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# ETE Road Map

According to Chapter IV and V of the
"Conclusions of the Melk Process and Follow-Up"

## Item 6
## Site Seismicity

## Preliminary and Final Monitoring Report

## ANNEX D

### SEISMIC HAZARD ASSESSMENT AT THE NUCLEAR PLANT SITES: CURRENT PRACTICE AND STATE OF THE ART IN GERMANY AND FRANCE

Working Group CERVUS

Report to the Federal Ministry of Agriculture, Forestry, Environment and Water Management of Austria

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# Seismic Hazard Assessment at Nuclear Plant Sites: Current Practice and State of the Art in Germany and France

Contribution to PM 3
Final Version


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**TABLE OF CONTENTS:**

## Executive Summary:

This report focuses on the state of the art regarding the determination of seismic loads and parameters which constitute part of the design basis for nuclear power plants in Germany and France.

The relevant seismic regulations in Germany mostly date back to the early 1990s. Therefore, when assessing the current state-of-the-art in Germany, a compilation and evaluation of the current practice is of foremost importance.

On the other hand, a new basic safety rule on seismic hazards was published in May 2001 in France. This regulation keeps the general approach developed earlier, but is more precise in several points. When assessing the current seismic state-of-the-art in France, therefore, it is of particular importance.

The German procedure to determine seismic design loads is mainly deterministic, supported by probabilistic considerations. A systematic stepwise approach is required, including uncertainty analyses and estimation of errors to guarantee overall conservativity. The quality of the data available has to be taken into account when estimating uncertainty bandwidths.

In France, the approach is even more focused on deterministic methods. It is similar to the German procedure in that a conservative determination of loads is aimed at. This is achieved basically by a generic addition of one unit MSK to the intensity of the maximum historical earthquake.

A comparison of the practice and state of the art in Germany and France with the evaluation of seismic hazards at the Temelin site in the Austrian Technical Position Paper (ATPP) of July 2001 indicates that, taking into account the information presented in the ATPP, neither German nor French requirements are fulfilled at Temelin. (ATPP was referred to in the call for tender of PN 6 for issues in discussion and open questions.)

For example, the following requirements appear not to be fulfilled at Temelin:

- Paleoseismic studies are part of the methodology to determine the design basis earthquake and have to be performed if possible, according to the current state of the art (Germany and France)
- Systematic analyses of bandwidths of uncertainty are required (Germany)
- Conservative determination of the design basis earthquake is aimed at by adding a safety margin of one unit MSK to the maximum historical earthquake (France)

Furthermore, as far as known to the authors, no information has been provided by the Czech side on the selection of fractiles for response spectra. Whereas in Germany,

this selection is debated in scientific circles, with a tendency toward the 84%-fractile becoming apparent, this point appears to be neglected in connection with Temelin. It is, however, of great importance since the choice of the 84%-fractile rather than the 50%-fractile for a given intensity will generally increase the loads by as much or even more than adding one unit to the intensity would.

Another issue which might be of some relevance is that, as far as known to the authors, there is no consideration of pre- and aftershocks of an earthquake at Temelin. French regulations, on the other hand, require assumptions of pre- or aftershocks with an intensity equalling that of the maximum historical earthquake.

# I. Introduction:

Seismic risk related to nuclear power plants has become an important safety issue in Germany and France during the 1990s.

Starting point for the assessment of the seismic hazard potential and the seismic design of nuclear power plants is the determination of the seismic loads for the design basis earthquake and the parameters characterising this earthquake, in particular the seismic engineering data (maximum accelerations, duration of excitation, free field response spectra).

In what follows, a summarising account of the state of the art regarding the determination of those seismic loads and parameters is presented, supplemented by a brief discussion concerning seismic design and instrumentation.

It has to be taken into account that on the one hand, the state of science and technology is codified, to some part, in regulations; on the other hand, it is in continuous development as new scientific results and methods become available. Therefore, for individual issues, the exact state of science and technology cannot always be determined in unambiguous manner.

With respect to codification today, there are significant differences between Germany and France. In Germany, the basic seismic regulations of the Nuclear Safety Standards Commission (KTA-Standards, 2201 series) date back to the early 1990s (1990 – 1992, with one exception, on seismic instrumentation, from 1996). They are considered as providing a general framework for the application of up-to-date methods. Therefore, when assessing the current state-of-the-art in Germany, a compilation and evaluation of the current practice is of foremost importance. Seismic site assessments performed within the last few years can serve as characterization of the current state.

