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

NEA/CSNI/R(98)5
Unclassified

STATUS REPORT ON SEISMIC RE-EVALUATION

71673

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter; Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consist of all OECD Member countries, except New Zealand and Poland. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of the NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

- *encouraging harmonisation of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
- *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
- *developing exchanges of scientific and technical information particularly through participation in common services;*
- *setting up international research and development programmes and joint undertakings.*

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded 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 scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency 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 amongst the OECD Member countries.

CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organisation of conferences and specialist meeting.

The greater part of CSNI's current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its programme, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

Foreword

PWG-3 deals with the integrity of structures and components, and has three sub-groups, dealing with the integrity of metal structures and components, ageing of concrete structures, and the seismic behaviour of structures.

A status report on the seismic behaviour of structures was prepared during 1996 by a task group to initiate activities in this field under PWG3. The topic of re-evaluation of existing facilities was identified as one of the five topics to be addressed. CSNI and PWG3 reinforced this as being the highest priority issue. Accordingly, this report was prepared, with UK NII taking the lead. The other topics identified were piping analysis and design, engineering characterisation of seismic input, ageing effects, and validation of analysis methods. This further list will be addressed with a workshop on the Finite Element analysis of degraded concrete structures, in October 1998 in the USA, and a workshop on seismic input in the USA in autumn 1999. There will also be a workshop on seismic risk jointly with PWG5, the risk assessment group, in Japan in August 1999. The topic of piping design has become less important, and there is debate about whether ageing effects are significant for seismic behaviour of structures or not. The group will consider possible future benchmarks for code validation as a follow-up to the workshop on FE analysis.

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EXECUTIVE SUMMARY

In May 1997, a meeting of the PWG 3 Sub Group on the Seismic Behaviour of Structures agreed several priority objectives, of which one was the production of a status report on seismic re-evaluation. Seismic re-evaluation is identified as the process of carrying out a re-assessment of the safety of existing nuclear power plants for a specified seismic hazard. This may be necessary when no seismic hazard was considered in the original design of the plant, the relevant codes and regulations have been revised, the seismic hazard for the site has been re-assessed or there is a need to assess the capacity of the plant for severe accident conditions and behaviour beyond the design basis. Re-evaluation may also be necessary to resolve an issue, or to assess the impact of new findings or knowledge.

A questionnaire on the subject was issued to all members of the Seismic Sub Group in the summer of 1997, and responses to the questionnaire had been received from most members by the end of 1997. This report is based on the responses to the questionnaire, together with comment and discussion within the group. The questionnaire covered the following main topics of interest in relation to seismic re -evaluation:

- General and Legislative Framework
- Overall Approach
- Input Definition and Analysis Methods
- Scope of Plant and Assessment of As-built Situation
- Assessment criteria
- Outcome of Re-evaluations
- Research

The responses to the questionnaire have been collated and reviewed with the objective of comparing current practice in the field of seismic re-evaluation in member countries, and a number of important points have been identified in relation to the position of seismic re-evaluation in the nuclear power industry throughout the world.

It is evident that seismic re-evaluation is a relatively mature process that has been developing for some time, with most countries adopting similar practices, often based on principles which have been developed in the US nuclear industry. Seismic re-evaluation of individual plants is typically carried out at intervals of approximately ten years. Major re-evaluations typically take 2 to 3 years to perform at a cost of approximately $US 1 million for software alone, although the majority of re-evaluations are carried out in less time and at lower cost.

Methods of seismic re-evaluation include PSA, margins assessments and deterministic analysis, and a common feature of the process is a seismic walkdown, often based on SQUG principles. The input motion levels, seismic categorisation, analysis methods and assessment criteria that are applied depend on the objectives of the re-evaluation. In several responses they are indicated to be generally similar to those specified for new plant. In situ inspection of structures and plant is generally adopted, although most countries use original specifications for material properties, with some in situ evaluation where possible. More realistic criteria than would usually be adopted for new plant are often employed in the assessment of plant behaviour for severe accidents or risk estimates.

The majority of countries are satisfied with the seismic re-evaluations that have been carried out to date, although there are a number of recommendations for improvements based on the experience gained so far. The process has resulted in some quite extensive physical modifications, improving the seismic robustness of structures, anchorages and restraints, particularly in older plants.

Approximately half of the responding countries reported that they were engaged in active research in the specific field of seismic re-evaluation, but it is noted that there is also considerable effort taking place in the wider field of seismic research, and that this has a direct bearing on the re-evaluation process, leading to an improved understanding of failure modes and more realistic assessments of section capacity. There is also a need to identify future areas of research.

It is recommended that some areas of the seismic re-evaluation process are considered in the future for the mutual benefit of the member countries. These include a better understanding of the benefits and disadvantages of the various methods employed in the re-evaluation process, the definition of the scope of plant to be selected for the re-evaluation process, definition of the criteria for re-evaluation, and the role and scope of the peer review process. Also included are the strengthening of plant, the incorporation of operational and research data/experience into the re-evaluation process and the identification of areas of new research that could provide benefits and improvements for the re-evaluation process.

1. INTRODUCTION

At the meeting of the PWG 3 Sub Group on Seismic Behaviour of Structures (hereinafter referred to as the Seismic Sub Group) in May 1997 several priority objectives were agreed. The first of these was to provide a status report on seismic re-evaluation. This was considered to be first priority because all member countries were involved in re-evaluating plant to a greater or lesser extent and proper and efficient performance of such assessments has very important safety and economic considerations. The potential benefit of such a report was seen as very important by IAEA, since they were in the process of developing guidance for seismic re-evaluation.

In order to progress this objective a small sub-group comprising the French, UK and US representatives was formed. They agreed on a questionnaire which was issued to all members of the Seismic Sub Group in the summer of 1997. The representative of the IAEA on the Seismic Sub Group offered to circulate the questionnaire to non-OECD countries and one response was received by this route, from Bulgaria.

By the end of 1997 responses had been received from virtually all members and those responses have been used to provide the basis for this report. The first complete draft was produced in January 1997 and reviewed by the French, UK and US representatives before circulation to all the members of the Seismic Sub Group, and subsequently to members of PWG3, for review. It was prepared by Mr Ian Hopkin of NDA Consulting Engineers under contract to the UK representative.

Seismic re-evaluation is the description applied to the process of carrying out a review or re-assessment of the safety of existing nuclear power plants when exposed to a specified seismic hazard. The process applies in particular to older nuclear power plants, which may not have been designed to resist a seismic hazard, or may have been designed to a lower standard. Although the process may be part of a systematic review procedure, there are four principal recognised conditions which can prompt the requirement for seismic re-evaluation to take place, as follows:

- No seismic hazard considered in the original design of the plant
- The relevant codes and regulations have been revised
- The seismic hazard for the site has been re-assessed as more onerous than that considered in the original design
- The need to assess the capacity of the plant for severe accident conditions and behaviour beyond the design basis

The questionnaire used in the survey is reproduced in Appendix A, and was developed under a series of ten main headings, as follows:

General:	Investigates the history of re-evaluation in each country; includes type and age of plant evaluated, and overall timescales and costs.
Legislative framework:	Examines the regulatory background.
Overall approach:	Provides general information on methods, including the use of walk-downs

Input definition:	Provides general information on the basis for specified input motions and typical values
Scope of plant:	Provides general information on the selection of plant for re-evaluation
Analysis methods:	Provides information in some detail on working practice in dynamic analysis procedures, including the treatment of uncertainties, and the inclusion of pipework and brick/block walls in the assessment
Assessment criteria:	Contains detailed questions relating to the basis of the criteria used in the assessment, including differences between new and existing plant and the effects of ageing and condition in service
Assessment of as-built situation:	Provides information on the extent to which the as-built condition is incorporated into the assessment
Outcome of re-evaluations:	Contains a brief review of the success of the programme and lessons learned to date
Research:	Contains a brief review of existing or planned research programmes associated with re-evaluation

A summary of the responses to each section of the questionnaire is contained in Section 2. The responses are discussed in Section 3 of the report, and conclusions and recommendations resulting from the discussion are contained in Section 4. Appendix A contains a copy of the questionnaire which was issued to the participants. Appendix B presents details of the participating countries, organisations and individual representatives, and a copy of each of the completed and returned questionnaires is presented in Appendix C. Appendix D contains some brief details relating to the nuclear power industry in each of the participating countries, together with a database of details of the nuclear power plants in each of the participating countries.

2. SUMMARY OF RESPONSES TO QUESTIONNAIRES

The objective of this section of the report is to compile a summary of the individual responses to each question in the questionnaire, so that the current practice in each of the participating countries can easily be assimilated and compared. Each of the sub-sections in this section therefore contains factual reporting of the responses under headings that correspond to the main sections in the questionnaire, e.g. the section headed 2.1 GENERAL below refers to the section in the questionnaire headed SECTION 1 - GENERAL. In addition, the numbers in parentheses (q x or qq x,y) are references to the corresponding questions in the questionnaire.

Discussion and comment relating to the responses is provided in Section 3. In some cases it has been necessary to apply some interpretation to individual responses in order to ensure, as far as possible, that all the responses are compatible and address common issues. In addition, further revision has been carried out as a result of comments and clarifications provided by members of the group. Although the overall context of the survey is intended to cover a wider range of installations, including nuclear chemical plants, the consensus of the group is that the responses that have been provided tend to relate to power reactors.

2.1 GENERAL

This objective of the first section of the questionnaire is to establish the general situation with respect to seismic re-evaluation in each of the participating countries, with particular reference to the following aspects:

- The current status of any seismic re-evaluation program
- The type and age of nuclear power plants involved
- Hazard level for new plant
- Typical timescales and costs involved in the seismic re-evaluation process

The responses to the questionnaire (qq 1.1, 1.2, 1.4) reveal that seismic re-evaluation programs are ongoing in all of the participating countries that are currently operating nuclear power plants, and that the types of plant involved in these programs are predominantly PWRs. Other types of plant featured in the programs are FBRs in France, BWRs in Germany, Japan, Spain, Sweden, Switzerland and the US, PHWRs (CANDU) in Canada and Korea, and GCRs (MAGNOX and AGR) in Japan and the UK.

