SEISMIC SAFETY OF NUCLEAR POWER PLANTS IN EUROPE AND THE MEDITERRANEAN REGION AT LARGE

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ABSTRACT

Nations that have launched large-scale electro-nuclear programs (such as the United States and France), in conjunction with the International Atomic Energy Agency (IAEA), have both implemented research & development programs targeting the reliable evaluation of seismic hazard and drawn up regulatory documents making use of the knowledge gained. Other countries envisioning a move towards nuclear electric technology have the opportunity of benefiting from the experience already acquired by the aforementioned countries, notably in this critical area. As the nuclear industry is not currently in a phase of expansion, most of the case studies for which IAEA expertise is sollicited concern plants undergoing a reassessment procedure, particularly in Eastern Europe. The prime motivation for this has been the need to ascertain how well the criteria and standards underlying the seismic safety of such facilities measure up to those generally accepted in international practice.

INTRODUCTION

The seismic safety of nuclear installations has become a subject of concern for various national and international institutions, notably the International Atomic Energy Agency (IAEA). The first countries to make extensive use of atomic energy to generate electricity (the United States and France, in particular) have, over past decades, been conducting research and development work aimed at gaining a better understanding of seismic hazard, in order to establish methods of seismic protection and to define criteria and standards.

Seismic safety issues generally involve two major components: those related to the derivation of design-basis parameters and those concerning the seismic capacity of structures, equipment, and distribution systems. The various steps entailed in evaluating seismic hazard result in determining levels of seismic reference motion to be taken into account in the anti-seimsic design of facilities. Although the first countries to develop nuclear power technology have codified their own regulations in this field, IAEA, in the framework of its own program (IAEA Safety Codes & Guides, NUSS program), has issued guides to aid in ensuring seismic safety, notably 50-SG-S1 (Rev. 1), which deals specifically with determining seismic motion. The guide specifies the stages of a procedure that defines two levels of reference motion, termed *SL1* and *SL2*.

A key element, fundamental to such an evaluation, is the compilation of exhaustive and uniform data in geology, in historical (particularly in Old World countries) and instrumental seismicity, in geophysics, and in any other branch of earth science capable of affording insight in the matter. The IAEA guide emphasizes the necessity of having the data be uniform, sanctioned by quality assurance, so a seismotectonic model can be elaborated for the region under investigation.

Under the aegis of the IAEA, a working group was formed in 1988, composed of representatives of countries around the Mediterranean basin; it has been endeavoring to establish the status of existing data and to make sure these are processed in a uniform fashion. This working group lays the groundwork for fruitful contacts between countries already experienced in this field and others that are only now embarking upon the siting process of a nuclear facility.

The proximity of an active, or worse yet, of a *capable* fault (one liable to generate surface rupture in the event of an earthquake) is highly prejudicial to the siting of a nuclear facility. In order to establish whether such a fault is present on a given site, various techniques in geology and seismology, as well as other branches of geophysics, are called on. The installation and operation of a seismic monitoring network centering around a postulated site, as recommended by IAEA (cf. "Application of Microearthquake Surveys in Nuclear Power Plant Siting" - IAEA-TECHDOC-343), constitutes an excellent framework for bipartite cooperation. An instance of such a cooperation is one between France's Institut de Protection & de Sûreté Nucléaire (IPSN) and the Tunisian utility, Société Tunisienne d'Électricité & du Gaz (STEG). IPSN has taken an active part in the interpretation of the results obtained by the network and has provided specialized training for some STEG personnel in this area.

The seismic safety of nuclear power plants in Eastern Europe has been the object of renewed attention in the wake of the recent political and social changes. The primary motivation for this has been the need to compare the criteria, standards, and methods underlying seismic safety in Eastern European nuclear power plants with those generally accepted in international practice. Seismic hazard assessment has been recently at issue at most of the sites because of the differences in the methods employed when the site investigations were being carried out prior to construction. Although most Eastern European nuclear power plant sites can be rated as low-to-medium seismicity sites, deficiencies in the tectonic and seismic data base as well as in the methods used in the 1970's have given rise to hazard re-evaluation programs. The results of the new studies consistently indicate that the design-basis ground motion parameters had been underestimated, sometimes by a considerable margin.

