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Full Length Research Paper

Seismic hazard and deaggregation assessment at the nuclear power plants (NPP) sites in Spain using an updated seismological database

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In this paper we present the results obtained in the seismic hazard reassessment at the sites, in the free field, of the seven Spanish nuclear power plants (NPPs), six of them are still operative till date. The computation was done using the spatially-smoothed seismicity approach, and an updated seismic catalog. In most cases, the results do not greatly differ from those previously reported. In addition, at two of these locations where the hazard levels were higher, we carried out a seismic deaggregation study. We were thus able to determine the characteristics of the seismicity responsible for seismic hazard in terms of distance, magnitude and azimuth. The results obtained show that seismic hazard at the Cofrentes NPP is entirely due to close-range seismicity (< 70 km), whereas hazard at the Almaraz NPP is due to earthquakes located from 190 to 350 km away. A clear limitation of this work is the fact that we cannot include into our seismic hazard assessment, at this stage, paleoseismic information for the Spanish NPP sites.

Key words: Seismic hazard, deaggregation, nuclear power plant, operation basis earthquake, safe shutdown earthquake.

INTRODUCTION

Seismic hazard assessment procedures have evolved significantly since the building of the first generation of Spanish NPPs began in the 1960s. We have moved from deterministic methods to both parametric and non parametric probabilistic calculation models. A probabilistic approach, initially proposed by Frankel (1995), has started to be widely used (*v.g.*, Frankel et al. (2000) in the US, Lapajne et al. (1997) in Slovenia, Peláez and López-Casado (2002) and Peláez et al. (2005) in Spain and Portugal, Stirling et al. (2002) in New Zealand, or Peláez et al. (2003, 2006) in Algeria). This approach attempts to combine the advantages of previous models, also taking implicitly into account the fractal characteristics of seismicity. This methodology, whose main attribute is that it spatially smooths the seismicity, not only decreases the epistemic uncertainty, due to incomplete knowledge and lack of data about the physics of the earthquake process, but it is also very suitable for the computation of the so-called seismic hazard deaggregation. We can therefore determine the characteristics of the seismicity causing the hazard at a particular place in terms of distance and magnitude, as well as in terms of azimuth, that is, in latitude and longitude.

By using this approach, together with an updated seismic catalog, we have been able to reevaluate seismic hazard in the whole of the Iberian Peninsula (Peláez and López-Casado, 2002), that is, Spain and Portugal, as well as seismic deaggregation studies at several interesting cities in this region (Peláez et al., 2002).

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Abbreviations: NPP, Nuclear power plant; **PGA,** horizontal peak ground acceleration; **OBE,** operation basis earthquake; **SSE,** safe shutdown earthquake; **SME,** seismic margin earthquake; **RLE,** review level earthquake.