The re-evaluation programs have progressed to different stages in each country (q 1.3), although, in all cases, the program is under way and assessment work is in hand. In the following countries, the assessment work is reported to be complete for at least some plants, with the regulatory review under way.

Belgium, Canada, Czech Republic, France, Germany, Korea, Spain, Switzerland, UK, US

The regulatory review is also reported to be complete, at least for a number of plants, in Belgium, France, Germany, Korea, Switzerland, the UK and the US.

The age of plant at which re-evaluation takes place (q 1.7) varies for each of the countries responding to the questionnaire. A summary of the reported age of relevant plants is provided in Table 2.1, and in Figure

2.1 which compares the period during which the relevant plant were commissioned with the overall period during which currently operable plants were commissioned.

The age at which plant re-evaluation is carried out (q 1.5) showed considerable variation, although the typical range is 10 to 20 years. Some countries also reported that plant currently under construction or newly built was also undergoing re-evaluation. A summary of the responses is given in Table 2.1, which considers both the age at which operable plant is undergoing re-evaluation, and whether plant under construction is being considered.

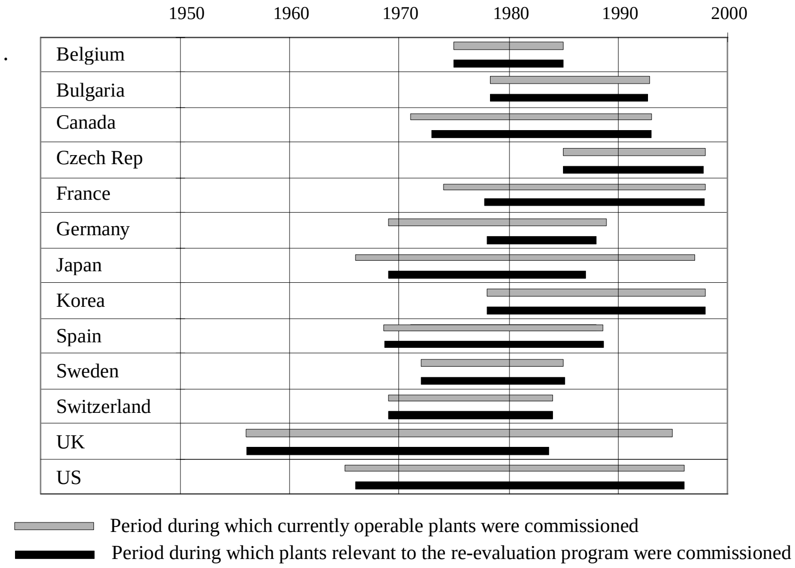

Figure 2.1
Comparison of Relative Age of Operable Plants and
Plants Relevant to the Program

	Q1.7, Age Range of Relevant Plant (Years)	Q1.5, Age at Re-evaluation	
		Age (Years)	Under Construction/Newly Built
Belgium	13 - 24	13 - 24	
Bulgaria	5 - 20	5 - 20	
Canada	5 - 25	20 - 25*	
Czech Rep.	10 - 12	12	✓
France	0 - 20	10 - 20	
Germany	10 - 20	10 - 15	
Japan	11 - 29	Not defined	
Korea	0 - 20	10	✓
Spain	13 - 17	10-29 years	
Sweden	12 - 25	10	
Switzerland	13 – 28	≥ 12 years	
UK	3 - 42	20 years	
US	2 - 32	Varies	

* General age at re-evaluation, although the study of a 2 year old standard design is being carried out to understand its behaviour beyond the design basis

Table 2.1
Age at Which Plant is Re-evaluated

The interval at which re-evaluation is carried out (q 1.6) was widely reported as being approximately every ten years (Belgium, France, Germany, Spain Sweden, Switzerland and the UK), although many countries replied that the interval was not specified (Canada, Korea and the US) or that there was no routine re-evaluation (Japan and the US). Two countries, the Czech Republic and the UK replied that re-evaluation was required for the Periodic Safety Review, and Bulgaria did not provide a response.

Participants were also requested for information on the hazard level for new plant (q 1.8). Two countries (Belgium and Sweden) replied that no new plants were being planned. The Belgian response refers to the *European Utilities Requirements for LWR Nuclear Power Plants*. This is a detailed specification of the common requirements for the design and construction of future light water reactor power plants, which has been drafted by a group of European utilities from the UK (NEL), France (EDF), Spain (UNESA), Belgium (Tractebel) and Germany (Preag). France replied that there is no quantification of the overall hazard. The responses of the remaining countries are summarised in Table 2.2, where the peak ground accelerations are representative of typical free field zpa values at the ground surface.

		Probability/Return Period	Peak Ground Acceleration*	Intensity
Bulgaria		10^{-4}		
Canada		10^{-3} to 10^{-4}		
Czech Rep.			0.1g	
Germany		10^{-4} to 10^{-5}	0.1 - 0.2g	VII - VIII
Japan	S1		0.2 - 0.45g	
	S2		0.38 - 0.6g	
Korea		10^{-3} to 10^{-4}		
Sweden**		10^{-5}		
Switzerland		10^{4} years		
UK		10^{-4}		
US (for certified standard design)	Design		0.3g	
	Margin		0.5g	

* Free field zpa at the ground surface ** Probability for SSE for existing plants - no new plants planned in Sweden.

Table 2.2
Comparison of Ground Motion Input Levels for New Plant

The US response noted that the design level earthquake for certification, 0.3g, is linked to a design response spectra similar to, or a modified, Regulatory Guide 1.60 requirements, and that the review level earthquake (RLE) is expected to be about 0.5g. The design basis or site specific SSE for new plants is established in accordance with the recently published requirements of 10 CFR Section 100.23 (NRC, 1997a). Detailed procedures to implement these requirements are given in Regulatory Guide 1.165 (NRC, 1997b).

The Japanese response refers to two hazard levels, S1 and S2. This is due to the fact that the seismic hazard for each site in Japan is defined in terms of two intensities of design earthquake, termed S1 and S2 (NRC, 1994). S1 is lower in intensity than S2, and is described as the maximum design earthquake. S2 represents the extreme design earthquake. The S1 earthquake is determined on the basis of historical events and fault activity, including capable faults that have been active within the last 10,000 years, and faults that are currently active. The S2 earthquake is determined on the basis of seismo-tectonic structures, active faults and a shallow-focus earthquake with a minimum Magnitude of 6.5. The S1 earthquake is generally considered to be equivalent to the Safe Shutdown Earthquake (SSE), based on current and historical US practice.

The two final questions in Section 1 of the questionnaire relate to the overall timescale and cost to complete the re-evaluation procedure (qq 1.9, 1.10). This will vary according to the complexity of the task, including factors such as the age of the plant and the seismicity level of the area in which the plant is located, and this is reflected in a number of the responses. The Korean response stated that the timescale varied on a case by case basis, while Sweden declined to give a figure as no procedures had yet been completed and the Japanese response also did not give an answer. The French response noted that the timescale is strongly dependent on the type of installation. Of the other responses received, the approximate timescales given are summarised in Table 2.3, either based on estimates or recent experience. The US response makes the point that, for very simple cases, the process may only take a few months.

Belgium	5 years
Bulgaria	5 years
Canada	3 years
Czech Rep.	3 years
Germany	1 - 2 years
Spain	2 - 3 years
Switzerland	3 - 5 years
UK	3 - 4 years
US	5 years (maximum)

Table 2.3
Comparison of Estimated Timescales for Re-evaluation

A number of responses declined to give an estimate of costs for the re-evaluation procedure, including those from France, Spain (not known), and Korea (varies on a case by case basis). The Swiss response includes a relatively complex breakdown of costs distinguishing between old and new plants, together with assessment criteria. The costs given in the remaining responses are reproduced in Table 2.4 in US$, including an estimated cost provided by Sweden. The figures presented in Table 2.4 generally cover the costs for the seismic re-evaluation analysis, including seismic hazard assessment, without modification to structures or equipment.

	US$m	Local Currency
Belgium	5.3*	
Canada	2.1**	C$3m**
Czech Rep.	0.15	Kc.5m
Germany	0.6	DM1m
Japan	1.0	
Sweden	1.6	Kr10 - 12m
UK	1.6 - 3.2	£1 - 2m
US	1.0***	

* Costs of re-evaluation for Tihange ** Recent cost for a 4 unit plant
*** Costs vary over a large range and are for studies only (no modifications)

Table 2.4
Comparison of Estimated Software Costs for Re-evaluation

Since the responses either include the costs in US$m, or, in some cases local currency or sterling, it has been necessary to convert those in other currencies to US$ for the purposes of comparison. In these cases, the original response containing the figure in local currency or sterling is also presented. The conversion has been carried out using exchange rates quoted on 25 November.

2.2 LEGISLATIVE FRAMEWORK

Of the responses received, those from the following nine countries reported that there are no regulations containing explicit guidance detailing how seismic re-evaluation is to be carried out (qq 2.1, 2.2):

Belgium, Canada, Czech Republic, France, Germany, Japan, Sweden, Switzerland, UK

Of these countries, three (Belgium, France and the Czech Republic) reported that the re-evaluation process is carried out on a site/plant specific basis. Both Korea and Spain reported that US NRC documents are used for the purpose of providing guidance in the seismic re-evaluation process, as shown in Table 2.6.