The involvement of IAEA and its experts from member states in the seismic safety issues of Eastern Europe has been substantial through national, regional, and extra-budgetary projects. Seismic safety review missions have visited nuclear power plants in Armenia, Bulgaria, the Czech Republic, Hungary, Poland, the Russian Federation, Slovakia, Slovenia, and Ukraine within the past five years. The experience of these five years has recently been channeled into a Coordinated Research Program entitled "Benchmark Study for the Seismic Analysis and Testing of WWER-type Nuclear Power Plants." The program has twenty-three participating institutions from fifteen countries and concentrates on WWER-440/213 and WWER-1000 plants. Paks Nuclear Power Plant in Hungary and Kozloduy Nuclear Power Plant (Units 5/6) in Bulgaria are prototype plants for this project. Tables 1 and 2 present general and seismic characteristics, respectively, for nuclear power plants in Eastern Europe.

Certain other countries have initiated nuclear projects that are scheduled to begin operation by the end of the century or shortly thereafter. These countries - Portugal, Morocco, Tunisia, Pakistan, and Indonesia, among others - have likewise profited from close cooperation with IAEA and its experts. The data collection effort, but also the exchange of knowledge and working procedures in the area of seismic risk assessment, not only lay a reliable groundwork for the nuclear projects directly concerned, but furthermore are of value to urban planners in protecting cities and populations in the event of earthquake. Concretely, they contribute such basic tools as historical earthquake catalogues, seismotectonic zoning studies, regional attenuation laws, and microzonation maps.

The purpose of this paper is to provide an overview of the various programs initiated by IAEA and experts from member states that deal with the seismic safety of existing and future NPP's, notably in Eastern Europe and Mediterranean countries.

SEISMIC SAFETY REVIEW SERVICES

Member states can obtain the advice of interdisciplinary teams of independent experts on site and safety aspects of planned or existing nuclear power plants (NPP's). Site safety and external hazard reviews may cover a broad range of disciplines - for example geology, seismology, hydrology, vulcanology, meteorology and tectonics - and the teams also look into such matters as the local population distribution and the impacts of possible man-induced events (e.g. an aircraft crash). When the focus is on the assessment of the seismic capacity of the plant, the review team includes experts in structural mechanics with experience of seismic plant walkdowns and the design of NPP structure, system, and component upgrades to resist seismic effects.

As only a few sites are at present being investigated with a view to the construction of new NPP's, the requests made by member states in recent years have been mainly for reassessments of the safety of existing plants. In particular, the Secretariat has been receiving requests for seismic safety review missions to the sites of WWER-type NPP's (see Table 3). These reviews focus on two major aspects, i.e. the adequacy of the design-basis seismic input and the seismic capacity of the plant structures, equipment, and distribution systems. For Eastern European nuclear power plants, it was established that the original design-basis seismic input values were consistently underestimated.

Another conclusion which has emerged from such missions is that WWER-440/230 and 440/213 plants (and also RBMK plants) do not have inherent structural resistance to the types of loads associated with earthquakes (and with similar external events). This is due to the fact that in such plants only the pressure boundary (i.e. the equipment that operates under pressure) is designed to withstand extreme loads; the superstructures housing the reactor, turbines, and emergency diesel generators are designed as normal industrial buildings with large spans and very little cross-bracing to take lateral (i.e. earthquake-induced) loads and are constructed in such a way that they have relatively low ductility. When the re-assessed seismic design basis acceleration is low (e.g. ~ 0.1g), minor structural strengthening may be sufficient; when it is even only slightly higher (0.2-0.3g), however, complex and expensive structural upgrading becomes necessary.