On the other hand, a new basic safety rule on seismic hazards was published in May 2001 in France (Règle fondamentale de Sureté RFS 2001-01). This regulation keeps the general approach developed in earlier regulations, but is more precise in several points. It attempts to integrate the progress in the seismic field which has occurred in the last twenty years into the codified safety rules. When assessing the current seismic state-of-the-art in France, therefore, the regulation RFS 2001-01 is of particular importance.

IAEA regulations, in particular Safety Guide No 50-SG-S1 [IAEA 1991], as well as new regulations now under preparation (among others, Safety Guide No NS-G-3.3, superseding 50-SG-S1 [IAEA 2002a, 2002b]), tend to be of a more general nature than German and French regulations and are not part of those regulations. They are not discussed further here.

Also not discussed is the Eurocode 8 (concerning buildings in zones with significant earthquake risk) since it is stated explicitly that this code is not applicable to nuclear installations.

# II. State of the Art of Seismic Hazard Assessment in Germany:

## *II.1 Survey of Regulations:*

The following regulations are relevant in Germany in connection with the seismic hazards of nuclear power plants:

Safety criteria for Nuclear Power Plants [BMI 1977]:

Those safety criteria contain general safety requirements for the design of nuclear power plants. Criterion 2.6 demands that the most severe external events have to be taken into account which can occur at the respective site according to the latest state of science and technology.

Guidelines for Pressurized Water Reactors of the Reactor Safety Commission [RSK 1981/1996]:

The guidelines contain references to the relevant rules and regulations. Regarding seismic hazards, the KTA-rules 2201.1 and 2201.5 (see below) are referred to in Para. 18.1.

Incident Guidelines [BMI 1983]:

Those guidelines define the design basis accidents (DBAs). For DBAs, precautions have to be taken according to the state of science and technology. The DBAs include earthquakes. Regarding to loads to be assumed for seismic design, reference is made to the design earthquake defined in KTA 2201.1.

Safety Standards of the Nuclear Safety Standards Commission, KTA-Standard 2201, parts 1-5:

The most essential regulation is KTA 2201.1 (Design of Nuclear Power Plants against Seismic Events; Part 1: Principles). This regulation lays down in a concrete and detailed manner how the design basis earthquake is to be established. The most important requirement is that the maximal loads have to be determined which could be caused by an earthquake at the site, according to the scientific knowledge available. Para. 2 (1) states: *"The design basis earthquake is the earthquake of maximum intensity at a specific site which, according to scientific knowledge, may occur at the site or within a larger radius of the site (up to approx. 200 km from the site)."*

Para. 2 (2) requires that *"the specification of the design basis earthquake shall include statements of the expected maximum accelerations, the duration of excitation, response spectra, etc on the basis of the seismic assessment taking into account the prevailing geological conditions."*

Further requirements laid down in KTA 2201.1 concern the analysis of historical earthquakes, the consideration of seismo-tectonic units and principles for the determination of the parameters characterising the earthquake, in particular the seismic engineering data (an English translation of KTA 2201.1 can be found in appendix 1 to this report).

The application of KTA 2201.1 has led to a deterministic determination of the design basis earthquakes at the German nuclear power plant sites. Probabilistic analyses of the seismic situation were, however, being performed as well in order to check and further support the site intensities which have determined by deterministic methods.

KTA 2201.1 explicitly requires a science-based procedure on the basis of the current state of science and technology [ÖKO 1996]. Since KTA 2201.1 does not specify the methods, procedures and standards to be applied in detail, the validity of this rule is not reduced even if the concrete state of science and technology develops further in some aspects. It is necessary to examine, for each individual case, whether the concrete methods and procedures which are being applied within the framework of KAT 2201.1 correspond to the state of science and technology.

The German industry norm DIN 4149 (concerning buildings in zones with significant earthquake risk) is not relevant in this context since it is stated explicitly that this code is not applicable to nuclear installations.

On the basis of the current regulations, the design basis earthquake has to be determined deterministically. A probabilistic definition of the design values is not possible, since the admissible probability for exceeding this earthquake is neither determined in the regulations, nor by juristic precedent. Thus, probabilities of occurrence sometimes as employed in Germany for the design basis earthquake (typically $10^{-4}$ to $10^{-5}$ per year) have no legal basis. Admissible probabilities can, in principle, only be determined via a definition of the admissible risk, which is a societal and not a scientific decision [ÖKO 1996].

