Originally published as:

Girard, J.-P., Grünthal, G., Nicolas, M., EISS Team (2005): Design earthquakes for ITER in Europe at Cadarache. - Fusion Engineering and Design, 75-79, 1109-1113

DOI: 10.1016/j.fusengdes.2005.08.018

Design earthquakes for ITER in Europe at Cadarache

Jean-Philippe Girard^{a,*}, Gottfried Grünthal^b, Marc Nicolas^c,
EISS Team

^a Direction de l'Énergie Nucléaire, CEA Cadarache, 13108 Saint-Paul-lez-Durance, France

^b GeoForschungsZentrum Potsdam, Germany

^c CEA-DAM Île de France, 91680 Bruyères-le-Châtel, France

Available online 3 October 2005

Abstract

The European site proposed for ITER is situated in the south of France, 40 km north-east of Aix-en-Provence, in a low to moderate seismic area according to the Global Seismic Hazard Map (GSHAP Group 1999). The tokamak building would be implemented on good bedrock made of limestone with a shear wave velocity of over 1300 m/s.

Input requirements and assumptions for ITER consider that an infrequent, severe earthquake (called SL-2), although unlikely to occur during the lifetime of the facility, is assessed to demonstrate adequate protection of the public. This earthquake is assumed to have a return period of 10,000 years. An investment protection level or inspection level (where all structures, systems and components are safe) with a peak ground acceleration (pga) at 0.5 m/s^2 is also considered. As a basis, orders of magnitude of consequences, if no countermeasures were taken, are given.

Four aspects are discussed: *regulation, implementation (of this regulation for the proposed site (site geology, tectonic and seismotectonic), a probabilistic seismic hazard assessment of the site and finally, the fulfilment of the requirements and assumptions, according to IAEA guides.*

As a conclusion of the studies, the main characteristics of the Cadarache European site are discussed. Preliminary studies have shown that the European site proposal will ensure a low level of project risk with respect to the seismic hazard.

Keywords: ITER; Cadarache; Seism; Geology

1. Introduction

Input requirements and assumptions for ITER consider that an infrequent, severe earthquake, although unlikely to occur during the lifetime of the facility, is assessed to demonstrate adequate protection of the public. This earthquake is assumed to have a return period of 10,000 years. An investment protection level or inspection level (where all struc-

tures, systems and components are safe) is also defined with a peak ground acceleration (pga) of $0.05 \times g$ (or 0.5 m/s^2).

2. Radioactive inventory and potential risk and impact

The ITER tritium inventory is in the order of a kilogram of tritium. The impact of such an inventory on nearest population could be in the order of few tens of milliSievert to the Sievert according to the chemical form of the tritium (gas or water) if no

* Corresponding author. Tel.: +33 4 42 25 66 74; fax: +33 4 42 25 25 99.
E-Mail address: jean-philippe.girard@cea.fr (J.-P. Girard)

confinement would be designed to prevent releases of the tritium. From 1 to 10 mSv is the upper limit of design values, usually considered for infrequent severe accident consequences. Even if no other contamination sources were considered (i.e. radioactive with irradiated dust, or chemical with beryllium), ITER would have to be designed to confine tritium during major accident such as severe earthquakes.

3. Seismic hazard assessment at the proposed European ITER site

The probabilistic seismic hazard assessment analysis for the proposed ITER site at Cadarache, France, is described in the following sections.

3.1. Seismicity data

For the probabilistic calculation of the seismic hazard at Cadarache, the French earthquake catalogue "Sisfrance" [1], calibrated in terms of moment magnitudes M_w , served as the basis for the study. The spatial distribution of epicentres in the region of southern France (including parts of Italy) is shown in Fig. 1 (see [2,3]).

3.2. Input parameters and computation algorithm

The uncertainty of the input parameters used for a probabilistic hazard calculation are considered in the so-called "logic tree" algorithm. For such input parameter, several values or models are entered with their relative weights. The seismic source zone model proposed in [4] was adopted, dividing France into 52 seismic source zones. The zones around

Cadarache are shown in Fig. 1. The source zone model was modified with respect to the Durance fault, which is considered as separate. Seismicity parameters calculated for each zone for the logic tree input are the characteristics (a - and b -values) of the Gutenberg-Richter frequency-magnitude relation based on complete data in each size class, maximum expected magnitudes and representative focal depths [5]. The input a - and b -values are given with ± 1 standard deviation to account for the uncertainty. The maximum magnitude values are obtained with a technique modified after Cornell [6] and Copper-smith [7] based on data from globally distributed stable continental regions. Five representative values of the focal depth distribution are given for each source zone. Samples of frequency-magnitude relations, maximum magnitude distributions and focal depth sets are given in Fig. 2. The obtained magnitude values are well above the respective maximum observed magnitude, e.g. for two of the zones in Fig. 1, the highest maximum values are more than two magnitude units above the observed magnitude. Since no sufficient numbers of strong-motion recordings exist for southern France, attenuation relations from similar tectonic regimes and with similar subsoil characteristics were applied for the Cadarache calculations. Since both, extensional tectonics and strike-slip movement are prevailing in the surrounding of the site, attenuation relations for the peak ground acceleration by *Spudich et al.* [8] for extensional regimes (33% weight) and by *Boore et al.* [9] assuming strike-slip mechanism (33%) and not specified mechanism (33%) were applied. According to the measured shear wave velocities at the Cadarache site, all relations are for rock type conditions.

