Standard Review Plan (SRP) for Light Water Reactors, or other licensing documents.

Additional guidance is provided in RG1.100 & NUREG-0800, Chapter 3.9.

SPAIN:

a. In the past the single axis test was used. Currently is not used.
b. The multi-axis random test according to IEEE 344 is normally used.

Q. 16:
When do you consider mechanical components to be inherently seismically rugged?

CANADA:
Rigid sturdy components with heavy mass with high natural frequency are considered inherently rigid. (e.g; valves and other process equipment)

FINLAND:
Rigid components, which natural frequencies well above the cut-off frequency are considered seismically rugged, provided that dynamic interference with the supporting structure can be excluded.

It is also possible to classify inherently rugged those components, that are designed to withstand larger accelerations during normal operation (e.g. engine startup) than are expected due to earthquakes.

GERMANY:
For all SSCs in (seismic) Class I and IIa verification of their seismic capacity according to KTA 2201.1 “Design of Nuclear Power Plants against Seismic Events; Part 1: Principles”, KTA 2201.3 “Design of Nuclear Power Plants against Seismic Events; Part 3: Building Structures”, and KTA 2201.4 “Design of Nuclear Power Plants against Seismic Events; Part 4: Components” is required. There is no generic assumption of seismic ruggedness.

SLOVENIA:
N/A

KOREA:
N/A

UK:
As per SQUG GIP advice and engineering judgment for clearly rugged components that do not exhibit seismically vulnerable features

BELGIUM:
When the capacity of the component is obviously far beyond the seismic induced stresses – by Experience based method (SQUG-NARE) or sound engineering judgment

SWEDEN:
When using experienced based methodologies according to Question 11 this is taken into consideration in the applied method.

FRANCE:
In general, no mechanical component is considered to be inherently seismically rugged. Analysis or testing is required.

JAPAN:
Seismically rigid is one of the answer but even in the case, you should be careful for anchoring.

CZECH REPUBLIC:
No mechanical component is required to be inherently seismic rugged. Analysis is required.

USA:
No mechanical component should be considered inherently rugged. Components must be deemed acceptable for the service application proposed by an approved method as described in NRC guidance documents listed in answers to other questions in this document.

SPAIN:
In mechanical components seismic design there is not generic assumption of seismic ruggedness.
However, some mechanical and electrical equipment such as motors or transformers, can be considered inherently robust; but its seismic qualification must be supported by dynamic analysis, based on a mathematical model collecting their geometric characteristics and stiffness, detailing those mobile elements (pump rotors, shafts and yoke valves, etc.) whose deformation could produce malfunction when permitted tolerances overcome, and consequently producing shock or friction between fixed and moving parts. The model thus created is analyzed for both dynamic loads and other solicitations, combining the results.
Related with seismic verification, in SMA applied to seismic IPEEE according to EPRI NP-6041-SL or SQUG (GIP), adequately anchored components, are considered inherently rugged for seismic ground amplitudes lower than the “bounding spectra” anchored by PGA value of 0.3g.

Q. 17:
Beyond what frequency a component is defined as seismically rigid?

CANADA:
Frequency equal to or greater than 33 Hz, unless the ground motion or floor motion characteristics warrant otherwise.

FINLAND:
50 Hz. *IEEE 344 Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations* definition. Rigid equipment have fundamental frequency larger than the cut-off frequency of the required response spectra (RRS), on the YVL B.7 spectra 50Hz

GERMANY:
There is no fixed frequency value beyond which a component is considered to be seismically rigid (c.f. question/answer 3).

SLOVENIA:
When having a natural frequency above 33 Hz (e.g. a pump,), is considered essentially rigid. This frequency is sufficiently high to avoid problems with amplification between the component and structure for all seismic areas.

KOREA:
N/A

UK:
A 40Hz zpa is adopted although realistically above 20Hz could be considered rigid.

BELGIUM:
33 Hz

SWEDEN:
50 Hz.

FRANCE:
A component is defined as seismically rigid when the component lowest natural frequency is greater than the PGA frequency.

JAPAN:
This should be discussed with relation to the response spectrum shape but "higher than 20 Hz is used as a simple indicator of seismically rigid.

CZECH REPUBLIC:
33 Hz.