Following seismic safety review missions, the seismic upgrading of structures, systems, and components at the Kozloduy NPP (Bulgaria), the Bohunice NPP (Slovakia), and the Paks NPP (Hungary) is under way. In Armenia, the geological and seismic hazards associated with the site of the Medzamor NPP, shut down after the 1988 Spitak earthquake, are being re-assessed. As to the NPP's not of Soviet design, seismic upgrading is in progress at the Karachi NPP, Pakistan, which went into service in 1972. Also in Pakistan, a seismic design review is being conducted of the Chinese-designed 300-MW(e) NPP under construction at Chashma, use being made of the experience gained in seismic reassessments of various existing NPP's.

BENCHMARK STUDY FOR THE SEISMIC ANALYSIS AND TESTING OF WWER-TYPE NPP'S

An overview of a procedure which is recommended to assess and enhance the seismic capacity of existing WWER reactors is provided. The major focus of this procedure is to make a cost-effective process available which will allow needed modifications to be prioritized and implemented in a timely manner, using the realistic assessment of responses and capacities. Major technical elements of this procedure are:

1) The identification of the most critical systems, components, and structures needed for safe shutdown and to maintain safe shutdown;

2) The evaluation of as-built conditions through data-gathering activity such as review of design drawings and construction specifications and detailed walkdown;

3) Realistic assessment of plant response and capacity evaluations for developing acceptance criteria and designing cost-effective fixes; and

4) Functional qualification of active mechanical and electrical components through use of generic test data applicable to all WWER's, plant-specific tests and earthquake experience data.

This procedure is sub-divided into three major categories: equipment, structures, and distribution systems, for prioritizing design and implementation of needed fixes. Some fixes, such as anchorage upgrades, are easily identifiable and could be designed for conservative seismic demand. This demand would be confirmed after a detailed plant response analysis is completed. Other fixes involving major structural elements or complex load paths would necessitate realistic response evaluations as well as capacity evaluation to design cost-effective fixes. The aim of the assessment is to show that the plant can withstand a Level SL2 earthquake without giving rise to a Level V accident (on the INES Scale). This will be interpreted as ensuring that service condition D (as defined by ASME), or the equivalent, is not exceeded. If this is not possible, modifications will be identified that, when implemented, will prevent the occurrence of the Level V accident. It should be noted that a Level V accident is defined as an "accident with off-site risk."

After identification and classification of systems to be considered, the seismic input, soil data, acceptance criteria and loading combinations are established. Considerable effort and decision-making is required to arrive at this point. In general, the seismic input is determined using the principles and methods established for new sites and plants (see e.g. IAEA 50-SG-S1, Rev. 1991). The only difference might be due to the "lifetime" of the plant when the input is calculated on a probabilistc basis. This is generally shorter for existing plants (if life-extension is not envisaged) and may lead to somewhat lower design values. The major difference with the seismic design of a new plant would be related to acceptance criteria, which would make use of existing safety margins to the fullest extent possible. Beyond the evaluation of the situation and setting up of criteria, the methodology is specific depending on the plant item in question, i.e. structures, distribution systems, and equipment.

Special emphasis is placed on the "easy-fixes" resulting from the structural evaluation of distribution systems and equipment, which, when implemented, may increase seismic safety most cost-effectively. This has already been observed in the seismic upgrading of the Kozloduy NPP, Units 1-2, for which IAEA has provided continuous support through review services, including the preparation of the Terms of Reference (TOR) for the seismic upgrading program. The TOR specifies four phases for the seismic upgrading of the Kozloduy NPP, Units 1-2, each phase increasing the safety level by implementation of "easier" fixes and assessing the seismic capacity of more complex items systematically. This eventually leads to the attainment of the seismic safety goal within a specified time frame.