On the other hand, the regulations, and KTA 2201.1 in particular, do not exclude probabilistic considerations which can serve as an additional support for deterministically determined design values. Probabilistic methods comply with the state of science and technology and are being applied in other countries (for example in the USA). Therefore, a supporting probabilistic analysis should indeed be performed if the data basis permits [ÖKO 1996, 1997].

It is required in principle that different, mutually independent procedures and data are applied when determining the design basis earthquake. The respective uncertainties of those methods and data have to be taken into account. A combination of different methods can reduce uncertainties and increase the meaningfulness of the results.

It can be concluded in summary that in Germany, the Safety Standard KTA 2201.1 is the decisive rule for the determination of the design basis earthquake and the seismic engineering data characterising this earthquake (maximum accelerations, duration of the excitation, response spectra). Methods and criteria for assessment are not prescribed in detail. They have to be selected in accordance with the given state of science and technology. Thus, the dynamic development of the state of science and technology is take into account.

## *II.2 Determination of the Design Basis Earthquake and the Design Values:*

The following presentation of the determination of the design basis earthquake and the design values in Germany is based upon a very recent re-assessment of the seismic risk for a nuclear power plant in Southern Germany (Biblis NPP, with two PWRs). The objective of this re-assessment was to define the design basis earthquake and the design values according to the current state of science and technology. The results were evaluated by the Reactor Safety Commission, the senior advisory body of the responsible German Federal Ministry [ÖKO 1996, 1997, 1999; RSK 2002]. Hence, the case of Biblis is well suited as an example illustrating the current state of the art in Germany. Other current German publications were also taken into account.

It will be shown in an exemplary and summary manner how a procedure according to the current state of science and technology could be performed in Germany, in accordance with German regulations. The procedure is structured in the following steps:

- Geologic and geophysical investigations and evaluations, definition of seismotectonic units, regional and local situation
- Determination of intensity and magnitude of the design basis earthquake
- Determination of the relevant parameters (seismic engineering data)
- Additional support for the design values – uncertainty analysis and probabilistic considerations, as well as assessment of conservatism

For each step, the objectives, measures and procedures are presented briefly here, taking into account the respective state of science and technology.

According to the present practice in Germany (which is in accordance with the regulations), pre- and aftershocks do not have to be taken into account in the seismic hazard analyses. Hence, determination or postulation of intensity and other parameters of pre- and aftershocks of the design basis earthquake are not required.

### II.2.1 Geologic and Geophysical Assessment, Seismotectonic Units, Regional and Local Situation:

The first step of the determination of the design basis values consists of the acquisition and evaluation of all geological and geophysical data and information required. The proscribed procedure varies according to the distance from the NPP. In accordance with KTA 2201.1 and the relevant IAEA regulation [IAEA 1991], the following zones have to be distinguished around the NPP site:

- Investigation and evaluation in an extended area with a radius of about 200 km
- Investigation and evaluation of the regional situation, in an area with a radius of about 25 km
- Investigation and evaluation of the local situation, in an area of about 1 $km^2$ around the NPP

In the largest area with a radius of about 200 km, the stratigraphical, lithological, tectonic and geophysical conditions, among others, have to be investigated and evaluated. The influences from neighbouring geologic and tectonic units, as well as the mutual influences of those units on each other, have to be determined. Potential earthquake inducing faults are of particular importance, because from their location, indications as to the hypocentral and epicentral distances of potential earthquakes can be derived.

Based on those investigations, a geotectonical model has to be developed, which permits the determination and assessment of the tectonic unit(s) around the site. Since the term ‘tectonic unit’ is not defined in KTA 2201.1, those units have to be determined according to the site-specific conditions and the objective of the investigation. It cannot be excluded, that several different models for the tectonic structure of the area appear equally plausible according to the state of science and technology. In any case, an analysis of the uncertainties has to be performed for the model(s). In addition, it has to be examined to which extent the selection of the tectonic units influences the determination of the design values for the design basis earthquake [ÖKO 1999]. Since earthquakes mostly occur at the borders of tectonic units, the term ‘tectonic unit’ should better be understood as ‘seismo-tectonic unit’ anyway.