USA:
Equipment, whose lowest natural frequency is greater than the frequency at start of Zero Period Acceleration (ZPA), or the cut-off frequency, is considered seismically rigid. It is also defined in RG 1.92.

SPAIN:
Equal to or greater than 33 Hz in frequency.

Q. 18:
What methods and criteria do you use for seismic qualification of the following specific mechanical components?
a. Valves with actuators?
b. Emergency power generators (Diesel or turbines)?
c. Large pumps (e.g., main reactor coolant pump)?

CANADA:
a. Valves with actuators? - Combined analysis and testing.
b. Emergency power generators (Diesel or turbines)? - Analysis and testing
c. Large pumps (e.g., main reactor coolant pump)? - Analysis

FINLAND:
a. Modal response spectrum or linear elastic time history analysis based on 3D modeling. Some testing have been done.
b. EDG's (diesel) globally qualified by analysis using modal response spectrum or linear elastic time history analysis. Individual parts (e.g. electric controls) validated by shaking table test.
c. Modal response spectrum or linear elastic time history analysis based on 3D modeling.

GERMANY:
Basically, there is no difference in the seismic qualification/verification approach for valves, emergency power generators, or pumps. For all components in (seismic) Class I and IIa (c.f. question/answer 7) verification of their seismic capacity according to KTA 2201.4 "Design of Nuclear Power Plants against Seismic Events; Part 4: Components" is required (c.f. question/answer 8 to 11 and 14).

SLOVENIA:
Active pump motors (and vital pump appurtenances) are seismically qualified by meeting the requirements of IEEE Standard 344-1971. If the testing option is chosen, sine-beat testing is justified. This justification may be provided by satisfying one or more of the following requirements to demonstrate that multi-frequency response is negligible or the sine-beat input is of sufficient magnitude to conservatively account for this effect (the equipment response is basically due to one mode; the sine-beat response spectra envelopes the floor response spectra in the region of significant response; the floor response spectra consists of one dominant mode and has a peak at this frequency). The criteria used for the design and installation of safety and relief valves and connected piping for overpressure protection of Class 2 system components is in accordance with ASME Boiler and Pressure Vessel Code, Section III. Valve discharge flow reaction forces are calculated by using maximum flow rate and taking into account both the pressure and momentum effects. Bending and torsion effects of the flow reaction forces are analyzed in detail. Both the transient loading immediately after initiation of the valve opening and the steady state loading are considered in the design of pipes and supports. Since the effects of transient load on the piping due to safety valve operation are dynamic in nature, dynamic load factors (DLF) are used to account for dynamic loading.

KOREA:
a. Valves with actuators? test
b. Emergency power generators (Diesel or turbines)? Test and analysis
c. Large pumps (e.g., main reactor coolant pump)? test

UK:
a. Valves with actuators? SQUG GIP & shaker table
b. Emergency power generators (Diesel or turbines)? SQUG GIP & shaker table
c. Large pumps (e.g., main reactor coolant pump)? SQUG GIP & shaker table

BELGIUM:

a. Valves with actuators? ASME QME recommended method: analysis & testing

b. Emergency power generators (Diesel or turbines)? - Mainly by Combination of analysis & testing – SQUG also used during seismic revaluation

c. Large pumps (e.g., main reactor coolant pump)? - Analysis

SWEDEN:

a. Valves with actuators?
The general praxis for new valves with actuators is a dynamic load criterion according to:
- The natural frequency of the valve including actuator shall be greater than 50 Hz.
- The dynamic load shall be assumed to induce a load of 6 g in any direction.

b. Emergency power generators (Diesel or turbines)?
Applied standards may vary depending on manufacturer. One standard that has been used for new EDGs is IEEE 344-1987.

c. Large pumps (e.g., main reactor coolant pump)?
With respect to mechanical integrity the criteria are in accordance with the applied KFM.

FRANCE:

a. Design by analysis and tests.
b. No information found.
c. No information found.

JAPAN:

The answer for this questionnaire was already replied in Q7.

CZECH REPUBLIC:

For all mentioned components we us SQUG-GIP, but modification is agreed from IAEA.

USA:

Acceptance methods for equipment qualification are listed in Regulatory Guide (RG) 1.100. Generally ASME QME-1-2007 and/or IEEE-344-2004 but these must be applied as accepted in RG 1.100.