Figure 1. Seismic source zones and seismicity around Cadarache with example of Gutenberg-Richter magnitude-frequency relation, maximum magnitude distribution curves (maximum observed M_w at vertical red line; maximum magnitude values at arrows, see [5] for details) and input focal depth set.

Figure 2. Seismic hazard curves for peak ground acceleration (median (50% curve), 16% and 84% fractile) for the site Cadarache.

3.3. Results of the seismic hazard assessment

Each of the branches (combinations) of the logic tree gives hazard solutions for a range of annual probabilities of occurrence for the proposed European site. Fractiles of the solutions of all branches are selected and plotted in Fig. 2, the median (50% curve) and the 16 and 84% fractiles are shown. ITER seismic design specifications are based on the median hazard for mean return periods of 102 and 104 years. The obtained median hazard values for Cadarache are respectively, 0.67 and 2.26 m/s^2 . From published seismic hazard maps in recent domestic assessments for Cadarache [4], hazard values in the ranges 0.5–0.7 m/s^2 for a mean return period of 100 years and 1.5–2 m/s^2 for 1975 years, mean return period were derived. These values are in good agreement with the findings of the present study (Fig. 2).

4. Site ground characteristic

The European proposed site for ITER is situated in the south-east of France on a limestone bedrock close to the confluence of the Durance and Verdon rivers in Provence. Extensive drillings of the pro-

posed site leads to select an area with dense limestone (density = 2.5 t/m^3) up to the natural level to implement the tokamak building and the other nuclear buildings. Sixty drillings from 20 to 60 m on the whole expected ITER building platform were carried out, and a 200 m deep drilling is available nearby on the Cadarache Centre. It has been shown through seven seismic refraction profiles that the limestone is homogeneous (little fractured) and free from any karstic cavity and from any marly or clayey beds. The characteristics of the ground have been measured and largely fulfill the requirement of ITER in terms of soil bearing capacity (400 t/m^2 for a design load of 100 t/m^2), in case aseismic bearings would be used, no differential settlement have to be feared. The shear wave velocity (which is a criteria of the ground in terms of classification of soil versus amplification of seismic hazard) has been measured through three cross-holes technique on the first 30 m under the zero level of the nuclear building. With a mean value over the first 30 m under the tokamak basemat of 1350 m/s, the soil can be classified as good hard bedrock, on a scale of three types of soil (poor, medium and good), the threshold for “good” is 800 m/s according to the French regulation and 1100 m/s according to the IAEA standards.

5. Regulation to be applied for ITER in Europe and in France

According, among others, to the tritium inventory, ITER will be a so-called “Installation Nucléaire de Base”. A prescriptive rule for the seismic hazard of such facility is available and has to be fulfilled. This rule has recently been updated (2001). The standard procedure is to integrate the elements of the seismological (instrumental seismicity, historical and prehistorical data), geophysical and geological database to construct a regional seismotectonic model consisting of a discrete set of seismogenic structures and zones of diffuse seismicity. The maximum potential earthquake of each seismogenic structure and each zone of diffuse seismicity should be assumed to occur at the point of the structure (or zone) closest to the site area. A regional attenuation relation should be used to determine the ground motion that each of these earthquakes would cause at the site. The Séisme Maximum Historique-Vraisemblable (SMHV) is (are) the earthquake(s) to occur with the maximum ground motion at the site area. The local conditions (site effects, capable faults, etc.) are also studied. The design earthquake Séisme Majoré de Sécurité (SMS) corresponds to the SMHV at the same location with a

Figure 3. Seismic hazard curves for peak ground acceleration (median (50% curve), 16% and 84% fractile) for the site Cadarache.

0.5 increment of magnitude for uncertainty and conservatism. The characteristics of the ground motions corresponding to SMHV and SMS levels should be expressed in terms of response spectra. The contribution of multiple seismic sources is represented by an envelope. The response spectra are standard and included in the rule. The response spectra database takes into account 1D geological site effects with three classes. Hard rock corresponds to $V_{s30} > 800$ m/s.