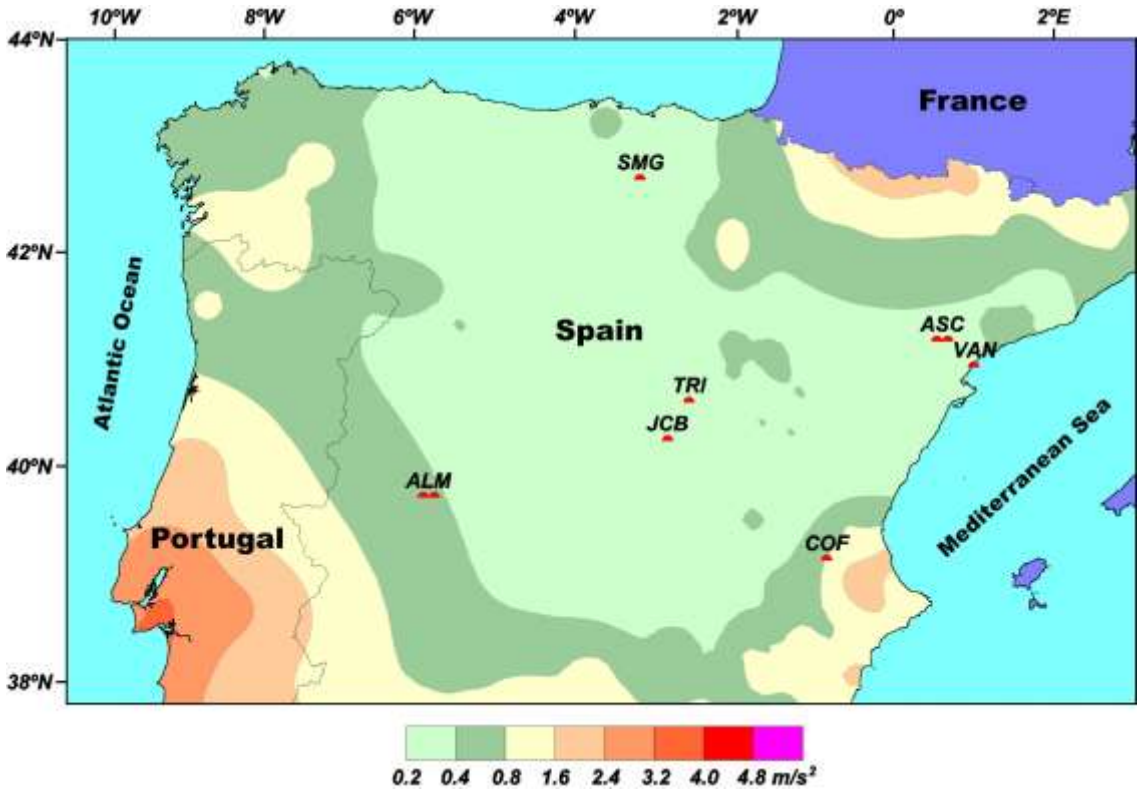

Figure 1. NPP sites in Spain (JCB was shut down in 2006). Background: Seismic hazard values for the area (mean *PGA*) with 10% probability of exceedance in 50 years (modified from Peláez and López-Casado, 2002).

Due to the importance of this type of works, particularly for sensitive facilities such as NPPs, we undertook this study, in which we present the results obtained in a new computation for the seven NPP sites, in the free field, in Spain (Figure 1). Other motivations were the newly employed approach and the recently improved and updated Spanish seismic catalog, covering in some cases more than three decades of seismicity than previously considered for the design of some of the NPPs. As we show, in most sites, the results do not differ significantly from those reported previously, which makes evident that all the NPPs were located in areas that can be considered of low seismic hazard level, that is, with expected mean horizontal peak ground acceleration (*PGA*) values below 0.08 g for a return period of 475 years. However, we should not forget the occurrence of historical destructive earthquakes that affected the areas around some of these locations.

In addition, we have carried out a seismic deaggregation study at the two sites whose computed seismic hazard values are higher, determining the relative contribution of the different seismic foci and sources to the seismic hazard and showing how different is the character of the seismicity affecting the hazard at these two NPPs.

We want to emphasize that the main limitation of our work, results and final discussion, is the fact that we can not include paleoseismic data in our assessment, as it is usual, when possible, in the seismic hazard characterization of NPP sites. Therefore, we have only taken into account a seismic database including the instrumental and the historical seismicity, just as it was done for the design of the original safety level earthquakes in the Spanish NPPs. The knowledge of active faults in Spain is far from being complete, and although systematic studies are starting to be carried out in some interesting areas, they are not complete enough yet to be included in probabilistic seismic hazard studies. In any case, the zones under study are located in tectonic and seismically active areas distant from the NPP sites. No active nor capable faults, nor significant seismogenic structures, have been identified in the near regional field for any of the NPP sites, as the safety standards advise (*v.g.*, IAEA, 2002).

METHODOLOGY

The used methodology to compute probabilistic seismic hazard, as was quoted previously, is the one proposed by Frankel (1995), although it had to be modified when taking into account the seismic characteristics of the Iberian Peninsula (Peláez and López-Casado, 2002). We have not included neither a characteristic earthquake

Table 1. Comparison between our results, those included in the Spanish Building Code (NCSE-02, 2004), and those selected for the SSE, OBE and SME (CSN, 1999; García-Monge et al., 2001).

NPP site	PGA		NCSE-02 (return period of 500 years) (g)	OBE (g)	SSE (g)	SME(g)
	475 years (g)	975 years (g)				
José Cabrera (JCB), 1968 (shutdown in 2006)	< 0.03	< 0.03	< 0.04	0.023	0.07	0.16
Santa María de Garoña (SMG), 1970	< 0.03	< 0.03	< 0.04	0.050	0.10	0.17
Vandellós II (VAN), 1987	< 0.03	0.04	0.04	0.100	0.20	0.30
Almaraz I and II (ALM), 1980, 1983	0.04	0.05	< 0.04	0.050	0.10	0.20
Ascó I and II (ASC), 1982, 1985	0.03	0.04	0.04	0.070	0.13	0.16
Cofrentes (COF), 1984	0.08	0.10	0.06	0.085	0.17	0.28
Trillo I (TRI), 1987	< 0.03	< 0.03	< 0.04	0.060	0.12	0.24