The investigation of the intermediate, ‘regional’ area with a radius of about 25 km serves the purpose to determine exactly the location of the design basis earthquake near the site. It must be assumed that earthquakes which can occur in the tectonic unit of the site can also occur in its close vicinity. Experience shows that for earthquakes as they occur in Germany, there will usually be no inadmissible damage to the NPP if the distance from the epicentre is more than 30 km.

For the determination of potential earthquake locations, the structures which can give rise to earthquakes have to be registered. In particular, faults within the regional area have to be identified with appropriate geo-scientific methods (e.g. neotectonic studies to determine the latest movement of faults). Faults and active structures which could, according to experience, lead to an earthquake in the site vicinity then have to be studies in more detail; their hypocentral distance has to be determined. All available data and information have to be used. The degree of uncertainty of the data has to be estimated and assessed.

Local site investigations have to be performed in an area of about 1 $km^2$ around the NPP. The situation in the subsoil is investigated in detail by means of drillings and other suitable methods (stratigraphy, lithology, study of stratification, neotectonic and recent movements and faults etc.). In particular, a representative profile of the soil strata has to be elaborated, which can then be used to assess the ground motion transmission characteristics of soils and rocks. Furthermore, the immediate vicinity of the site has to be checked for faults. By means of geophysical methods, the velocity as well as the attenuation and amplification of seismic waves and their influence on the parameters of the design basis earthquake (resonance effects) have to be determined. The results of those investigations are required for model calculations for the assessment of the influence of the local subsoil as well as for the definition of criteria for the selection of representative strong motion data (soil/rock-classes).

As for the other zones, an assessment of data uncertainty and plausibility of information has to be performed for the local area.

II.2.2 Determination of Intensity and Magnitude of the Design Basis Earthquake:

The requirements of the regulations (KTA 2201.1) as well as the knowledge and methods representing the current state of science and technology have to be taken into account when determining intensity and magnitude of the design basis earthquake.

It follows conclusively from KTA 2201.1 that the design basis earthquake cannot be weaker than the maximum historical earthquake. On the other hand, it cannot be stronger than the maximum earthquake possible from a purely physical point of view (maximum possible earthquake).

For the determination of the design basis earthquake, it is of importance that the intensity at epicentre and the magnitude of the maximum historical earthquake are not exactly known. They can only be determined with a given bandwidth of uncertainty [ÖKO 1999]. Furthermore, the determination of the maximum possible earthquake will be beset by a relatively large uncertainty. Therefore, the intensity and magnitude of the design basis earthquake also can only be determined within a bandwidth of uncertainty. Intensity and magnitude of the design basis earthquake are not exact values but random variables which can vary within a certain range.

This procedure lays the basis for the uncertainty analysis required, the probabilistic support of the design parameters (see section II.2.4 below) and the assessment of the conservativity of the results.

According to the current state of science and technology, intensities can only be given as integers. The intensity scale is an ordinal scale; only steps of one are defined. At most, steps of ¼ or ½ could be introduced in order to indicate that the intensity lies somewhat below or above an integer. Decimal numbers are not admissible.

The determination of the intensity of the design basis earthquake according to the current state of science and technology is performed in a deterministic manner, with the following (basic) steps [ÖKO 1997, 1999]:

- Assessment of the past seismic activities in the extended site area: The objective is the identification of the earthquake with the highest intensity which has been observed in historical times – for the seismo-tectonic unit of the site (200 km radius to be considered, taking into account the division into units). The temporal and spatial distribution of the earthquakes, as well as their frequency distribution has to determined and evaluated in an extensive manner. Earthquake catalogues and other information available has to be used. A part of the relevant parameters will have to be re-evaluated (e.g. magnitudes of historical quakes). For some earthquakes, it will also be necessary to evaluate the uncertainty of the parameters. Furthermore, a re-evaluation of the most important historical quakes will be necessary, if there are doubts that the parameters as listed in earthquake catalogues are accurate [ÖKO 1999]. For this purpose, all relevant historical sources have to be evaluated.