6. Implementation of the seismic hazard regulation for ITER at Cadarache

The seismicity of southern France probably results from the convergence between Africa and Eurasia which proceeds at a rate of 0.8 cm/year at the Provence longitude. The potentially seismogenic structures delimit a large panel of Mesozoic cover. It includes E-W compressive faults (Mont Ventoux, Montagne de Lure, Lubéron, Costes and Trévaresse) and N-E left-lateral strike slip (Durance, Nîmes and Cévennes). The major historical earthquake of Provence (over the last 1000 years) is associated with Costes Trévaresse structure (Lambesc, 1909, $M = 5.5$). The Durance fault is associated with only few and moderate historical seismic events ($M = 5-5.3$), but paleoseismic evidence for larger earthquakes ($M = 6.5-6.7$) were found on a subsidiary fault near Manosque. For the zone of diffuse seismicity, the maximum magnitude observed is 4.9. Only one earthquake $M > 6$ occurred within 200 km over the last 1000 years. In application of the French safety seismic hazard rule, the SMHV for ITER area cor-

responds to an $M = 5.3$ event located at the Durance Fault at a hypocentral distance of 7.1 km (when the minimum distance between this fault and the ITER site is considered). The corresponding SMS is an $M = 5.8$ event at the same position. The length and the displacement associated of the Durance fault prehistoric event about 9000-26,000 years ago and the Gutenberg-Richter analysis conduct to consider at the SMS level a $M = 7$ earthquake at a hypocentral distance of 18.5 km. The SMS design spectrum for the Cadarache site (Fig. 3) is finally determined from the median ground motion for hardrock expected for two events: an $M = 5.8$ earthquake located 7.1 km and an $M = 7$ earthquake located 18.5 km. This spectrum has an estimated return period of 13,000 years in good agreement with the IAEA level SL-2 requirement.

7. Discussion and conclusion

Based on an acceptable methodology according to the IAEA safety recommendation, the safety level seismic hazard for ITER fulfils the requirements and assumptions. When the semi-empirical method is compared to the seismic probabilistic assessment, a margin in terms of return period ascertains that an infrequent severe earthquake defined as the SMS in the French regulation has a return period of more than 10,000 years. As a basis for comparison, the standard 10,000 years return period hazard is estimated to a peak ground acceleration of less than 2.3 m/s^2 . Finally the inspection level acceleration ($\text{pga } 0.05 \times g$) should occur less than once in the facility life. As a reference, the standardized 475 year mean return period hazard (i.e. 10% of chance to occur in 50 years) is close to 1 m/s^2 . Thus, the construction of ITER in Europe at Cadarache [10] as a nuclear facility according to the French regulation with demonstrated and validated seismic hazard, warranties a low level of project risk from this point of view. Position of nuclear buildings has been optimized to reduce seismic hazard at the basemat. Moreover, in order to minimize constraints on the equipment, it is proposed to use aseismic bearings for the tokamak building [11].

References

- [1] Sisfrance catalogue: <http://www.sisfrance.net>.
- [2] E. Baroux, N. Béthoux, O. Bellier, Analyses of the stress field in south-eastern France from earthquake focal mechanisms, *Geophys. J. Int.* 145 (2001) 336-348.
- [3] N. Béthoux, O. Ouillon, M. Nicolas, The in-

- strumental seismicity of the western Alps, *Geophys. J. Int.* 135 (1998) 177-194.
- [4] C. Martin, P. Combos, R. Secanell, G. Lignon, D. Carbon, A. Fioravanti, B. Grellet, Revision du Zonage Sismique de la France, Rapport no. GTR/MATE/0701-150Av3, 2001, 251 pp.
- [5] G. Grünthal, R. Wahlström, Sensitivity of parameters for probabilistic seismic hazard analysis using a logic tree approach, *J. Earthq. Eng.* 5 (2001) 309-328.
- [6] C.A. Cornell, Statistical analysis of maximum magnitudes, *The Earthquakes of Stable Continental Regions*, vol. 1, 1994, pp. 5-1-5-27 ((EPRI) TR - 102261- V1).
- [7] K.J. Coppersmith, Maximum earthquake assessment, in: *The Earthquakes of Stable Continental Regions*, vol. 1, 1994, pp. 6-1-6-24 ((EPRI) TR-102261-V1).
- [8] P. Spudich, W.B. Joyner, A.G. Lindh, D.M. Boore, B.M. Margaris, J.B. Fletcher, SEA99: ground motion prediction relation for use in extensional tectonic regimes, *Bull. Seism. Soc. Am.* 89 (1999) 1156-1170.
- [9] D.M. Boore, Joyner, T.E. Fumal, Horizontal response spectra and peak acceleration from North American earthquakes, *Seism. Res. Lett.* 68 (1997) 128-153.
- [10] C. Lyraud, J.M. Bottreau, A. Fardeau, O. Guerin, A. Maas, S. Mattei, et al., Readiness of Cadarache for starting ITER construction, in: *Proceedings of the 23rd SOFT, Venice, Italy, 2004*.
- [11] A. Fardeau, F. Blanc, J.-D. Cardettini, J.R. Mandine, R. Guerin, L. Patisson, et al., Studies for site preparation for ITER construction, in: *Proceedings of the 23rd SOFT, Venice, Italy, 2004*.