model, because in Spain we have insufficient paleoseismic information, nor a background area, because of the spatial quality, historical extension and completeness of our seismic catalog (Mezcua and Martínez-Solares, 1983; Martínez-Solares and Mezcua, 2002). As we quoted above, the knowledge of active faults in Spain is incomplete and, in any case, the significant active faults are too distant from the NPP sites. A major obstacle is the fact that there are few earthquakes directly associated to active faults that allow us to establish recurrence relationships for them. Concerning the use of a background zone, that is, a uniform area focused to seismic hazard analyses including all observed seismicity, we prefer to include in our assessments a threshold seismic hazard value which could be assigned to those areas not reaching it (Peláez and López-Casado, 2002). When using this approach, the background zone increases the seismic hazard in quiescent regions, but at the expense of decreasing seismic hazard values in seismically active regions.

The used approach is a probabilistic method based in the well known total probability theorem:

$$P(\zeta > y) = \int_{\tilde{x}} P(\zeta > y \,|\, \tilde{x})\; f_{\tilde{x}}(\tilde{x})\, d\tilde{x}$$

The exceedance probability of a given ground motion level y is computed by means of a multiple integral extended to all random variables which affect the results (usually, magnitude and distance). In the integral, f is the density function of probability and P the conditioned probability of exceeding y given a certain value for the intervening variables. The computation of this integral is not carried out as it is usual in the zonified method (Cornell, 1968) but as it is proposed by Frankel (1995). Moreover, seismic sources are defined as areas where b and m_{max} parameters of the Gutenberg-Richter relationship (Gutenberg and Richter, 1944) are constant, as in the zonified method, but seismicity is considered where it occurs. Used seismic sources can be consulted in Peláez and López-Casado (2002). In our assessment, we smooth the b and m_{max} parameters in each seismic source, following the procedure by Bender (1986).

This methodology considers seismicity where it occurs, just mentioned, but spatially smoothes it in order to include the uncertainty in the earthquake location, to consider that the rupture is not a point process, and to take into account the lack of data (incompleteness) in the seismic catalog. To perform the smoothing, a Gaussian function is used, depending on a spatial parameter c (correlation distance) that makes it more or less intense; each earthquake is spread into a circle with radius equal to 3c. The most important attribute of this Gaussian function is the fact that it preserves the total number of earthquakes after smoothing.

According to Frankel (1995), different seismic models are used to include the seismicity of the area in the assessment. These models are detailed below. The subjective weights which each model contributes are given according to the considered return period, assuming that the models covering a time interval comparable to the return period provide the most important contribution.

Initially, we use four seismic models including only shallow (< 30 km) seismicity: (a) earthquakes with magnitude above M_S 5.5 after 1300 (for this model, we use a c value equal to 15 km, contributing with a weight w equal to 0.4 in the evaluation of the seismic hazard for a return period of 975 years), (b) those with magnitude above M_S 4.5 after 1700 (in this case, c = 15 km and w = 0.2), (c) those with magnitude above M_S 3.5 after 1920 (c = 10 km and w = 0.2), and *d)* those with magnitude above M_S 2.5 after 1960 (c = 5 km and w = 0.2). Once we have the hazard generated by these four seismic models, computed weigthing the hazard results calculated separately, we add that generated by a seismic model that includes earthquakes from 30 to 60 km in depth with magnitude above M_S 2.5 after 1960 (c = 5 km). In order to establish these models, after removing all the non-Poissonian earthquakes identified by means of a cluster analysis, we studied the completeness and Poissonian character of the final catalog. Finally, the attenuation relationship regionalization proposed for the Iberian Peninsula by López-Casado et al. (2000) is adopted.

In order to compute the hazard from the total probability theorem, the region was divided into square cells with dimension 10 × 10 km. The exceedance probability of a given ground motion level is evaluated summing the contribution of all cells in the area. These are the same cells that are later used for the seismic hazard deaggregation process.

More details concerning data and methodology can be consulted in Peláez and López-Casado (2002).

RESULTS AND DISCUSSION

Table 1 shows the seismic hazard values specifically computed for the sites under study, expressed in terms of horizontal mean *PGA* for return periods of 475 and 975 years (10 and 5% probability of exceedance in 50 years, respectively). Besides, Figure 2 shows the seismic hazard curves for the four NPP sites with higher seismic hazard.