SPAIN:

a. Combined analysis and testing, or testing alone.
b. Usually, combined analysis and testing.
c. Analysis.

Q. 19:
Do you utilize experience-based data and methodologies from actual earthquakes? How and when? For:
a. New designs
b. Replacement components
c. Design modification of existing plants
d. Re-evaluation of margins and capacity in existing plants
e. Other, please specify.

CANADA:
a. New designs - No
b. Replacement components - Yes when justified.
c. Design modification of existing plants - Yes when justified.
d. Re-evaluation of margins and capacity in existing plants - Yes.
e. Other, please specify.

FINLAND:
In the Finnish or Fennoscandian context there is very little data to be utilized. However, OL3 is equipped with a local seismic network, collecting data from local micro-earthquakes.

GERMANY:
Experience-based data are used as part of the verification by plausibility considerations (c.f. question/answer 11e).

SLOVENIA:
No, however the free-field ground response spectra for SSE and OBE have been generated by experts, on the basis of site geology and seismology surveys. The seismic input data is distributed to NE Krško and all design participants who may require it for dynamic analysis or testing of Category I structures, systems or equipment. Results of dynamic analysis are checked and reviewed by experienced specialists. Results are also verified by comparison with hand calculations and with outputs previously obtained for other projects to the extent that valid comparisons can be made. Seismic responses and appropriate response spectra are transmitted to equipment suppliers by incorporation into the equipment specifications.

KOREA:
For: d

UK:
a. New designs - YES
b. Replacement components - YES via the SQUG NARE and SQURTS approach
c. Design modification of existing plants - YES
d. Re-evaluation of margins and capacity in existing plants - YES
e. Other, please specify.

BELGIUM:
a. New designs - (No)
b. Replacement components - (Yes in certain conditions)
c. Design modification of existing plants
d. Re-evaluation of margins and capacity in existing plants **-** (yes)
e. Other, please specify.

SWEDEN:

a. New designs

Experience based methodologies are in general not used for new design.

b. Replacement components

Experience based methodologies may be used for when replacing components.

c. Design modification of existing plants

Experience based methodologies may be used for design modification. However, analysis is usually also needed in order to fulfill the requirement in regulations SSMFS 2008:13.

d. Re-evaluation of margins and capacity in existing plants

Experience based methodologies may be used when assessing capacity of existing plants.

e. Other, please specify.

FRANCE:

a. No
b. No
c. No
d. Yes, through SQUG methodology.
e.

JAPAN:

Actual experience data of earthquake is not used for seismic design in Japan although they are frequently used for design verification.

CZECH REPUBLIC:

a) New design: if will be actual in future. I suppose application of PSHA and the identical solution as in the case of NPP Temelín (see item 1)
b) see item 1
c) see item 1
d) we use SMA methodology and RLE

USA:

Regulatory Guide 1.100 (RG 1.100), Seismic Qualification of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plans, provides the staff guidance for the use of earthquake experience data.

Section B, Discussion, of RG 1.100 says that for the Unresolved Safety Issue A-46, the Seismic Qualification Users Group (SQUG) concluded, and the NRC agreed, that the use of experience data was feasible for the purpose of verifying the seismic adequacy of equipment in the older, USI A-46 plants. This Section of RG 1.100 goes on to say that the staff does not accept the use of SQUG guidelines for the seismic qualification of equipment in non-USI A-46 plants licensed under 10 CFR Part 50 or in plants licensed under 10 CFR Part 52.

Section C, Regulatory Positions, of RG 1.100 provides the staff positions related to the use of earthquake experience for seismic qualification of electrical equipment and active mechanical equipment. Generally, the staff position is that the use of experience data (earthquake or test experience data) for seismic qualification is subject to review by the NRC staff. Topical reports may be submitted to the NRC for approval. The guidance in Section C also lists areas of review as well as changes and exception to provisions in IEEE 344 and ASME-QME-1.

SPAIN:

a. New designs: Not utilized.
b. Replacement components: Yes, in certain conditions (SQUG NARE)
c. Design modification of existing plants: Yes, in certain conditions.
d. Re-evaluation of margins and capacity in existing plants: Yes, SQUG and IPEEE SMA.