For the Paks NPP, a Terms of Reference document has recently been prepared with the objective of unifying the acceptance criteria. The first step of the phased upgrading program comprises the so-called "easy fixes." These were identified using the following criteria:

1) The item must be fixed to ensure the required margin;

2) The technical solution and cost of the fixes should depend only slightly on the limited variation of the earthquake level;

3) The fixes should be relatively easy to carry out and capable of being effected during planned outages.

The actual benchmarking of analysis and testing is mainly envisaged for structural systems in the beginning of the project.

Full-scale dynamic testing of the reactor structures of both the Kozloduy (Unit 5 or 6) and Paks (Unit 1, 2, 3 or 4) Nuclear Power plants has been slated for the period 1994-1995. Although some testing has already been performed on these structures on previous occasions, a more systematic and integrated approach to testing is envisaged for the benchmark study. Preparations for full-scale dynamic testing of the Paks NPP are currently under way.

The Coordinated Research Program on the benchmark study involves twenty-three institutions from fifteen countries. This is a three-year program initiated in 1993. Two research coordination meetings have been held so far, the first at the Paks NPP in September 1993 and the second at the Kozloduy NPP in June 1994.

Table 1. Nuclear power plants in Eastern Europe (selected).

Plant	*Country*	*No. of Units*	*Power/Type*	*Status*
Kosloduy	Bulgaria	4	440/230 WWER	In operation
Kosloduy	Bulgaria	2	1000 WWER	In operation
Belene	Bulgaria	2	1000 WWER	Construction stopped
Cernavoda	Romania	4	660 Candu	Under construction
Krsko	Slovenia	1	630 PWR	In operation
Paks	Hungary	4	440/213 WWER	In operation
Bohunice	Slovakia	2	440/230 WWER	In operation
Bohunice	Slovakia	2	440/213 WWER	In operation
Mochovce	Slovakia	2	440/213 WWER	Under construction
Dukovany	Czech Republic	2	440/213 WWER	In operation
Temelin	Czech Republic	2	1000 WWER	Under construction
Medzamor	Armenia	2	440/230 WWER	Construction stopped

Table 2. Seismic design basis (*SDB*) for NPP's in Eastern Europe (selected).

Plant	*Original SDE (PGA)*	*Re-assessed SDB (PGA)*	*Upgrading Status*
Kozloduy	No explicit design	0.2 g	Continuing in first four units
Bohunice	No explicit design	0.25 g (continuing)	Continuing
Mochovce	0.05 g	0.1 g (continuing)	Continuing
Belene	0.1 g	Continuing	Continuing
Cernavoda	0.15 g	No re-assessment	Continuing
Paks	No explicit design	0.35 g (continuing)	Continuing
Krsko	0.3 g	Continuing	Continuing
Temelin	0.06 g	0.1 g	Continuing
Medzamor	0.1 g	0.4g (continuing)	Continuing

Table 3. Engineering safety review services related to site and external hazards:

S	Review of site investigations for all disciplines involved.
S-F	Follow-up mission of previous reviews of site investigations
SI	Review of investigations for determining the seismic input parameters specific to the site
SI-F	Follow-up mission of previous reviews of seismic input definition
SC	Review of seismic capacity and necessary upgrading of systems, structures, and components (SCC) of the plant
SC-F	Follow-up mission of previous reviews of seismic capacity and upgrades of SSC
W	Workshop
WP	Review of work plans and technical procedures for the site and seismic safety assessment
B	Activities related to benchmark project for seismic safety of WWER-type NPP's.