Concerning these curves, evidently, we cannot obtain reliable hazard results for return periods above 1000 years without including paleoseismic data in our

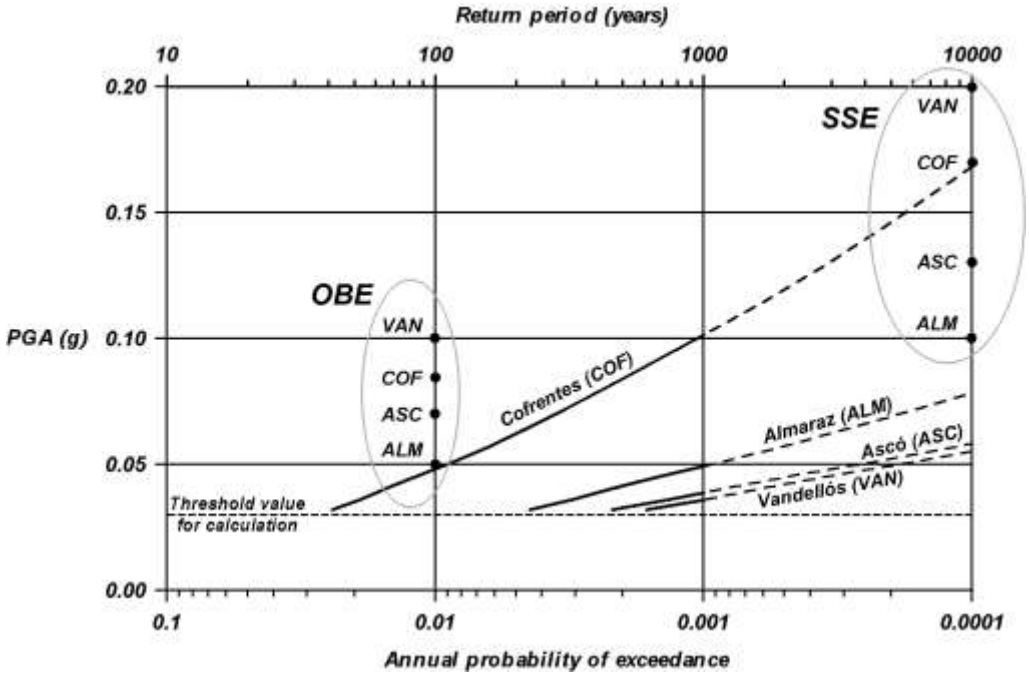

Figure 2. Seismic hazard curves for the Spanish NPP sites of Vandellós (VAN), Almaraz (ALM), Ascó (ASC) and Cofrentes (COF). We also include the values chosen for the SSE and OBE (CSN, 1999), considering the IAEA (2002, 2003*b*) standards.

assessment. This is due to the seismic model that covers the largest period embraces only 700 years. Therefore, we consider that results between annual probability of exceedance of 10^{-3} and 10^{-4} are not definitive, but an extrapolation of given values for return periods below 1000 years.

We can see in Table 1 that at four of the locations (JCB, SMG, VAN and TRI) the mean *PGA* value is lower than the threshold value for calculation (0.03 g) for a return period of 475 years. Even for a return period of 975 years, the values continue to be lower than the threshold at three of these locations (JCB, SMG and TRI). The highest seismic hazard value was obtained at the Cofrentes NPP site, where we found mean *PGA* values of 0.08 g for a return period of 475 years, and 0.10 g for 975 years. By using the Murphy and O'Brien (1977) relationship between macroseismic intensity and acceleration, just as a reference, we can state that these acceleration values could correspond to macroseismic intensities of approximately VI-VII and VII, respectively.

By comparison of these results with those appearing in the current Spanish Regulation for Seismic-Resistent Buildings (NCSE-02, 2004) (Table 1), we can see that there are some differences, particularly in the case of the Cofrentes NPP (0.08 versus 0.06 g for a return period of 475 years). The threshold for calculation of the Regulations' values was 0.04 g. Seismic hazard is lower than this threshold at five of the sites (JCB, SMG, VAN, ASC and TRI). At another location (ALM), it is 0.04 g, and slightly higher at the remaining one (COF). Our results are, in general, less conservative, with the exception of the Cofrentes site, where we also have derived higher seismic hazard values.

Given the low seismic hazard level in the region where the NPPs are located, it does not seem crucial whether a zonified/parametric probabilistic methodology (NCSE-02, 2004) or a mixed methodology (Peláez and López-Casado, 2002) is used. Figure 1 shows the locations of the NPPs within the context of seismic hazard values in the Iberian Peninsula.