Korea	Seismic PSA	NUREG - 1407
Spain	Deterministic	NUREG - 0098 Standard Review Plan
	Probabilistic	G.L. 88-20 SPL. 4 & 5 NUREG - 1407

Table 2.6
NRC Documents Used in Korea and Spain for Guidance

The most comprehensive response on the subject of detailed guidance in the process of re-evaluation was provided by the US, listing the following documents as being available for this purpose:

NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," June 1991 (Relevant references noted in this document include. NUREG/CR-2300; NUREG/CR-2815, Vol. 2; NUREG/CR-4840; NUREG/CR-4334; NUREG/CR-4482; NUREG/CR-5076; and EPRI NP-6041).

NRC Generic Letter 88-20, Supplements 4 and 5, "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities, 10 CFR 50.54(f) and NUREG-1407," June 1991 and 1995.

NUREG/CR-0098, "Development of Criteria for Seismic Review of Selected Nuclear Power Plants" May 1978.

NRC Safety Evaluation Report on "Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment," April 28, 1992.

DOE/EH - 0545, Seismic Evaluation Procedure for Equipment in US Department of Energy Facilities, Dept. of Energy, March 1977

In addition to there being no detailed guidance for the execution of the re-evaluation process, several countries also reported that there are no regulations that apply to the process of re-evaluation. These were Canada, Japan, Korea, Sweden and the UK. The French response did not contain a reply to this question. The German response reported that there are no specific regulations, but that the re-evaluation process is carried out using currently valid rules and regulations, together with experimental data and state of the art methods. The practice/guidance that was referred to by a number of countries generally fall under the broad headings of a number of organisations, specifically ASME, IAEA, IEEE, NRC, and, in some cases, local national regulations, as presented in Table 2.7.

	ASME	IAEA	IEEE	NRC	National
Belgium	✓				
Bulgaria		✓			
Czech Republic		✓		✓	
Spain				✓	
Switzerland	✓		✓	✓	✓
US				✓	

Table 2.7
Practice/Guidance Used in Re-evaluation Process

The question of whether continued operation depends on the outcome of the re-evaluation process (q 2.3) produced responses that generally fall into one of three categories, as follows:

Yes	Bulgaria, Canada, Czech Republic, France, UK
No	Japan, Korea, Spain
Qualified	Belgium, Germany, Sweden, Switzerland, US

The qualifications attached to the responses in the third category given above are summarised below:

Belgium	Reviewed on a case by case basis
Germany	Yes for plant that was not originally designed for seismic loads
Sweden	No decision has yet been presented by the regulatory body
Switzerland	No, but backfitting required for any non-compliances
US	No, but additional regulations apply if the re-evaluation indicates that the plant does not comply with licensing basis.

2.3 OVERALL APPROACH

The question of whether a formally agreed approach had been adopted in each of the participating countries (q 3.1) produced a similar response to whether there was explicit guidance on how re-evaluation was to be carried out, and the responses of the countries are summarised as follows:

Yes	Bulgaria, Czech Republic, Spain, UK, US
No	Belgium, Canada, France, Germany, Japan, Korea, Sweden and Switzerland

The responses to the questionnaire show that a number of countries adopt the same approach for all facilities, regardless of location or type (q 3.2). These countries are the Czech Republic, Japan and Korea. The French and Bulgarian responses did not contain a reply to this question, and the responses of the other countries are summarised below:

Belgium	Site/plant specific
Canada	Both margins and PSA used to date
Germany	Site/plant specific - no standard approach
Spain	Site/plant specific
Switzerland	Site/plant specific according to objectives of the re-evaluation
UK	Approach varies according to hazard and original design
US	Approach varies with location, type and sometimes other factors

The Swiss response recognises a major difference between old plant which require a complex re-evaluation taking into account increased hazard levels, and new plant which are only subject to a simpler periodic review.

Margins methods are not used by seven of the responding countries (qq 3.3, 3.4). These are Belgium, France, Germany, Japan, Korea, Switzerland and the UK, although the UK reported that margins methods are sometimes used. EPRI, IAEA and NRC methods are referred to in the responses. In Sweden all utilities have adopted US practice after earlier work carried out using jointly developed national methods. Specific responses from countries using margins methods are summarised in Table 2.8.

	EPRI	IAEA	NRC
Bulgaria		✓	
Canada	✓		
Czech Republic	✓		
Spain	✓		✓
US	✓		✓

Table 2.8
Use of Margins Methods

A seismic PSA is generally not part of the re-evaluation process in the following countries (q 3.5):

Belgium, Czech Republic, France, Japan, Sweden, UK

The response from Switzerland, states that a seismic PSA is carried out for new plants, but does not apply to old plants until the re-evaluation and any modifications that are required have been carried out. Both the Czech Republic and Sweden reported that it is planned to include seismic PSA in the re-evaluation process in the future. Seismic PSA is included in Bulgaria, Germany, Korea, Spain and the US, and in Canada for offshore plants.

Only one response (Korea) reported that conventional deterministic methods are not used (qq 3.6, 3.7) . No adjustment is applied to these method in Belgium and Japan. Adjustment has been applied in Bulgaria, the Czech Republic, France, Germany and Switzerland, but there is no consistent practice in these countries. The responses from the other countries are summarised below:

Canada	CDFM approach (EPRI NP-6041) with associated assumptions
Spain	According to NUREG/CR - 0098
UK	CDFM approach (EPRI)
US	NUREG/CR - 0098 for SEP programme. Methods are liberalised in CDFM calculations to obtain HCLPF

A seismic walkdown is included in the re-evaluation process in all the responding countries except France and Switzerland (qq 3.8. 3.9). In Switzerland, walkdowns are carried out, but as part of the seismic PSA. In France an evaluation of the existing condition of the plant and structures is recommended. The SQUG criteria are used as the basis for the walkdown in the following countries:

Belgium, Bulgaria, Canada, Czech Republic, Korea, Spain, Sweden, UK

The Swiss response notes that the SQUG criteria may be used, but the German response reports that the SQUG method is not used, and other methods, such as routing rules for piping are used instead. The US response reports that in addition to the SQUG criteria, walkdowns are being carried out in the IPEEE program using the EPRI margin method, which is very similar to SQUG.

2.4 INPUT DEFINITION

All the responses from participating countries reported that the definition of the seismic input level for seismic re-evaluation is site or site/plant specific (q 4.1). The French response noted that the definition of the seismic hazard is carried out according to national regulations (RFS 1.2.C).

Methods used in the assessment of the seismic input motion vary from country to country, and are not always consistent within the practice of individual countries, sometimes with both deterministic and probabilistic methods being used (q 4.2). Some responses did not clearly indicate which approach had been adopted. For example the Czech Republic reports that a combined seismic hazard assessment/seismo-tectonic analysis is used, with reference to the standard IAEA 50-SG-S1, Bulgaria refers to hazard analysis and the Japanese response does not give any clear indication of how the assessment is carried out. A summary of the approach (deterministic/probabilistic) reported in the remaining responses is given Table 2.9:

	Deterministic	Probabilistic
Belgium	✓	
Canada		✓
France	✓	
Germany	✓	✓
Korea		✓
Spain	✓	✓
Sweden		✓
Switzerland		✓
UK	✓	✓
US	✓	✓

Table 2.9
Summary of Methods Used in Determination of Input

Typical values of peak ground acceleration, annual return frequency and type of spectrum are provided in most responses for re-evaluation seismic ground motion input levels, sometimes referred to as the Review Level Earthquake (RLE) (q 4.3). Typical return periods are not reported in the responses from Belgium, France, Japan, Spain and the US. In the case of the US, it is reported that complete probabilistic seismic hazard curves were used for seismic PSA, and Bulgaria and the UK reported a probability of 10^{-4} per annum. The reported values of the return period are summarised in Table 2.10.

10^4 years	Canada, Czech Republic, Switzerland
10^3-10^4 years	Korea
10^4-10^5 years	Germany
10^5 years	Sweden

Table 2.10
Summary of Reported Return Periods for Input Motion

The reported values of typical peak ground accelerations in terms of free field zpa at the ground surface are summarised in the plot presented in Figure 2.2, showing the range of reported values, with digital values to the left of the plot. As noted above, these are generally associated with return periods of 10^4 years or probabilities of 10^{-4}. The Japanese values are assumed to apply at a rock outcrop with a shear wave velocity of more than 700m/s, although it should be noted that nuclear power plants in Japan are generally sited on rock.

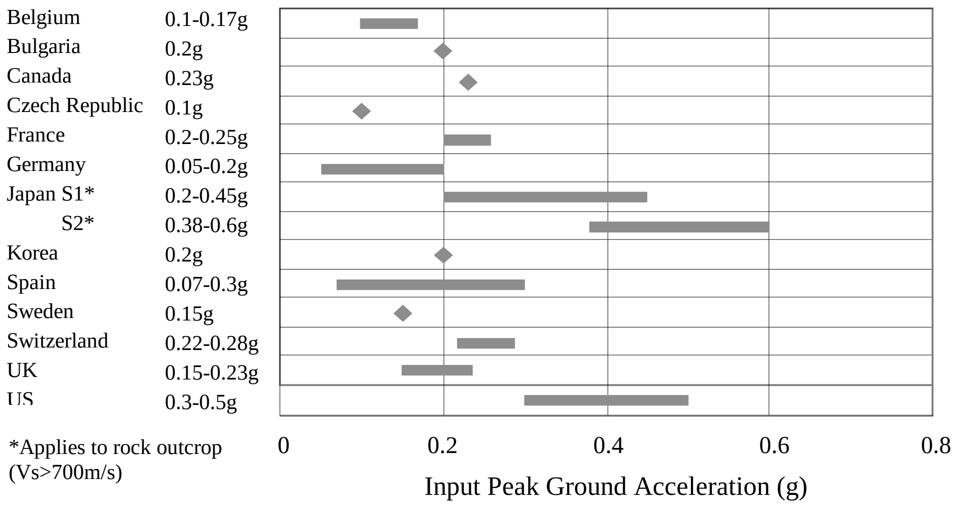

Figure 2.2
Summary of Typical Peak Ground Accelerations
(RLE, free field zpa at ground surface)

A typical type of spectrum used to define the input motion is not reported in the Japanese response, and the French response reports that spectra are plant specific, but enveloping spectra may be used, e.g. NRC. A summary of the remaining responses is provided in Table 2.11:

	NRC	UHS	National	Site specific
Belgium				✓
Bulgaria				✓
Canada		✓		
Czech Rep.	✓			✓
Germany	✓			✓
Korea	✓			
Spain	✓			
Sweden			✓	
Switzerland	✓		✓	
UK		✓	✓	✓
US	✓	✓*		✓

* US response notes that the use of UHS is not recommended.