Category: Beyond Design Basis

Q. 20:
Do you require establishing seismic fragility level? If so, how and for what components? (testing or analysis)

CANADA:
Yes. It is required by regulations for all new build plants. It was not done for existing plants. Required for all components used for reactor shutdown, cooling and control. Both testing and analysis are acceptable methods to establish component fragility level.

FINLAND:
Yes. Finnish nuclear safety regulations (YVL guides) require this for all new build plants under seismic classes S1 and S2A (see answer to Q7). Seismic fragility analyses are managed with seismic PRA covering all nuclear power plants. Fragility curves are analysis-based. Dynamic 3D analysis is required for design and seismic PRA. Testing is done to the design value (DBE or/and APC or enveloped APC + DBE).

GERMANY:
In the German nuclear regulations and safety standards there are no requirements for beyond design basis earthquakes (i.e. earthquakes exceeding the loads of the design basis earthquake).

SLOVENIA:
There are no special national codes and standards which cover establishing fragility level. In a probabilistic response analysis, the characteristics of free-field ground motion are defined by the shape of the median uniform hazard spectrum (UHS) corresponding to a return period of interest (UHS for Krško site has a 10 000-year return period). The median UHS for the probabilistic analyses was anchored to a peak ground acceleration (PGA) of 0.6 g. The lists of Seismic fragilities of none relay and relay components were determined in Fragility analysis performed by ABS (2004). Usually, it is chosen a peak ground acceleration (PGA) in order to characterize ground motion level. Of course, any other indicator related to accelerograms could be chosen. However, peak ground acceleration (or spectral acceleration) remains the preferred parameter in seismic PSA. The fragility of a structure (or component) is determined with respect to "capacity". Capacity is defined as the limit seismic load before failure occurs. Therefore, if PGA has been chosen to characterize seismic ground motion level, then capacity is also expressed in terms of PGA.

KOREA:
(testing or analysis) no in design.

UK:
Yes we consider fragility curves to support SMA and demonstrate absence of cliff-edge effects for disproportionate increases in risk for a small increase in the hazard loads. Developed for plant and structures

BELGIUM:
Not specifically required so far…

SWEDEN:
No.

FRANCE:
Seismic Margin Assessment is sometimes used to demonstrate seismic capacity beyond design basis.

JAPAN:
Fragility data were acquired by JNES Fragility test series as shown in Figure 2.

CZECH REPUBLIC:
In Czech Republic there is no requirement for beyond design basis earthquake.

USA:
Please see the answers to question 21 and question 23.

SPAIN:
Seismic IPEEE (Individual Plant Examinations for External Events) plant analyses were required around year 2000 for all operating reactors, and following the scope associated with their plant categorization. The IPEEE analyses were oriented towards the identification of plant vulnerabilities to external events beyond the design bases. In accordance with applied seismic margin methods (EPRI and USNRC), the aim was to determine a plant seismic capacity known as the "high confidence of low probability of failure" (HCLPF) capacity. The HCLPF is essentially equivalent to 95% confidence of less than 5% probability of failure.

Q. 21:
Do you have requirements/expectations for seismically designed components to be able to withstand beyond design basis earthquake?

CANADA:
Yes. Seismic PRA and SMA analyses are required to evaluate margins beyond design basis.

FINLAND:
Yes. Finnish nuclear safety regulatory guide YVL B.7 require seismic PRA studies considering also Design Extension Condition C (DEC C) level rare external events. The required DEC C earthquake frequency of occurrence $<10^{-7}$/year on the median confidence level.

Regarding deterministic analysis, criteria are so far set for seismic design of pressure boundary components. To ensure integrity and operability, service level D and C criteria shall be demonstrated, respectively. Best estimate analysis methodology may be applied in each case.

GERMANY:
In the German nuclear regulations and safety standards there are no requirements for beyond design basis earthquakes (i.e. earthquakes exceeding the loads of the design basis earthquake).

SLOVENIA:
There are no special national codes and standards which require for seismically designed components to be able to withstand beyond design basis earthquake. In response to the Fukushima accident, the SNSA issued a decision to the Krško NPP to perform a Special Safety Review. The programme of this review is completely in line with the ENSREG specifications for European Stress Tests. The Krško has fulfilled its commitment in time and sent the full scope Stress Test report to the SNSA.
In addition to obligate the plant to perform the stress tests, the SNSA also issued a decision requiring from the plant to reassess the severe Accident Management strategy, existing design measures and procedures and implement necessary safety improvement for prevention of severe accidents and mitigation of its consequences.