A special comment should be made concerning the choice of the operation basis earthquake (OBE) and the safe shutdown earthquake (SSE), which corresponds respectively to SL-1 and SL-2 (safety level 1 and 2) earthquakes, according to the standards of the International Atomic Energy Agency (IAEA, 2000, 2002 and 2003*a*). SSE is associated with ultimate safety requirements, while OBE corresponds to a less severe, more probable earthquake level. Although there is no single criterion of choice for these two levels of seismic hazard, today in some countries (most states in the US, Switzerland, Brazil or Slovakia) they are usually taken to coincide with a mean *PGA* level with probability of exceedance of 10^{-2} and 10^{-4} per year (IAEA, 2002 and 2003b), respectively.

By accepting this standard, we can conclude that the levels for OBE and SSE are not only correct, but conservative (Table 1 and Figure 2), as it has been

Table 2. Seismic hazard deaggregation results. Computed controlling earthquakes.

NPP	Modal value		Average value	
	D (km)	M_S	D (km)	M_S
Almaraz I and II (ALM)	280-290	6.0-6.5	259	6.2
Cofrentes (COF)	30 - 40	5.5-6.0	33	5.6

previously pointed out by some authors (García-Monge et al., 2001), specially taking into account the seismic margin earthquake (SME) (Table 1). In some cases, such as the NPP at Vandellós, we can even say that they are even too much conservative. SME, also known as review level earthquake (RLE), is the ground motion level that compromises plant safety, that is, for all safety relevant components, the seismic adequacy is verified at least up to that SME.

We are confident about the obtained seismic hazard results for return periods below 1000 years, and therefore our comment on the SL-1 earthquake is totally justified. On the contrary, the fact that the results with probability of exceedance of 10^{-4} per year are an extrapolation, give us confidence about our opinion on the choice of the SL-2 earthquake, although without having full certainty.

Finally, we should mention the fact that the present standards of the Nuclear Regulatory Commission require that the SSE should never be less than 0.1g (USNRC, 1997a), which was not fulfilled by the José Cabrera NPP, that is, the first Spanish NPP which became operative. Since 2006, this NPP is definitively shut down.

As different authors have pointed out (*v.g.*, Chapman, 1995; Bazzurro and Cornell, 1999; Harmsen and Frankel, 2001), computations of seismic hazard deaggregation are necessary to perform a complete interpretation of seismic hazard results at any location. Indeed, they are now even being taken into account in some regulations (DOE, 1995; USNRC, 1997b; 1997).

The low seismic hazard values at most of the NPP sites, with values lower than the threshold value for seismic hazard computation, do not allow us to compute the deaggregation. The only exceptions are the results from the Almaraz and Cofrentes sites, where a higher level of seismic hazard was found.

The methodology used to calculate seismic deaggregation in magnitude and distance is that proposed originally by Bernreuter (1992) for computing the controlling earthquake, that is, the earthquake that would most severely affect a location in terms of magnitude *m* and distance *d* from a probabilistic point of view. In the seismic hazard assessment, we calculated the hazard separately in cells (Δd, Δm). Then, the final deaggregation result (Table 2) is shown either as the cell providing a maximum value ($\hat{M}$, $\hat{D}$) (modal value), or by obtaining the centroid of all the cells ($\overline{M}$, $\overline{D}$) (average value). In this last case using the equations:

$$\overline{M} = \frac{\sum_m \sum_d H_{md}\, m}{\sum_m \sum_d H_{md}} \qquad \log \overline{D} = \frac{\sum_m \sum_d H_{md} \log d}{\sum_m \sum_d H_{md}}$$

where *m* is the magnitude, *d* the distance, and H_{md} the contribution to the seismic hazard of the magnitude *m* (in fact, $m \pm \Delta m/2$) at a distance *d* ($d \pm \Delta d/2$) from the location (Bernreuter, 1992). The maximum values, instead of the modal ones, appear as more representative when applied either to the seismoresistant design, to the computation of the SSE or when considered in the characterization of a design spectra (Peláez et al., 2002).

The same cells and magnitude intervals used in the hazard computation are now also used to assess the deaggregation. This is computed by multiplying the relative contribution to the hazard of each cell by the weight assigned to each of the seismic models.

No matter which criterion is chosen, we can see that seismic hazard at the Cofrentes NPP is entirely caused by close-range seismicity, whereas at Almaraz it is mostly due to distant seismicity. This is much more evident by plotting the results for the geographic deaggregation (Figure 3) and for the deaggregation in terms of magnitude and distance (Figure 4).

The individual contributions of each cell used in the seismic hazard computation are plotted in Figure 3, expressed as a percentage of the total value of seismic hazard. In the case of the Cofrentes NPP, we detected a local seismic source as the clear cause of seismic hazard in this site. At Almaraz, different regional seismic sources were found, mainly in the central region of Portugal, whose total contribution gives us the seismic hazard level obtained in this site.