No.	*Type*	*Country*	*NPP/Location*	*Date*	*Plant Type*
			Year 1989		
1	S	Iraq	Site survey	February 89	–
2	S	Tunisia	Site survey	April 89	–
3	S	Indonesia	Muria	May 89	(not defined yet)
4	S	USSR	Gorki DHP	June 89	
5	S	Morocco	Sidi Boulbra	December 89	–
			Year 1990		
6	S	Poland	Zarnowiecz	March 90	–
7	S	CFSR	Temelin	April 90	WWER-1000
8	S	Iraq	Near Tikrit	May 90	–
9	S	Bulgaria	Belene	June 90	WWER-1000
10	S	Bulgaria	Kozloduy	June 90	WWER-440/230-1000
11	SC	Romania	Cernavoda	September 90	PWR 600
12	S	Pakistan	Chashma	November 90	PHWR 300
13	SC	Romania	Cernavoda	December 90	PHWR 600
			Year 1991		
14	S	Indonesia	Muria	January 91	(not defined yet)
15	S	Slovenia	Krsko	March 91	PWR 600
16	SC	Bulgaria	Kozloduy	April 91	WWER-440/230
17	W	Bulgaria	Kozloduy	May 91	WWER-440/230
18	S	Tunisia	NPP site survey	May 91	–
19	S	USSR	Crimea	June 91	WWER-1000
20	W	Romania	Cernavoda	September 91	PHWR 600
21	W	CSFR	Temelin	September 91	WWER-1000
22	SC	CSFR	Bohunice	September 91	WWER-440/230
23	S	Tunisia	Site survey	November 91	–
24	WP	Indonesia	Muria	December 91	(not defined yet)
25	WP	CSFR	Temelin	December 91	WWER-1000

Table 3 (cont.).

No.	*Type*	*Country*	*NPP/Location*	*Date*	*Plant Type*
			Year 1992		
26	SI	Bulgaria	Kozloduy	February 92	WWER-440/230
27	W-WP	Slovenia	Krsko	March 92	PWR 600
28	SI	Bulgaria	Kozloduy	April 92	WWER-440/230
29	SC-F	CSFR	Bohunice	May 92	WWER-440/230
30	SI-SC	Armenia	Medzamor	May 92	WWER-440/230
31	S-F	CSFR	Temelin	June 92	WWER-1000
32	W-S	Malaysia	Site survey	June 92	–
33	SC	Bulgaria	Kozloduy	August 92	WWER-440/230
34	SC	Pakistan	Chashma	August 92	PWR 300
35	S	Indonesia	Muria	September 92	(not defined yet)
36	SI	Slovenia	Krsko	October 92	PWR 600
37	S-F	Indonesia	Muria	November 92	(not defined yet)
38	SC	Bulgaria	Kozloduy	November 92	WWER-440/230
39	S	Tunisia	Site survey	December 92	–
			Year 1993		
40	S-WP	Indonesia	Muria	February 93	(not defined yet)
41	SI-F	Bulgaria	Kozloduy	February 93	WWER-1000, 440/230
42	SC	Pakistan	Chashma	March 93	PWR 300
43	S-F	Czech Republic	Temelin	April 93	WWER-1000
44	SC-F	Slovakia	Bohunice	April 93	WWER-440/230
45	S-MP	Indonesia	Muria	April 93	(not defined yet)
46	W	Pakistan	Chashma	May 93	PWR 300
47	SC	Pakistan	Kanupp	May 93	PHWR
48	S	Croatia	Site survey	June 93	–
49	SC	Russian Fed.	Smolensk	June 93	RBMK
50	W	China	(generic)	July 93	–
51	S-F	Indonesia	Muria	July 93	(not defined yet)
52	SI-B	Hungary	Paks	September 93	WWER-440/213
53	WP	Armenia	Medzamor	August 93	WWER-440/230
54	SI	Bulgaria	Belene	September 93	WWER-1000
55	SI	Slovakia	Bohunice	October 93	WWER-440/230-213
56	SI	Slovakia	Mochovce	October 93	WWER-440/213
57	SI-WP	Armenia	Medzamor	November 93	WWER-440/230
58	S	Indonesia	Muria	November 93	(not defined yet)
59	S	Morocco	Sidi Boulbra	November 93	–
60	SC	Hungary	Paks	December 93	WWER-440/213
61	SC-F	Pakistan	Chashma	December 93	PWR 300
62	W	Turkey	Akkuyu	December 93	(not defined yet)