KOREA:
No.

UK:
Performance based requirements are established ie non-leak requirement, no collapse, no tension, max displacement, etc

BELGIUM:
Under consideration – New PSHA under way for both sites.

SWEDEN:
No requirements. However, the Swedish Nuclear Power utilities have performed assessments of the mitigation systems assuming spectral values corresponding to a recurrence frequency of 10^{-7} per year at site (PGA=0.42 g in horizontal direction) The assessments were performed in the stress test of each reactor.

FRANCE:
SMA follows EPRI-SMA method and requirements.

JAPAN:

We have requirement for the residual risk evaluation by the reviewing guide of seismic design. Seismic design practice include considerable margin in each design step, so we can expect big margin in total.
(I think this was proved in 2007 Niigata-ken Chuetsu-oki EQ and 2011 Tohoku-chiho Off pacific EQ.)

CZECH REPUBLIC:

See item 20.

USA:

The NRC has expectations for seismically designed components to be able to withstand beyond design basis earthquakes. The answer to question 23 provides additional information pertaining to the NRC expectations for new reactors and for operating reactors as well as on the methods used for the assessment of these margins. The next two paragraphs provide information on related NRC regulations applicable to new reactors.

Title 10, Part 52 of the Code of Federal Regulations (10 CFR 52), provides regulatory requirements for DC and COL applications for new light water reactors. Information requirements for design-specific probabilistic risk assessment (PRA) for a DC application are in 10 CFR 52.47(a)27 while information requirements for a plant-specific PRA for a COL application, which incorporate requirements for site-specific design information, are in 10 CFR 52.79(a)46. DC/COL-ISG-20, referred to in question 23, provides an approach acceptable to the staff to meet these requirements.

For new reactors, information requirements in 10CFR50, 50.71(h)(1) are that no later than the scheduled date for initial loading of fuel, each holder of a combined license under subpart C of 10 CFR part 52 shall develop a level 1 and a level 2 probabilistic risk assessment (PRA). The PRA must cover those initiating events and modes for which NRC-endorsed consensus standards on PRA exist one year prior to the scheduled date for initial loading of fuel. Paragraph 50.71(h) also has information requirements related to the maintenance and upgrade of this PRA as well as information requirements for the PRA upgrade by a COL holder in relation to the submittal of an application for a renewed license.

SPAIN:

As mentioned in Q.20, seismic IPEEE analyses are already available for all operating plants. In accordance with followed seismic margin methods (EPRI and USNRC), were obtained HCLPF capacity of the Spanish plants by comparing plant seismic designs against a 0.3 g Review Level Earthquake (RLE). At that moment compliance with this earthquake level was not being required.
Following Fukushima accident and within the European ‘stress test’, the scope of previous IPEEE seismic margin analysis, has been extended to include the SSCs required to guarantee the integrity and cooling of the spent fuel pool. Also, among the measures aimed at guaranteeing greater plant robustness in response to seismic events, the licensees have revised, or proposed the revision of equipment margins used to address station blackout (SBO) and severe accident situations. In all these cases, the licensees have verified the possibility of assigning a seismic margin equal to or greater than 0.3g to these SSCs or, otherwise, have proposed the additional measures required for compliance.

Q. 22:
What kind of margins do you require/expect in the design of SSCs important to safety to withstand beyond design basis earthquake?

CANADA:
A factor of 1.67 is recommended over the design 'HCLPF' value calculated using probabilistic methods.

FINLAND:
The margin is determined site specifically with seismic PRA. There facility's HCLPF must be higher than DEC-C's SSE PGA. Since the medium confidence level DBE frequency is 10^{-5}/year and DEC-C 10^{-7}/year, it means that safety level is 2 – 3 times DBE SSE. (See also answers to Q4 and Q21).

GERMANY:
In the German nuclear regulations and safety standards there are no requirements for beyond design basis earthquakes (i.e. earthquakes exceeding the loads of the design basis earthquake).

SLOVENIA:
See the answer bellow in Q# 23.

KOREA:
Expect margin of code specified allowable stress.