Figure 4 also shows the different contributions to hazard. In the case of Cofrentes, we can observe a single lobe whose maximum contribution lies between 10 and 70 km distance and M_S 4.5 - 6.5, whereas in the Almaraz site, the deaggregation in magnitude and distance shows two lobes. Their maximum contributions lie both approximately in the M_S 5.0 - 7.0 range, with one of them within 190 to 270 km away and the other one within 270 to 350 km. These deaggregation results remain constant even for the return period considered for the SL-2 earthquake, due to the fact that only the historic record has been used. Evidently, the addition of paleoseismic

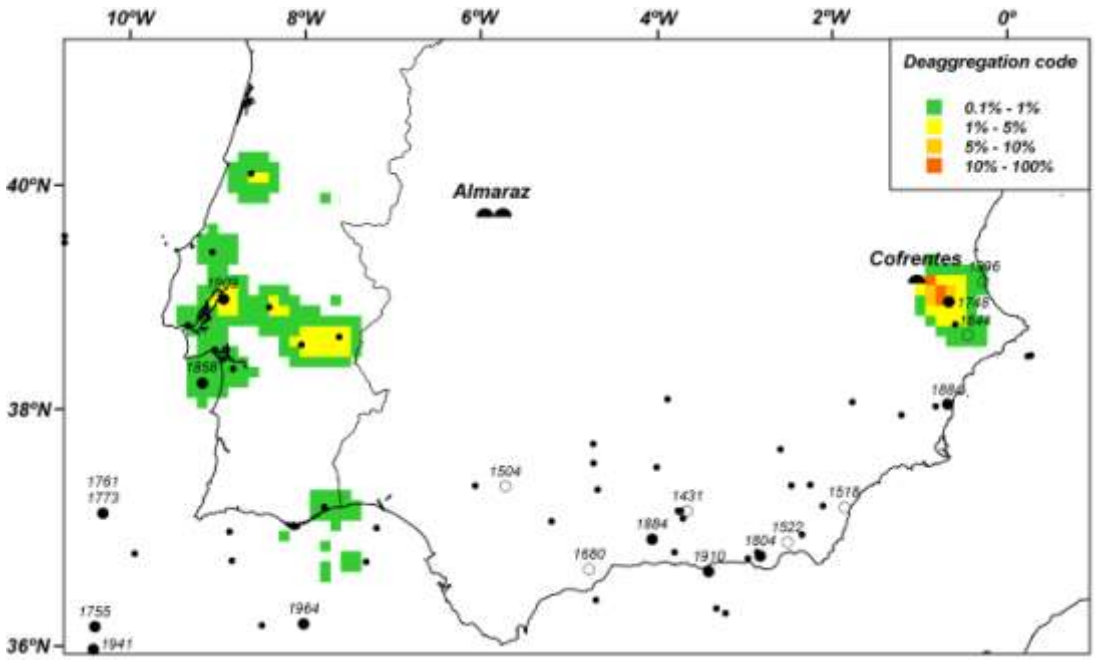

Figure 3. Joint deaggregation in azimuth for the NPP sites of Almaraz (left/west side of the graphic) and Cofrentes (right/east side). The most important earthquakes in the region are shown: $4.5 \leq M_S < 5.5$ (small filled circles) and $M_S \geq 5.5$ (large filled circles) earthquakes since 1700, and $M_S \geq 5.5$ earthquakes since 1300 (large open circles). Main earthquakes located in each deaggregation influence area are: 1396, Tabernes de la Valldigna (Spain), I_{MM} = IX; 1644, Muro de Alcoy (Spain), I_{MM} = VIII; 1748, Estubeny (Spain), I_{MM} = IX; 1858, Setubal (Portugal), I_{MM} = IX; 1909, Benavente (Portugal), I_{MM} = IX.