Table 2.11
Summary of Typical Spectra for Input Motion

The final question in Section 4 of the questionnaire related to whether the hazard defined for use in the re-evaluation is the same as for a new plant at the same location (q 4.4). The general answer given in the responses was yes, with the German response qualified as being the same in principle. The Swedish and UK responses did not provide an answer, as no new plant is planned. The exceptions were Canada and the US, whose responses indicated that the re-evaluation earthquake would normally be larger than the design earthquake, particularly if re-evaluation is being performed to understand severe accident behaviour or assess plant capacity, and the French response stated that a new plant could have a different hazard.

2.5 SCOPE OF PLANT

This is a relatively short section in the questionnaire, containing only two questions relating to the scope and selection of plant assessed in the re-evaluation (qq 5.1, 5.2).

The responses generally reported that only safety related plant is included in the re-evaluation process, although the responses were indicative of some confusion over the meaning of the word plant (i.e. complete power station rather than equipment). In response to the question on selection, there was almost equal weight given to the three choices offered in the questionnaire. These were selected on the basis of following regulations, recognition of likely robustness or relation to safety functions, and the responses are summarised below in Table 2.12.

	Regulations	Safety function	Likely robustness
Belgium	✓	✓	✓
Bulgaria	✓	-	-
Canada		✓	-
Czech Rep.	✓	-	-
France	-	✓	-
Germany	-	✓	-
Japan	✓	✓	-
Korea	-	-	✓
Spain	✓	-	-
Sweden	-	✓	-
Switzerland	✓	✓	✓
UK	✓	✓	✓
US	✓	✓	-

Table 2.12
Summary of How Plant is Selected for Assessment

2.6 ANALYSIS METHODS

This section of the questionnaire contains questions related to working practice in the use of soil-structure interaction (SSI) analysis, response spectrum analysis and time history analysis. It also seeks to establish whether pipework and brick/blockwork walls are routinely analysed.

Responses reporting that soil-structure interaction was routinely carried out as part of the re-evaluation process were received from the following countries (q 6.1):

Belgium, Bulgaria, Canada, France, Germany, Japan, Korea, Spain, Sweden, UK

The German response was qualified by the comment that this was the case for some plants only. The response from the Czech Republic reported that there was a requirement that all Seismic Category I structures must be on rock, with a minimum area of 500m x 500m.

The Swiss response report that soil-structure interaction analysis would only be carried out if the original design was considered to be too simple, and the response from the US reported that the need to carry out

SSI analysis would normally be assessed on a number of factors, including the availability and adequacy of the original calculations, the purpose of the re-evaluation and the need to reduce conservatism.

All but two of the countries responding to the questionnaire reported that uncertainty bands were applied to the results of SSI analysis (q 6.2). The two countries that stated that uncertainty bands were not used were Japan and Sweden.

The response to the question of what percentage bands are typically applied produced responses that quoted bands both for ranges of soil parameters and for broadening floor/secondary response spectra (FRS), although the responses do not always specify which category the quoted band applies to (q 6.3).

The responses are summarised in Table 2.13 in terms of these two categories. It should be noted that some assumptions have been made in cases where the response is not specific regarding the category to which the reported margins apply. For example, the Belgian response of '+/-15%' has been assumed to apply to broadening of the FRS.

		Soil Shear Modulus	FRS Broadening
Belgium		-	±15%
Bulgaria		±50%	-
Canada		±50%	±15% (min.)
Czech Rep.		-	5%
France		-33%/+50%	-
Germany		±30%	-
Korea		-50%/+100%	-
Spain		-50%/+100%	-
Switzerland	KKB	-33%/+50%	-
	KKM	-	±20%
UK			±15%
US		EPRI NP-6041	See table 2.14

Table 2.13
Summary of Reported Percentage Bands for SSI

The US reference to EPRI NP-6041 contains the following explanations of the EPRI requirements:

> In EPRI NP-6041 three cases are recommended: 50% of the modulus corresponding to the best estimate of the mean large strain condition, 90 % of the modulus corresponding to the best estimate of the low strain condition, and a best estimate shear modulus. Refer to EPRI NP-6041 for additional details.

The questionnaire also asks which of three specific factors are explicitly taken into account (q 6.4). The three factors are:

- Variations in soil properties
- Uncertainties in modelling
- Structure-soil-structure interaction (SSSI)

The Japanese response reports that none of these are explicitly considered, but are taken into account in normal working practice. The remainder of the responses are summarised in Table 2.14.

	Soil properties	Modelling	SSSI
Belgium	✓	-	-
Bulgaria	✓	✓	✓
Canada	✓	✓	✓
Czech Rep.	-	-	✓
France	✓	✓	-
Germany	✓	✓	✓
Korea	✓	✓	✓
Spain	✓	✓	✓
Sweden	-	✓	✓
Switzerland	✓*	✓**	✓
UK	✓	✓	✓
US	✓	✓	✓**

* KKB (Beznau Units 1 & 2) only - see percentage bands above ** Implicitly included

Table 2.14
Summary of Factors Considered in Analysis

The replies to the questionnaire and subsequent comments generally indicate that response spectrum analysis is generally used in all countries for structures or major plant (q 6.5).

In cases where response spectrum analysis is used, the questionnaire asks whether the following also apply (q 6.6):

- Are damping levels assumed to be as for new plant?
- Are mode combination methods as for new plant?
- Are simplified models (relative to new plant) used?
- Is peak broadening the same as for new plant?

The responses to these questions are summarised in Table 2.15. In the case of Sweden, where no new plants will be built, the responses relate to practice adopted in the design of the most recently constructed plants.

	Damping as new plant	Mode combinations as new plant	Simplified models cf. new plant	Peak broadening as new plant
Belgium	Yes	Yes	Yes	Yes
Bulgaria	No	Yes	No	Yes
Canada	Yes	Yes	Yes	Yes
Czech Rep.	No	Yes	Yes	No
France	Yes	Yes	Yes	Yes
Germany	Yes	Yes	Yes	Yes
Japan	Yes	Yes	No	Yes
Korea	Yes	Yes	No	Yes
Spain	Yes	Yes	No	Yes
Sweden	Yes	No	Yes	Yes
Switzerland	Yes	Yes	No	Yes
UK	Yes	Yes	Yes	No
US	No	Similar	Yes	Yes*

* Peak broadening or peak shifting

Table 2.15
Comparison With Practice for New Plant

The questionnaire asked for responses regarding the use of time history analysis, and, specifically, if time history analysis is used, whether real or artificial time histories were used, and whether multiple analyses were required (qq 6.7, 6.8): Of the responses received, the reply from the Czech Republic reports that time history analysis is not used, and states that calculations are made in the frequency domain and that accelerograms are used for the determination of floor response spectra. All of the other responses report that time history analysis is used, and the responses are summarised in Table 2.16.

	Time history analysis?	Real/Artificial?	Multiple Analysis?
Belgium	Yes	Artificial	No
Bulgaria	Yes	Artificial	Yes
Canada	Yes	Artificial	Yes
France	Yes	Artificial	Yes
Germany	Yes	Artificial	No
Japan	Yes	Artificial	No
Korea	Yes	Both	No
Spain	Yes	Artificial	No
Sweden	Yes	Artificial	No
Switzerland	Yes	Artificial	No
UK	Yes	Artificial	No
US	Yes	Both	Yes

Table 2.16
Reported Practice for Time History Analysis

On the subject of whether pipework systems and brick/blockwork walls are routinely analysed, the responses were mixed and these are summarised in Table 2.17 (qq 6.9, 6.11).

	Pipework routinely analysed	Brick/block walls routinely analysed
Belgium	No	Yes
Bulgaria	Yes	Yes
Canada	No	Yes
Czech Rep.	Yes	No
France	Yes	Yes
Germany	Yes	Yes
Japan	Yes	Yes
Korea	No	No
Spain	Yes	Yes
Sweden	Yes	Yes
Switzerland	No	No
UK	No	Yes
US	No	Yes

Table 2.17
Reported Practice for Analysis of Pipework and Brick/blockwork

The questionnaire also asked whether any of the procedures used in the seismic re-evaluation process in relation to SSI, response spectrum and time history analysis, or the treatment of pipework systems, vary from those adopted for new plant (q 6.10). The responses from the following countries reported that the procedures do not vary from those for a new plant (qualified as not in principle by Germany):

Belgium, Germany, Japan, Korea, Spain, Switzerland

In Canadian practice the existing plant is assessed against screening criteria, whereas new plant requires rigorous design in compliance with current codes. The UK also reported that the procedure varies because of the use of the EPRI CDFM approach. Both the French and US responses report that the procedures do vary, and that, in general, some of the conservatism in the design procedure has been removed in the re-evaluation to compute more realistic responses.

2.7 ASSESSMENT CRITERIA

This section of the questionnaire addresses fundamental information relating to the criteria that are used in the assessment of different components in the re-evaluation process, and whether the criteria take account of the age and condition of plant or reduced plant life.