UK:
A robust set of mutli-leg arguments are presented in the safety case to cover conservatisms in the seismic hazard derivation, structural response, analysis, code conservatisms, ductility etc In UK a value of acceptable BDB is not recommended as this merely moves the cliff-edge question to the higher value. In Finland it is noted that the mean 10-5 pa URS is used as a useful surrogate to incorporate sufficient BDB behavior.

BELGIUM:
1.5xSSE

SWEDEN:
No more margins are required for the moment.

FRANCE:
SMA examines only a limited number of SSCs important to safety, using the concept of the success path, which represents a set of components that can be used to bring the plant to a stable condition and maintain this condition for 3 days.

JAPAN:
After 3.11 accident, seismic stress test was requested by government to all utilities.
This evaluation was implemented using newly developed DBGM Ss after 2007 Niigata-ken Chuetsu-oki earthquake (See table below).
According to the utilities evaluation, all Japanese plants looks to have a margin of two times except Kashiwazaki-Kariwa plants.
The Margin of Kashiwazaki-Kariwa looks to have a margin of 1.3 to 1.5 because the DBGM of the Kashiwazaki-Kariwa was already very high even then.

Table 4. DBGM at the time of back check phase (Before 3.11)

(at the Back Check Phase after NCO Earthquake)

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*2**	532
Mihama	C, Fo-A Fault (M6.9)→B-Fault(M7.7)	**600→750*2**	405
Ooi	C, Fo-A Fault (M6.9)→Fo-A+Fo-B(M7.4)	**600→700*2**	405
Takahama	Fo-A Fault (M6.9)	**550**	370
Shimane	Shinji Fault (M7.1)	**600**	456
Ikata	Median Tectonic Line Faults (M7.6)	**570**	473
Genkai	Takekoba F.(M6.9) →Enhancement of uncertainty consideration	**500 →540*3**	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

Note: *1 Black bold numbers are Ss by interim report (March 2008).
*2 **Red bold** numbers are corrected values by the amendment of interim report (31 March 2009) and **still under examination** in governmental committee (29 June 2009)
*3 Kyushu Electric Report for Joint Committee dated 10 Feb.,2009

CZECH REPUBLIC:

No margins are required.

USA:

See the answer to question 23.

SPAIN:

As mentioned in Q.21, is required a HCLPF ≥ 0.3g.

The SMA includes all SSCs important to safety by using the success path concept (two path): the SSCs required to guarantee the integrity and cooling of the spent fuel pool, and associated equipment to mitigate SBO and severe accident management.

Q. 23:
How do you quantify the margins beyond design basis earthquake?

CANADA:
SMA and SPRA are used to quantify the margins beyond the design.

FINLAND:
Seismic PRA is quantifying margins as described in answer to Q22.

GERMANY:
If the macroseismic intensity of the site specific design basis earthquake (exceedance frequency 10^{-5}/a) exceeds I_{EMS} = VII, a seismic PSA has to be performed as part of the (periodic) safety reviews (every 10 years). In the framework of the seismic PSA HCLPF values are determined for safety related SSCs.

SLOVENIA:
Slovenian Nuclear Safety Administration (SNSA) required consequential actions/safety improvements by the operator to reduce risk of severe accidents and their consequences as low as feasible. NEK issued a program with extended design-based values. A Peak Ground Acceleration (PGA), which represents the seismic design bases for all new improvements, is 0.6 g and is equal to two-time the design Safe Shutdown Earthquake (SSE). This value is higher than 10000 year return period according to the PSHA study from 2004. It was recalculated of floor response spectra (FRS) for all Main Complex Buildings and Essential Service Water Building at NPP Krško site, which are to be used for the design of Design Extension Conditions (DEC) of Systems, Structures, and Components (SSC). The new floor response spectra for DEC is calculated based on the state-of-the-art standards and methodology and for seismic intensities of 0.6 g (2×SSE), as well as for higher intensities, i.e. PGA= 0.7 g and PGA=0.8 g. Different equipment damping values should be considered.

KOREA:
Fragility analysis.

UK:
Multi-leg arguments on conservatisms – some qualitative and some quantified.

BELGIUM:
Using EPRI-SMA based approaches.

SWEDEN:
No margin quantification is required in the current regulations.

FRANCE:
EPRI-SMA method uses conservative and realistic procedures based on actual earthquake experience a generic test data.