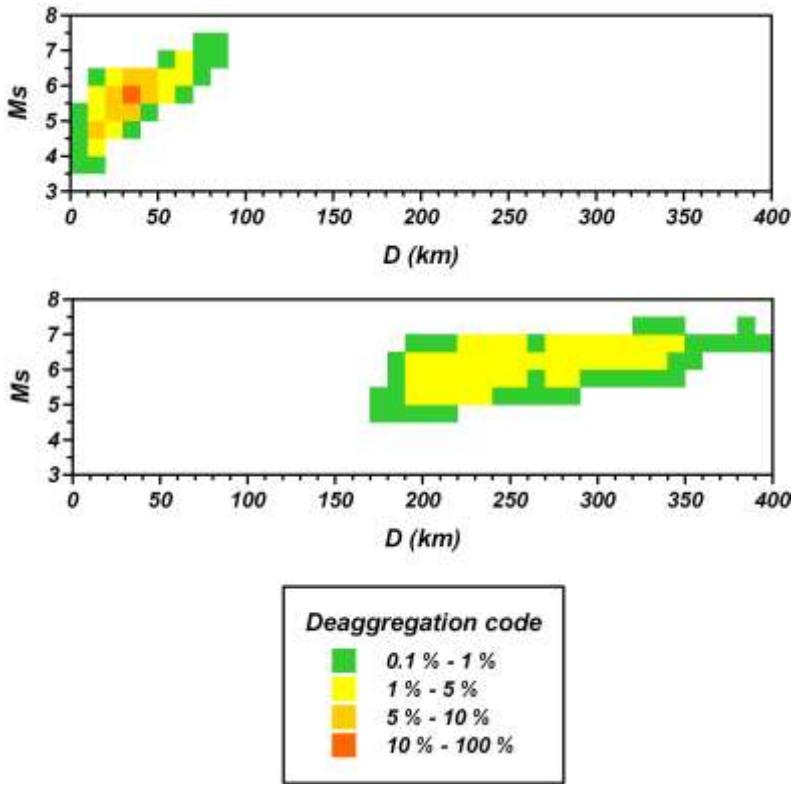

Figure 4. Deaggregation in magnitude and distance for the Cofrentes (top) and Almaraz (bottom) sites.

data through the earthquake characteristic model could change both the deaggregation and seismic hazard results.

Because of the scarcity of strong ground movements, computation of the SSE response spectrum on the basis of a standard spectrum, scaled according to the value of the estimated *PGA*, has been extensively used as an approximation in the design of NPPs (Cornell, 1970). In our case, this approximation does not seem to be suitable for both locations at the same time, because of the different characteristics of the seismicity affecting the hazard results.

Conclusion

We have reevaluated the seismic hazard at the locations, in the free field, of the NPPs in Spain using a methodology based on a spatial smoothing of seismicity. We have also used an updated seismic database, which, in some cases, represents more than three decades of seismicity beyond that taken into account for the design of some of the Spanish NPPs. The results obtained are somewhat different, although not drastically, from those calculated using parametric methodologies as accepted by the present Bulding Regulations in Spain. Both the seismic hazard and the later deaggregation results are clearly limited by the fact that only the historical and instrumental record can be used in seismic hazard studies in Spain.

In view of the results, the value chosen for the OBE and SSE in most of the NPPs seems to be very conservative, especially considering the SME values, although in the case of the Cofrentes NPP site, it is affected by a higher level of seismic hazard.

Finally, at the two locations where the highest hazard was obtained, we carried out a seismic deaggregation study. As a result, we found that the seismic hazard at one of these locations is dominated by local earthquakes (< 70 km) whereas, at the other, hazard is caused by seismicity occurring beyond 200 km from the site.

The type of analysis reported here should be a key aspect when computing new realistic design response spectra, in particular, the spectra defining the OBE and SSE (OBE/SSE Ground Response Spectra, or In-structure OBE/SSE Response Spectra).

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REFERENCES

Bazzurro P, Cornell CA (1999). Disaggregation of seismic hazard. Bull. Seism. Soc. Am., 89: 501-520.

Bender B (1986). Modeling source zone boundary uncertainty in seismic hazard analysis. Bull. Seism. Soc. Am., 76: 329-341.

Bernreuter DL (1992). Determining the controlling earthquake from probabilistic hazards for the proposed Appendix B. Lawrence Livermore National Laboratory Report UCRL-JC-111964.

Chapman MC (1995). A probabilistic approach to ground-motion selection for engineering design. Bull. Seism. Soc. Am., 85: 937-942.

Cornell A (1968). Engineering seismic risk analysis. Bull. Seism. Soc. Am., 58: 1583-1606.

Cornell A (1970). Design seismic inputs, *in* Seismic design for nuclear power plants (Hansen RJ, ed.). M.I.T. Press, Cambridge, pp. 114-138.

CSN (1999). Spanish nuclear power plants (in Spanish). Consejo de Seguridad Nuclear Report INT-01.02, Madrid.

DOE (1995). DOE Standard. Natural phenomena hazards assessment criteria. US Department of Energy Standard Report DOE-STD-1023-95.

Frankel A (1995). Mapping seismic hazard in the Central and Eastern United States, Seism. Res. Lett., 66: 8-21.