On the question of whether the assessment criteria adopted for re-evaluations differ significantly from those used for new plant, the questionnaire asked for a response on four specific categories, as follows (q 7.1):

- For civil structures
- For pressure boundary structures
- For anchorage
- For foundations and soils (liquefaction, stability etc.)

The responses that have been received are summarised in Table 2.18.

	Civil structures	Press. boundary structures	Anchorage	Foundations and soils
Belgium	No*	No	Yes	No
Bulgaria	Yes	Yes	Yes	Yes
Canada	No	No	No	No
Czech Rep.	SMA	SMA	No	No
France	Yes	Yes	Yes	Yes
Germany	No	No**	No**	No
Japan	No	No	No	No
Korea	No	No	No	No
Spain	No	No	No	No
Sweden	Not applicable	Not applicable	Not applicable	Not applicable
Switzerland	Yes	No	No	No
UK	No	No	Yes (SQUG GIP)	Not applicable
US	Yes	Yes	Yes	Yes

* Except for specific non-linear analysis   ** Qualified by ‘not in principle’

Table 2.18
Do Assessment Criteria Differ Significantly From Those for New Plant?
(‘No’ answers shaded for clarity)

As noted above, the Swedish response was ‘Not applicable’, as no new plants will be built in Sweden. In addition, the Belgian response reports that the criteria differ for anchorages, and the Czech response for civil and pressure boundary structures was ‘SMA’, with neither response giving any further explanation. The US response provides a fairly comprehensive response listing a number of specific areas of difference, which can be viewed in Appendix C. It states that in general, an attempt is made to determine best estimate responses and calculate realistic capacities taking credit for non-linear energy absorbing capacities. The aspects of the re-evaluation process that are addressed in this approach include the seismic input motion and various aspects of the analysis procedure, load combinations, material properties, strength prediction and energy absorption.

The question of what level of reliability is assumed for the assessed plant (q 7.2) produced a wide variety of responses, including the response that there is no specific statement for reliability (Canada), no criteria for reliability (Switzerland), not explicitly considered (France) and a response of 10^{-5} from Bulgaria. The German response was ‘no’. The Japanese response was that it was the same as new plant, with no further details, the Korean response was ‘Core Damage Factor of 10^{-5}, and HCLPF is assumed in Spain.

The Belgian response reports that the safety systems have to meet the single failure criteria deterministically, and the plant PSA analysis uses generic reliability data for standard components. The Swedish response related to the probability of exceedence of the design input motion of 10^{-5} for the SSE and 10^{-7} for the ‘Relief Mitigation Earthquake’, although the 10^{-7} event is currently regarded as a hypothetical criterion, and is unlikely to be applied in real practice. The UK response states that adequate reliability is assured by requiring additional plant for more frequent events.

The Czech response simply stated ‘HCLPF>PGA’, and the most comprehensive response is provided by the US, also in terms of the High Confidence Low Probability of Failure (HCLPF). The US response is reproduced below:

> In both the margin and PSA methods, a measure of plant capacity achieved is the High Confidence Low Probability of Failure (HCLPF) capacity. Approximately, the HCLPF capacity can be inferred as a seismic level at which there is 95% confidence that the failure probability is less than 5%. In PSA method, in addition to the HCLPF capacity, other measures, such as annual core damage frequency and frequency of a large release out side of containment are available.

In response to the question of whether it is necessary to demonstrate the required reliability formally (q 7.3), the Belgian reply is the same as that given for the reliability level, and the Swedish reply stated that the verifying process is still ongoing. The remaining responses are summarised below:

Yes	Bulgaria, Czech Republic, Japan
No	Canada, France, Germany, Korea, Spain , Switzerland, UK, US

The response from the US was considerably more detailed than implied by the summary above, and can be viewed in Appendix C.

On the question of whether the plant is required to meet the single failure criterion (q 7.4), the Japanese response stated that this was the same as for new plant, and no response was provided by Canada. Swedish practice has not yet been established, and there was therefore no Swedish response to this question or the remainder of Section 7 of the questionnaire, although additional comments have been provided by Sweden, and these are included in this review. The following countries reported that plant were required to meet the single failure criteria:

Belgium, Bulgaria, Czech Republic, France, Germany, Korea, Spain, Switzerland, UK, US

The next three questions in the questionnaire ask what criteria are used for brick or block walls, pipework and relays (qq 7.5, 7.6, 7.7). The Japanese response states that the same criteria as for new plant are used, with no further explanation. The remaining responses are summarised in Table 2.19, including comments from Sweden, based on current national practice.

	Brick/block	Piping	Relays
Belgium	Test results/ codes	ASME	N/A
Bulgaria	IAEA	IAEA	IAEA
Canada	Cracking/overturning	Review of supports. EPRI guidelines	Bad actor/chatter evaluation, shake table tests
Czech Rep.	No answer	HCLPF	GIP
France	Seismic codes	As design	Tests
Germany	Stability	ASME (in principle)	Test criteria
Korea	EPRI NP-6041	EPRI NP-6041	IEEE C 39, 98
Spain	Structural integrity	ASME	SQUG
Sweden	Codes	Screening/Analysis	
Switzerland	Overturning	ASME, NRC RG 1.61	IEEE
UK	Strength/stability	Screening/Analysis	GIP, system analysis
US	Case-by-case basis, EPRI NP-6041	EPRI NP-6041	NUREG-1407

Table 2.19
Criteria for Analysis of Brick/block, Piping and Relays

The response from the US was considerably more detailed than implied by the summary above, and can be viewed in Appendix C. The answer of ‘not applicable’ in the Belgian response for relays is due to the fact that current policy is to replace suspect relays. There is no explanation for the ‘N/A’ response from Korea on piping.

A more consistent set of responses was provided for the final three questions in this section which asked whether the criteria used take into account ageing or plant condition, reduced plant life and multiple plant sites (qq 7.8, 7.9, 7.10). The responses to these questions are summarised in Table 2.20:

	Ageing/condition	Reduced life	Multiple plant
Belgium	Yes	N/A	No
Bulgaria	Yes	No	Yes
Canada	Yes	No	No
Czech Rep.	No	No	No
France	Yes	No	?
Germany	No	No	No
Japan	No	No	No
Korea	Yes	No	No
Spain	No	No	No
Switzerland	No*	No	No
UK	Yes	No	No
US	Yes	No	No

* A program to consider ageing is currently has been implemented

Table 2.20
Factors Considered in Analysis

2.8 ASSESSMENT OF AS-BUILT SITUATION

This section contains three questions relating to the as-built situation (qq 8.1, 8.2, 8.3). The questions ask firstly if the as-built situation is taken into account in the re-evaluation, secondly if the as-built situation is defined from drawings or in situ inspection, and thirdly whether the material properties are taken from original specifications or in situ evaluations. The responses to these questions are summarised in table 2.21:

	Taken into account?	Drawings/inspection	Original specification/evaluation
Belgium	Yes	Both	Specification
Bulgaria	Yes	Both	Both
Canada	Yes	Both	Specification
Czech Rep.	Yes	Both	Specification
France	Yes	Both	Both
Germany	Yes	Both	Specification
Japan	Yes	Drawings	Specification
Korea	Yes	Both	Specification
Spain	Yes	Both	Specification
Sweden	Yes	Both	Both
Switzerland	Yes	Drawings	Both
UK	Yes	Both	Both
US	Yes	Both	Evaluation

Table 2.21
As-Built Conditions Considered

2.9 OUTCOME OF RE-EVALUATIONS

All of the responses received, except for the French and Swedish response, judged that the re-evaluation process had been a success (q 9.1). The Swedish response reports that, for the moment, it has created more problems than it was expected to solve. These problems are not specified, and the French response was ‘mitigate answer’. The US response reports that the IPEEE program in the US is deemed a success in identifying plant-specific dominant problems and simple fixes. It is also noted that many lessons have been learned which should be useful to others embarking on a re-evaluation program, and that an insight NUREG is under preparation by NRC staff.

Answers to the question asking what aspects might be improved if starting again are listed below according to country (q 9.2). No answer was provided in the Bulgarian or Swedish response, the Belgian response was ‘N/A’, and the Spanish reply stated that the re-evaluation is currently in progress.

Canada	Process for determining site seismic hazard parameters, process for the selection of components to be reviewed, more extensive training in assessment techniques
Czech Rep.	Duration of maximum phase, floor response spectra, instrument response spectra
France	Improve definition of general philosophy and associated criteria. Methods for the demonstration of the seismic behaviour of a given building should be developed.
Germany	Use of a general procedure for re-evaluation with uniform criteria - draft currently in preparation at GRS
Japan	Re-evaluation criteria and guide should be established
Korea	Include the collection and evaluation of operational data and seismic qualification data for equipment and components
Switzerland	Seismic qualification of all buildings containing safety related systems using rigorous methods
UK	The identification of a better balance between simple and complex structural models
US	Use of UHS spectra should not be permitted. UHS have very low energy in lower frequencies and resulting demands are not meaningful for a margin assessment. UHS are also not consistent with the URS. Margin and PSA methods should not be simplified to a point that the disciplined integrity of the overall process is jeopardised. More guidance on fragility/margin calculations. Peer review process is critical to success, as re-evaluation involves considerable judgement.