JAPAN:
In the Seismic Design Reviewing Guide, the evaluation of residual risk for beyond DBGM is requested.

CZECH REPUBLIC:
The EPRI SMA represent margin.

USA:

Seismic Probabilistic Risk Assessment is the preferred approach for quantifying margins beyond design basis earthquakes. Seismic Margin Assessment (SMA) is also an acceptable approach in certain cases. Examples of these cases are design certification applications, and combined license (COL) applications. Interim Staff Guidance DC/COL-ISG-20, *Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors*, provides staff guidance for an SMA assessment. This guidance includes approaches acceptable to the staff for seismic fragility assessment for the related uses.

Seismic re-evaluations in response to the Near Term Task Force (NTTF) item 2.1 (seismic) follow the guidance in the industry-issued guidance for screening, prioritization, and implementation details (SPID), EPRI Report 1025287 dated November 2012, as endorsed in the February 15, 2013 NRC letter to NEI, Endorsement of Electric Power Research Institute Final Draft Report 1025287, “Seismic Evaluation Guidance” (ADAMS accession number ML12319A074). This guidance addresses acceptable methods, which include seismic probabilistic risk assessment and seismic margin assessment, and the conditions for their applicability. NRC guidance for SMA for seismic re-evaluations, when applicable, is in JLD-ISG-2012-04, *Guidance on Performing a Seismic Margin Assessment in Response to the March 2012 Request for Information Letter* (ADAMS accession number ML12286A029). The guidance listed in this paragraph includes approaches acceptable to the staff for seismic fragility assessment for the related uses.

SPAIN:

The HCLPF Spanish plant values were determined by following EPRI or NRC-SMA methods. Conservative Deterministic-Failure-Margin (CDFM) has been used in determining the HCLPF.

Q. 24:
What methodologies do you use for ensuring capacity of mechanical components beyond design basis earthquake?

a. Seismic Margin Assessment
b. Seismic PRA
c. PSA-based SMA
d. Testing
e. Deterministic methods
f. Other please specify

CANADA:

a. Seismic Margin Assessment - Yes.
b. Seismic PRA - Yes.
c. PSA-based SMA - Yes
d. Testing - Yes
e. Deterministic methods - No
f. Other please specify - None

FINLAND:

a. Seismic Margin Assessment - No
b. Seismic PRA - Yes
c. PSA-based SMA - Yes. DEC-C SSE study in Seismic PRA
d. Testing - Yes, when required in b/c.
e. Deterministic methods – Yes, see answer to Q21.
f. Other please specify - None

GERMANY:

In the German nuclear regulations and safety standards there are no requirements for beyond design basis earthquakes (i.e. earthquakes exceeding the loads of the design basis earthquake).

SLOVENIA:

Seismic Margin Assessment is/was used for ensuring capacity of mechanical components beyond design basis earthquake.

KOREA:

b. or c.

UK:

a. Seismic Margin Assessment - YES
b. Seismic PRA - YES
c. PSA-based SMA - YES
d. Testing - YES
e. Deterministic methods - YES
f. Other please specify - Earthquake experience data from higher level events

BELGIUM:

a. **Seismic Margin Assessment**
b. Seismic PRA
c. PSA-based SMA
d. Testing
e. **Deterministic methods**
f. Other please specify

SWEDEN:

No regulatory requirement to perform such an assessment. However, the methodology applied for beyond design basis earthquake in the stress test was mainly deterministic methods.

FRANCE:

a. SMA.
b. No information found.
c. No information found.
d. Testing is generally defined to cover an earthquake level beyond DBE.
e. Following Fukushima accident, complementary deterministic methods are currently used for some of the SSCs that have to withstand ~1.5 SSE.

JAPAN:

As explained in earlier questionnaire, fragility data for each component may be acquired through past test data in Japan.
Regarding the residual risk evaluation required by the new reviewing guide, you can do seismic risk analysis using fragility data

CZECH REPUBLIC:

a) Seismic Margin Assessment – yes
b) Seismic PRA - yes
c) No
d) No
e) No
f)

USA:

See the answer to Question 23.

SPAIN:

a. Seismic Margin Assessment: Yes.
b. Seismic PRA: No.
c. PSA-based SMA: No.
d. Testing: Yes.
e. Deterministic methods: Yes.
f. Other: Earthquake experience data.