Frankel A, Mueller CS, Barnhard TP, Leyendecker EV, Wesson RL, Harmsen SC, Klein FW, Perkins DM, Dickman NC, Hanson SL, Hopper MG (2000). USGS national seismic hazard maps. Earthq. Spectra, 16: 1-19.

García-Monge J, Beltrán F, Sánchez-Cabañero JG (2001). Seismic margin assessment of Spanish nuclear power plants: a perspective from industry and regulators. Workshop on the Seismic Re-evaluation of all Nuclear Facilities, Ispra, Italy, 26-27 March, 1: 71-81.

Gutenberg B, Richter ChR (1944). Frequency of earthquakes in California. Bull. Seism. Soc. Am., 34: 185-188.

Harmsen S, Frankel A (2001). Geographic deaggregation of seismic hazard in the United States. Bull. Seism. Soc. Am., 91: 13-26.

IAEA (2000). IAEA safety glossary. Terminology used in nuclear, radiation, radioactive waste and transport safety. International Atomic Energy Agency Report

IAEA (2002). Evaluation of seismic hazards for nuclear power plants. International Atomic Energy Agency Safety Standards Series No. NS-G-3.3

IAEA (2003a). Consideration of external events in the design of nuclear facilities other than nuclear power plants, with emphasis on earthquakes. International Atomic Energy Agency TecDoc 1347

IAEA (2003b). Seismic design and qualification for nuclear power plants. International Atomic Energy Agency Safety Standards Series No. NS-G-1.6 / DS 304

Lapajne JK, Motnikar BS, Zabukovec B, Zupančič P (1997). Spatially smoothed seismicity modelling of seismic hazard in Slovenia. J. Seismol., 1: 73-85.

López-Casado C, Molina S, Delgado J, Peláez JA (2000). Attenuation of intensity with epicentral distance in the Iberian peninsula. Bull. Seism. Soc. Am., 90: 34-47.

Martínez-Solares JM, Mezcua J (2002). Seismic catalog of the Iberian peninsula (880 b.C.- 1900) (in Spanish). Instituto Geográfico Nacional Report, Madrid.

Mezcua J, Martínez-Solares JM (1983). Seismicity of the Ibero-Maghrebian area (in Spanish). Instituto Geográfico Nacional Report, Madrid.

Murphy JR, O'Brien LJ (1977). The correlation of peak ground acceleration amplitude with seismic intensity and other physical parameters. Bull. Seism. Soc. Am., 67: 877-915.

NCSE-02 (2004). Code of earthquake-resistant building: General part and construction (NCSE-02). Ministerio de Fomento, Madrid.

Peláez JA, López-Casado C (2002). Seismic hazard estimate at the Iberian Peninsula. Pure Appl. Geophys., 159: 2699-2713.

Peláez JA, López-Casado C, Henares J (2002). Deaggregation in magnitude, distance and azimuth in the south and west of the Iberian Peninsula. Bull. Seism. Soc. Am., 92: 2177-2185.

Peláez JA, Hamdache M, López-Casado C (2003). Seismic hazard in Northern Algeria using spatially-smoothed seismicity. Results for peak ground acceleration. Tectonophysics, 372: 105-119.

Peláez JA, Delgado J, López-Casado C (2005). A preliminary probabilistic seismic hazard assessment in terms of Arias Intensity in southeastern Spain. Eng. Geol., 77: 139-151.

Peláez JA, Hamdache M, López-Casado C (2006). Seismic hazard in terms of spectral accelerations and uniform hazard spectra in

Northern Algeria. Pure Appl. Geophys., 163: 119-135.

SSHAC (1997). Recommendations for probabilistic seismic hazard analysis: guidance on uncertainty and use of expert. Senior Seismic Hazard Analysis Committee - Lawrence Livermore National Laboratory Report UCRL-ID-122160, US Nuclear Regulatory Commission Report NUREG/CR-6372.

Stirling MW, McVerry GH, Berryman KR (2002). A new seismic hazard model for New Zealand. Bull. Seism. Soc. Am. 92: 1878-1903.

USNRC (1997a). Earthquake engineering criteria for nuclear power plants. Appendix S to Part 50: Domestic licensing of production and utilization facilities. US Nuclear Regulatory Commission's regulations, Title 10 (Energy), Chapter 1 (Nuclear Regulatory Commission), of the Code of Federal Regulations.

USNRC (1997b). Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion. Appendix C: Determination of controlling earthquakes and development of seismic hazard information base. US Nuclear Regulatory Commission Regulatory Guide 1.165.