The final question in this section asks what significant physical modifications have resulted from the re-evaluation (q 9.3), and the responses are summarised below according to country:

Belgium	Strengthening of structures, replacement of building + hydraulic systems in one case
Bulgaria	Upgrading of structures and equipment
Canada	Strengthening of anchorages and masonry walls
Czech Rep.	Anchorages
France	Strengthening of anchorages, shear walls, foundations and steelwork frames
Germany	Depends on plant, e.g. modification of supporting structures to improve stability of structure/plant, pipe supports, elimination of destructive interaction between components, cable trays, battery racks, stiffening of masonry walls
Japan	None
Korea	Strengthening of structures and equipment anchorages and supports. Removal of potential for seismic interaction between equipment and components.
Spain	Anchorages and interaction of equipment. In many cases the replacement of equipment.
Sweden	To date, some strengthening of anchorages for electrical cabinets and battery racks
Switzerland	Strengthening of control room ceilings, brickwork, steel structures and pipe supports, additional walls in auxiliary buildings. Improvements in procedures, such as parking of cranes. New heat removal systems added (requirement for these covers other external events as well)
UK	Strengthening of blockwork walls, anchorages, piping system replacement
US	In the IPEEE program plant improvements related to seismic events have generally taken the form of various hardware fixes, maintenance actions, and procedural enhancements. Hardware fixes have included such items as: anchoring equipment, bolting cabinets together to avoid impact, improving existing anchorage or supports, installing missing fasteners and bolts, installing spacers on battery racks, replacing vulnerable relays, and some structural fixes. Maintenance actions have included the removal of corrosion on equipment anchorages, and application of corrosion protection.

> Procedural improvements include proper storage of maintenance equipment, proper parking of cranes and chain hoists, and resetting of relays. Most frequently reported dominant failures include: offsite power, electrical control panels, block walls, and interactions between buildings or systems. Other reported contributors include: buildings, switchgear, cable trays, fuel oil tanks, transformers, pumps, switchgear chatter, ice condenser, AFW pipe, MFW heaters, containment fans, battery racks, invertors, battery chargers, accumulators, bus under voltage relays, motor control centres, electrical buses, surge tanks, control road drive, load centres, and room cooling.

2.10 RESEARCH

On the subject of research, the questionnaire asked if there was any research in progress which is specifically focused at re-evaluation, and also whether there were plans to carry out research focused on re-evaluation problems (qq 10.1, 10.2). The responses of the following countries reported that there was no current research or any plans to carry out research related to re-evaluation problems:

Belgium, Canada, Germany, Japan, Sweden

The Bulgarian response stated that research was in progress and that further research was planned, but did provide any further details. The Czech Republic reported current research into seismic assessment, with specific work in the areas of seismic hazard, response spectra and modes of behaviour. Research is also planned in methodology.

Switzerland also recorded proposals for future work in the seismic hazard assessment, with a review of the seismic hazard level for all existing plants. Research is planned by Korea in the use of deterministic methods for seismic re-evaluation, and the collection and evaluation of seismic qualification data for equipment and components.

The Spanish response reported that three research projects are in progress on seismo-tectonic aspects related to the Iberian Peninsula and surrounding area, as follows:

- Study of regional stress fields to aid in the definition of seismic zones.
- Study of historical movements of the Camp fault/associated earthquakes in the Quaternary period
- Development of a database of seismic records and associated structural damage in geographic areas similar to the Iberian Peninsular

France reported that research is focused on the improvement of non-linear analysis of buildings, taking into account specific details, and that coupled experimental and analytical programs are being conducted for the most critical items of equipment, in an effort to improve calculation methods and quantify margins. In particular, work is being carried out on the simulation of non-linear behaviour of structures, to provide data for the assessment of margins. This work includes the validation of analytical methods, such as the use of constitutive models and finite element formulation, against the results of shaking table tests, and the effectiveness of rules for structural detailing is also being assessed. Areas of study that have been identified as topics for future work are the fragility of equipment and the definition of appropriate allowable stress and strain criteria for use in re-evaluation work.

The UK reported that there are several IMC projects which are particularly relevant to re-evaluation (the abbreviation IMC refers to ‘Industry Managed Contracts’ and applies to a co-ordinated research effort involving both the regulators and licencees in the UK). These projects are as follows:

- Seismic performance of unreinforced masonry panels
- Study on relay chatter
- Evaluation of seismic fragility
- Study on conservatism in design codes in relation to uncertainties in material properties

The UK response notes that the IMC programme will continue to address such problems, giving an example of a proposed project on seismic experience data on the performance of high temperature steam pipework.

In the US response it is reported that a last phase of a probabilistic seismic hazard analysis method development program is currently being carried out. In this phase, trial applications are being carried out for a methodology developed last year.

The US response also reports that other programs which relate to re-evaluation, but which are not specifically focused on the subject are currently ongoing, as follows:

- Structural ageing program - In this program effects of ageing on the seismic performance will be evaluated. Intent is to identify risk significant components and determine whether ageing effects lead to a serious detriment in margin or capacity. Develop mitigation criteria and performance evaluation methods.

- Large scale testing of concrete containment models by NUPEC (Japan). This is a collaborative program in which NRC is analysing models which have been, or will be, tested to failure. This work will contribute to the verification of analytical methods for margin/fragility prediction.

3. DISCUSSION

3.1 GENERAL

The responses have confirmed that seismic re-evaluation of plants not originally designed for seismic loading has been carried out by all responding member countries. In all countries except Bulgaria and Sweden the work has reached the stage where it has been reviewed by the regulatory authorities or is in the process of review. There is no intention for the regulatory authorities in Japan to review the seismic re-evaluation of the older plants.

In the majority of countries evaluation is carried out typically when plant is between 10 and 20 years old and then at 10 year intervals thereafter, often as part of a much wider ranging safety review. In Canada, re-evaluation has been carried out on plants that are 20-25 years old, and a 2 years old standard design is being re-evaluated in order to obtain a better understanding of its behaviour beyond the design basis. In Korea and the Czech Republic plants under construction or newly built plants have been re-evaluated. In the USA there is no explicit age criterion for re-evaluation. The current IPEEE program for all operating plants is being carried out on plants generally in the 10 to 20 year range.

From the majority of replies a major re-evaluation typically takes two or three years to complete, although the implementation of modifications can take considerably longer. The reported cost of a major seismic re-evaluation exercise ranges from $US 1 million to $US 5 million. Typically the cost of analysis alone appears to be in the region of $US 1 to 2 million. The costs of any modifications required are extremely variable, and will account for a wide variation in the cost of the overall process.

Thus the responses demonstrate that a formidable commitment is being made to seismic re-evaluation of nuclear plant throughout the OECD member countries. Any generic lessons which can be learned from the exercise are clearly of significant benefit.

3.2 LEGISLATIVE FRAMEWORK

In over half the countries there are no prescribed regulatory guidelines for seismic re-evaluation, although in most cases successful re-evaluation is a requirement of continued operation. Where guidelines are cited (Czech Republic, Korea, Spain and USA) they are normally accepted engineering standards or the USA standards and methods explicitly developed for seismic evaluation or PSA; NUREG/CR-0098, NUREG - 1407, etc.

The general absence of explicit regulatory guidance for seismic re-evaluation is notable. This is probably a reflection of the fact that there are many complex judgements to be made in re-evaluation studies and there is a benefit in keeping as many options open as is reasonable. It is also striking that, even in the absence of detailed guidance, there is a large degree of similarity in the approach adopted to most aspects - implying that there is a significant amount of technical consensus in the international community.

3.3 OVERALL APPROACH

In line with the absence of regulatory guidelines the overall approach adopted for seismic re-evaluation varies substantially. All the basic methods are used in some combination; i.e. deterministic, probabilistic, margins methods and experience data. Despite the flexibility and variations in the use of methods reported there are some basic principles which seem to apply:

- All countries except Canada and Korea report that deterministic methods are used for re-evaluation. In Canada and the UK the CDFM margins approach is used and Korea uses PSA.
- In all countries where margins methods are used they are based on the US methods (EPRI or EPRI plus NRC) except in Bulgaria (IAEA methods), and Germany, where evaluations are carried out on a case by case basis.
- Most countries also carry out seismic PSA; the exceptions being Belgium, France, Japan and the UK.
- All countries except France, Japan and Germany use the SQUG approach for judging acceptability of relevant plant. In Germany other methods, such as routing rules for piping are used instead.
- Alternatives are used; such as screening rules for piping (Germany and the UK).

It is clear that a variety of methods for seismic re-evaluation is considered to be viable and, often, more than one method is applied within a single country. This diversity of approach is likely to be an overall benefit for safety but it may be worthwhile to understand in more detail the benefits and disadvantages of the various methods in particular circumstances and it is recommended that this should be explored through a specific conference or workshop.

3.4 INPUT DEFINITION

In all cases the input is reported as being site specific. This is considered to be appropriate in order to avoid excessive conservatism and to ensure consistent levels of conservatism in the assessments. Peak ground accelerations for free field zpa at the ground surface are typically in the range 0.05g to 0.25g; the exceptions being the US and Japan where accelerations in the range 0.3g to 0.5g and 0.2g to 0.6g respectively are adopted. The assessment level appears to be intended to be consistent with an annual return frequency of 10^4 years or less frequent. This may be compared with typical code requirements for general industrial and residential structures in seismic regions, such as those in Eurocode 8 (CEN, 1994, see also GSHAP 1996,1997), which specifies that the return period used in the hazard definition is 475 years. Although this would not be applicable to a nuclear power plant, it does demonstrate that the requirements for hazard definition that have generally been adopted in the nuclear industry worldwide are consistent with an appropriate recognition of the potential risk that a major accident poses.

In the majority of countries the peak ground acceleration considered in the re-evaluation process covers a range of values, reflecting the site specific nature of the input definition, where the range covers differences in both the regional seismicity and the influence of local site response characteristics. The majority of countries also use probabilistic methods in the assessment of the seismic hazard, although some countries reported using deterministic methods or both. In cases were both have been used, e.g. Spain and the US, deterministic methods were used for earlier re-evaluations (SEP) and probabilistic methods were used for later and current work (IPEEE), reflecting a general trend towards the use of probabilistic methods in seismic hazard assessment. There is also a high level of consistency among responding countries in the definition of the hazard probability level, generally set at 10^{-4}, or return period, typically 10^4 years. The US response drew attention to the inadvisability of using UHS for re-evaluation, due to the lack of energy over the important low frequency portion of the spectra.

The response to the question on design levels for new plant (Question 1.8) confirms that the level of seismic excitation used for the re-evaluations is broadly consistent with the excitation levels used for design. Thus there is a significant and consistent attempt to base the re-evaluation of plant, many of which were not originally designed for seismic loading, on the standard applied to new plant. In the US, the primary purpose for re-evaluation is to understand the behaviour for severe accidents, beyond the design basis. Therefore, re-evaluation earthquake levels are generally higher than design levels.

3.5 SCOPE OF PLANT

The scope of systems, structures, and components (SSCs) to be included in a re-evaluation is a complicated question that depends on the objective of the re-evaluation. Other non-technical factors, such as available time and resources, may also affect the scope. A number of comments are given below which are largely based on the experience of the extensive re-evaluation programme that has been carried out to date in the US. These are followed by a discussion of the response to the questionnaire.

If the objective of re-evaluation is to estimate seismic risk or understand severe accident behaviour beyond design basis, and the seismic PSA method is used, it is necessary to include all seismic induced initiators (i.e., transients, small LOCAs. large LOCAs, etc.) and all SSCs involved in accident scenarios at the beginning of the analysis. These SSCs are carefully screened, based on system, capacity, and walkdown considerations by following the guidelines provided in the methodology. Margin methods, however, developed from PSA insights for US light water reactors (LWR), limit SSCs to those related to seismic induced transients and small LOCAs. One of the observations made during the development of margin methods was that it was very difficult to ignore small LOCAs because the effectiveness of walkdowns in containments is limited. The decay heat removal systems, and associated water sources are included in both methods for extended mission time (typically 72 hours).

If the purpose of the re-evaluation is very specific or limited, for example for Unresolved Safety Issue (USI) A46 in the US, in which the objective was to verify the seismic capacity of mechanical/electrical components in some plants, the SSCs are selected on the basis of seismic induced transients, safe shut down, and maintaining safe shut down for the extended time.

The question of scope is more difficult in cases where no seismic hazard was considered in the original design of the plant, design documents are not available, or the original design differs significantly from LWRs, so that generic insights that are available from the LWR experience are not easily extended to the re-evaluation. In such cases, use of the seismic PSA method, with inclusion of all potential scenarios, would be ideal, but lack of time and resources may not permit the full implementation of this technique. Margin and other methods with an appropriate scope can also be adapted for these situations. The IAEA Seismic Re-evaluation Guideline, currently under preparation, is expected to provide more guidance in this area.

The response to section 5 of the questionnaire was slightly confused because the meaning of the word "plant" appears to be ambiguous in some countries (where it is understood to mean complete stations, rather than equipment within them). However it is believed that in all countries only sufficient safety related structures, systems and components necessary for safe shutdown following a seismic event are assessed. The scope of this is determined by analysis of the functions required for safe shutdown, by safety classification, guidelines or by consideration of likely robustness (Guided by PSA where appropriate).

There is general agreement that the selection should include all safety-related structures, systems and components, together with any non safety-related SSC that could impact in any way with the safety-related items.

The consideration of additional criteria that are a result of, but not directly attributable to seismic response, in the selection of SSC have also been proposed. An example of such criteria is the effect of a small Loss of Coolant Accident (LOCA), which might be induced by the seismic event. It is apparent that there is no general consensus of opinion on the adoption of such criteria in the selection of SSC to be considered in the re-evaluation process.

It is clear from the responses to the questionnaire, and subsequent discussion and comment within the group, that this is one aspect of the re-evaluation process that is prone to some uncertainty. The scope of plant to be selected for inclusion in seismic re-evaluation would therefore be a good subject for a workshop, and this is recommended, with the objective of establishing clear guidelines for the selection process.

3.6 ANALYSIS METHODS

In all countries soil-structure interaction analysis is carried out if it has not previously been done and it is appropriate for the site type. Uncertainty bands are applied to the results except in Japan and Sweden. The range of uncertainty applied varies from ±15% to ±30 % peak broadening and from +50%/-33% to +100%/-50% on shear modulus.

It is very difficult to express the basis for uncertainty bands in a brief response as requested in the survey. However the ranges indicated are generally consistent with the range which might be justifiable for a new plant and this appears to be a reasonable way of summarising the responses; i.e. except for the two countries which explicitly neglect uncertainties, the ranges adopted are similar to uncertainty ranges which would be applied for a new plant.

Variations in soil properties are explicitly taken into account in analysis work in all countries except for the Czech Republic and Sweden. Similarly uncertainties in modelling are also taken into account in most countries, with the exceptions being Belgium and the Czech Republic. Structure-soil-structure interaction is also accounted for in most countries, but not in Belgium or France. All three of these factors are therefore explicitly taken into account in five countries: Bulgaria, Canada, Germany, Korea, and Spain.

Response spectrum analysis is used for equipment analysis in all countries except Sweden, where time history analysis appears to be used in preference. Time history analysis is also used for equipment (i.e. as opposed to building response analysis for the generation of floor response spectra) in all countries except Czech Republic, Germany and Switzerland.

In general, where response spectrum analysis is used for analysis of equipment the methods are identical to those which would be used for new plant. In Belgium, Canada, Germany, UK and USA some simplification of models can be used and in the US and the Czech Republic different damping and peak broadening is adopted. In Bulgaria damping levels may be different. In the UK peak broadening is only used in sensitivity studies, and in the US peak shifting is identified as an alternative to peak broadening.

In all cases artificial time histories are adopted for time history analysis except in the USA where real time histories are recommended for non-linear analysis. This is the only routine application of multiple time history analysis. In half the countries responding pipework systems are routinely analysed: Bulgaria, Czech Republic, France, Germany, Japan, Spain and Sweden. In the others piping systems are assessed using either a walkdown/similarity approach or by sample or simplified analysis. Analysis appears to be carried out where the walkdown/similarity criteria cannot be met, i.e. Belgium, Canada, Korea, Switzerland, UK and USA. Switzerland also notes that analysis might be carried out in lieu of a walkdown in cases where the seismic hazard level has been increased.

In all countries except Czech Republic, Korea and Switzerland brick and blockwork walls are assessed. In the latter two, walls with a safety function are assessed by PSA or margins methods. These walls do not have a primary structural function, but represent a risk to safety related equipment.

Overall it may be seen that a range of analysis methods is used for seismic re-evaluation. In general, whatever analysis method is used, there is no deliberate attempt to reduce margins relative to those which would be adopted for the same plant or equipment at the design stage. The exception is the USA where there is a deliberate attempt to generate best estimate responses. Alternative methods are routinely used for pipework.

3.7 ASSESSMENT CRITERIA

In the overwhelming majority of cases the assessment criteria used for seismic re-evaluation do not differ significantly from those used for the design of new plant. Where they do differ it is to be consistent with seismic margins methods, experience data or to remove identified conservatism from the normal design criteria.

The degree of reliability incorporated into seismic re-evaluations is not easily summarised; the responses generally referring to the reliability implied by input or assessment levels. This probably reflects the fact that design conservatism is conventionally used as a surrogate for reliability, and the relationship between the two is difficult to quantify.

The questionnaire requested information explicitly on the criteria used for blockwork walls, piping and relays because it was anticipated that the approach to these items would be more diverse than for other equipment. The responses confirm this to be the case for blockwork walls and piping; with around six different approaches being identified for each. For relays the responses indicated the use of either generic data, such as SQUG, or specific testing.

The response to the question on ageing was surprisingly mixed, given that most engineers would regard the condition of the plant as being important. It may be that any significant degradation is expected to be identified and rectified by other safety processes. Since ageing has been identified as a relevant issue by PWG 3, it would be appropriate to understand the position in regard to seismic re-evaluation more thoroughly.

Overall, the response to this section of the questionnaire has demonstrated that there is probably less consistency and consensus in the topic of assessment criteria than in most other areas of the re-evaluation process. It is therefore recommended that the group should address this area of the procedure, and this would make a very good subject for a workshop.

3.8 ASSESSMENT OF AS-BUILT SITUATION

In most cases the existing, or ‘as is’, condition of the plant is taken into account. In general both as-built drawings, recording the final construction details, and in situ inspection of the current condition of structures, systems and components are used in this process. The exception is Switzerland, where it is done only exceptionally. In general material properties are based on the original specifications although this is sometimes supplemented by in situ data or material files in Belgium, France, Sweden, Switzerland and the UK. In the USA actual data is the preferred option.

3.9 OUTCOME OF RE-EVALUATIONS

The outcome of the re-evaluation exercise is overwhelmingly considered to have been successful. The only country which qualified this conclusion is Sweden, where the exercise appears to have generated the need to consider a significant number of problems The USA intend to publish a NUREG to summarise the outcome of the IPEEE exercise. There appear to be many aspects where the ruggedness of plant has been improved as a result of the re-evaluation exercise. These include:

- Replacement of buildings which would be difficult to modify or the introduction of new buildings with equipment for all external events
- Strengthening of buildings
- General upgrading of structures and equipment
- Strengthening of masonry walls
- Improved anchorage/ equipment supports
- New mechanical systems
- Strengthening of cable trays and battery racks
- Piping support modifications
- Removal of seismic interactions

Most countries identified potential improvements for any future application of the re-evaluation process. The improvements identified include:

- Development of more rational hazard
- Development of the process for definition and identification of components to be reviewed
- More extensive training in assessment techniques
- Better balance between simple and complex structural models
- Better definition of criteria in general
- Improvement in fragility data
- Redefinition of the seismic hazard as a result of the PSA

Hence, although nearly all countries are satisfied with the evaluations which have been completed there are aspects identified which would benefit from further work. More detailed exchanges on these topics would help to identify any aspects of common interest which might be progressed on a joint or co-operative basis. In addition an extensive amount of modification has been carried out as a result of the re-evaluations and it may be that further insights on the detail of these may be helpful for future re-evaluations

3.10 RESEARCH

There is widespread recognition of the need for potential improvement of re-evaluation methods, but only eight of the thirteen responding countries reported that research was in hand or planned for the future.

Taking into account the perceived need to improve re-evaluation methods, the relative paucity of reported research is perhaps a reflection of the specific detail of the questions asked in the survey. It is certainly apparent that there is much more important research which is being carried out, or is planned, than has been reported in response to the questionnaire, presumably because the particular research was not categorised as being specific to the re-evaluation process. In many cases, however, this research will have some significance for re-evaluation studies. For example, large-scale testing in Japan, particularly those involving fragility testing, will lead to improved understanding of failure modes and more realistic capacity assessment for use in the re-evaluation methods, such as margins and PSA.

Considering the responses to sections 3.9 and 3.10 together it appears that there may well be a benefit in the Seismic Sub Group giving further consideration to research into how the relevant methods and aspects of seismic re-evaluation might be improved, and this should therefore be included in a workshop on re-evaluation.

3.11 OTHER TOPICS

Although the peer review process was not identified as a specific topic in the questionnaire, and therefore in the review of responses, it is evident this is a major element in the re-evaluation process. Many of the methods that have necessarily been adopted in the development of re-evaluation procedures require the application of considerable engineering judgement, and this in turn means that peer review is essential to the successful application of those methods.

This also raises the question of the qualification of experts, particularly in specialist fields, whose opinion may be vital. It is therefore recommended that the complete subject of peer review and the qualification of experts is the subject of future group discussions or a workshop.

4. CONCLUSIONS AND RECOMMENDATIONS

The responses to the questionnaire clearly identify a number of important points in relation to the position of seismic re-evaluation in the nuclear power industry throughout the world. Some of the most significant conclusions arising from the current survey of member countries are summarised as follows:

- Seismic re-evaluation is a mature process that has been developing in all of those countries responding to the questionnaire for some time.
- Seismic re-evaluation is carried out for various objectives:
    - to establish a seismic capability for older plant which had no seismic capability included at the design stage
    - to establish a seismic capability for older plant, following revisions to codes and standards
    - to establish a seismic capability for older plant, following a reassessment of the seismic hazard
    - as part of the periodic review process for established plants
    - to obtain a better understanding of the beyond design basis behaviour (i.e. severe accident analysis)
    - as an aid to estimating seismic risk.

  There is therefore a diverse range of approaches adopted, depending on which of the above objectives is intended and other considerations for any specific range of plant. It is concluded therefore that this report provides valuable insights for anyone developing a seismic re-evaluation programme (such as in Eastern European countries), to improve the effectiveness, both technically and commercially, of current programmes and provides information which may be taken into account by IAEA when considering guidance documentation.

- Although formal guidelines and regulations have not been established in most countries, the re-evaluation process is proceeding with a disciplined approach in all cases. Also, most countries are adopting practices that are essentially similar in many ways, often according to principles first established in the US nuclear industry.
- The process of carrying out a major re-evaluation typically takes 2 - 3 years to complete at a cost of approximately $US 1 million for software alone. Although the re-evaluation process is generally repeated at approximately ten year intervals, the majority of these regular assessments do not involve a major re-evaluation, and can usually be completed in less time and at a lower cost.
- Several different re-evaluation methods are employed in practice, including PSA, margins and deterministic analysis. A seismic walkdown is a key feature of re-evaluation in most countries, usually based on the SQUG criteria, or similar.
- Input motion levels, seismic categorisation, analysis methods and assessment criteria applied in re-evaluation are generally similar to those specified for new plant, ensuring that similar standards of seismic resistance are available for plants of all ages. To understand plant behaviour for severe accidents or risk estimates, more realistic criteria are used.
- All responding countries take account of the as-built situation, and the majority of countries include in situ inspection as part of this process. Most countries rely on the original specification for material properties rather than in situ evaluation.
- Although nearly all countries are satisfied with the evaluations which have been completed to date, several aspects of the process are identified which might be improved in the future. These include:

- Suitable hazard definition
- Improvement in fragility determination
- Improvement in equipment selection
- Overall methods and criteria, including selection of structural models

- The amount of modification carried out as a result of the re-evaluations can be extensive, including strengthening of buildings, walls, anchorages and equipment/pipework supports, and the removal of seismic interactions
- The physical modifications resulting from the re-evaluation have led to significant improvements in the seismic ruggedness of older plant in most countries.
- A majority of countries reported that they were engaged in, or were planning, research focused on re-evaluation. There is, however, considerable additional seismic research activity, which was not identified in the responses received for this report, but which has a direct bearing on the re-evaluation process. This will lead to an improved understanding of failure modes and more realistic capacity assessment. Future research should also be the subject of group discussions or a workshop.
- The peer review process has been identified as a major element in the re-evaluation process. The methods that have generally been adopted in the development of re-evaluation procedures involve a considerable amount of engineering judgement, meaning that peer review is essential in the application of these methods. The qualification of experts is also an important aspect of this process, particularly in specialist fields. It is therefore recommended that the complete subject of peer review and the qualification of experts is the subject of future group discussions or a workshop.

This study suggests that there are several areas of the seismic re-evaluation process which could be considered in the future for the mutual benefit of the member countries. These include:

- The pursuit of a more detailed understanding of the benefits and disadvantages of the various methods of re-evaluation in particular circumstances
- The definition of the scope of plant to be selected for the re-evaluation process, including the consideration of secondary hazards induced by the seismic event
- Definition of the criteria for re-evaluation, including hazard and fragilities, and their relation to overall reliability
- The role and scope of the peer review process, together with the qualification of experts in specialist fields
- The strengthening of plant
- The incorporation of operational and research data/experience into the re-evaluation process
- Identification of areas of new research that could provide benefits and improvements for the re-evaluation process

It is recommended that the Seismic Sub Group should consider the best means to promote progress on the above items, possibly through a Specialists Meeting or Workshop.

5. REFERENCES

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ABBREVIATIONS

ACI	American Concrete Institute (US)
AECB	Atomic Energy Control Board (Canada)
AECL	Atomic Energy of Canada Ltd (Canada)
AGR	Advanced Gas Cooled Reactor
ANL	Argonne National Laboratory (US)
ANPA	National Agency for Environmental Protection (Italy)
ASAR	As Operated Safety Analysis Report
ASCE	American Society of Civil Engineers (US)
ASME	American Society of Mechanical Engineers (US)
BE	British Energy plc (UK)
BNL	Brookhaven National Laboratory (US)
BWR	Boiling Water Reactor
CDFM	Conservative Deterministic Failure Margin
CEA	Commissariat à l'Energie Atomique (France)
CEC DG XI	Commission of the European Communities, Directorate General XI (EC)
CEN	Comité Européen de Normalisation (European Committee for Standardisation)
CSN	Consejo de Seguridad Nuclear (Spain)
EC	European Commission
EDF	Electricité de France (France)
EPRI	Electric Power Research Institute (US)
FBR	Fast Breeder Reactor
GCHWR	Gas Cooled Heavy Water Reactor
GCR	Gas Cooled Reactor
GIP	Generic Implementation Procedure
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit mbH (Germany)
HCLPF	High Confidence Low Probability of Failure
HSK	Hauptabteilung für die Sicherheit der Kernanlagen (Switzerland)
HTGR	High Temperature Gas Cooled Reactor
HWLWR	Heavy-Water/Light-Water Reactor
IAEA	International Atomic Energy Agency

IEEE	Institute of Electrical and Electronics Engineers Inc.
INITEC	Empresa Nacional de Ingenieria y Tecnologia (Spain)
IPEEE	Individual Plant Examination of External Events
JRC Ispra	Joint Research Centre (EC)
KAERI	Korea Atomic Energy Research Institute (Korea)
KINS	Korea Institute of Nuclear Safety (Korea)
LMFBR	Fast Breeder Reactor
LMGMR	Liquid Metal Cooled, Graphite Moderated Reactor
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
NEA	Nuclear Energy Agency (OECD)
NEL	Nuclear Electric Ltd (UK)
NII	HM Nuclear Installations Inspectorate (UK)
NRC	Nuclear Regulatory Commission (US)
NRI	Nuclear Research Institute (Czech Republic)
NUPEC	Nuclear Power Engineering Corporation (Japan)
OBE	Operating Basis Earthquake
OECD	Organisation for Economic Co-operation and Development
OHN	Ontario Hydro (Canada)
OSE	Operational Shutdown Earthquake
PHWR	Pressurised Vessel Heavy Water Reactor
PLWBR	Pressurised Light-Water Breeder Reactor
PRA	Probabilistic Risk Assessment
Preag	PreussenElektra AG (Germany)
PSA	Probabilistic Safety Assessment
PSHA	Probabilistic Seismic Hazard Analysis
PWR	Pressurised Water Reactor
RCS	Reactor Cooling System
RLE	Review Level Earthquake
SEP	Systematic Evaluation Program
SKI	Statens Karnkraftinspektion (Sweden)
SME	Seismic Margin Earthquake
SNL	Scottish Nuclear Ltd (UK)
SONS	State Office for Nuclear Safety (Czech Republic)

SQUG	Seismic Qualification Utilities Group (US)
SSC	Structures, Systems and Components
SSE	Safe Shutdown Earthquake
SSI	Soil-Structure Interaction
SSN	Servizio Sismico Nazionale (Italy)
SSSI	Structure-Soil-Structure Interaction
SUJB	State Office for Nuclear Safety (Czech Republic)
UHS	Uniform Hazard Spectra
UK	United Kingdom
UNESA	Union Electrica-Fenosa SA (Spain)
URS	Uniform Risk Spectra
US	United States
USI	Unresolved Safety Issue
VE	Vattenfall Energisystem (Sweden)
ZPA, zpa	Zero Period Acceleration