- Determination of the maximum possible earthquake, which could occur, according to scientific knowledge, within the tectonic unit: For this purpose, a statistical analysis of earthquake activity has to be performed. The frequency curve of the magnitudes, the dimension and activity of faults and the crustal stress situation all have to be studied and taken into account.
- Determination of the distance from the site and the focal depth in which the identified maximum earthquake could occur: Location, dimension, type and activity of faults in the vicinity of the site have to be taken into account.
- Determination of the intensity at the site, for the identified maximum earthquake: Attenuation of intensity in the site region and local subsoil have to be taken into account.
- Subsequent to the determination of the most likely values for the epicentral intensity and the magnitude of the maximum earthquake observed in historical times, the bandwidths of uncertainty for those values have to be estimated. Minimal uncertainty bandwidth would be +/- 0.5 intensity units, typically, +/- 1 will have to be assumed. For badly documented quakes, a larger bandwidth is appropriate.
- The next step is the determination of the safety margin to be added to the most likely values of epicentral intensity and magnitude of the maximum earthquake. The reason for those additions is that the observation period for the quakes usually is not completely covered; gaps occur, significant quakes may be overlooked. The value of this addition depends, among other factors, on the quality of the documentation of earthquake activity in the observation period. Furthermore, all available data have to be taken into account (e.g. length of observation period, size of the observed area, paleoseismic investigations, statistical and probabilistic considerations concerning the bandwidths of uncertainty). There is no consensus on whether only integers can be used for the addition. In a recent recommendation, the Reactor Safety Commission regards the use on non-integers as admissible [RSK 2002].
- Analysis of uncertainties and determination of uncertainty bandwidths: In the last step, the probability distribution for intensity and magnitude is performed, for example using the logical tree method. The uncertainties, bandwidths and weighings which have entered the determination of the tectonic model, the maximum historical earthquake and the safety margin addition for intensity and magnitude all have to be taken into account. The probability distribution expresses the uncertainty which remains when determining the intensity and magnitude of the design basis earthquake according to the current state of science and technology.

### II.2.3 Determination of the Seismic Engineering Data:

The seismic engineering data are required as input data for the dynamic calculations to be performed for purposes of NPP design. Those parameters include maximum accelerations, strong motion duration and response spectra of the design basis earthquake. They are determined, based on a statistical evaluation of the strong motion seismograms representative for the NPP site.

The strong motion data have to be acquired and evaluated. Several sources of data are available for this purpose. In any case, a representative set of strong motion seismograms is required for the site in question. The statistical meaningfulness and stability of the data has to be proven. When selecting seismograms, the highest-ranking selection criteria are the site-specific situation and the achieving of a minimum uncertainty. Achieving a small uncertainty implies that the sample size has to be above a certain minimum. It is estimated that that the lowest justifiable boundary would be about 25 strong motion seismograms [ÖKO 1997]. In addition, criteria for the selection of strong motion seismograms representative for the site such as magnitude, hypocentral depth, epicentral distance, site specific subsoil properties and soil/rock class have to be taken into account.

Using the representative set of strong motion seismograms, the response spectra, the maximum acceleration and the strong motion durations can be statistically analysed (determination of mean value, median and fractiles). This has to be performed separately for the horizontal and the vertical component of the acceleration.

The definition of the free-field response spectra and the strong motion duration has to be based on site-specific response spectra. Only those fulfil the requirements of minimum uncertainty and of taking into account the site-specific situation. Use of site-specific response spectra conforms to the state of science and technology. The use of standardized, generic spectra does not fulfil the requirements mentioned and therefore does not conform to the state of science and technology [ÖKO 1997]. The derivation of response spectra from the magnitude is in accordance to the state of science and technology [RSK 2002]. However, other approaches are also acceptable (determination of spectra from the intensity, determination from magnitude and hypocentral distance).

For the free-field response spectra and the strong motion duration, which are the basis for the design of the NPP, bandwidths of uncertainty have to be specified, using fractiles. The degree of conservativity aimed at for the determination of the seismic engineering data of the design basis earthquake is expressed in the selection of a fractile. KTA 2201 does not contain a requirement regarding the selection of fractiles for the design basis earthquake. In the practical application in Germany so far, mostly 50%-fractiles and 84%-fractiles have been discussed. According to a recent study [ÖKO 1999], taking all relevant arguments for fractile selection into account, the 50%-fractile cannot be regarded as conservative basis for NPP design. The 84%-fractile is enveloping the uncertainties with better conservativity. However, the selection of other fractiles could also be appropriate.

KAISER [1996] states that the use of the 50%-fractile for the determination of design response spectra from a sample of spectra is not suitable, since in this case, the variation of the data base is not taken into account and information on hypocentral processes and the influence of the subsoil on the response spectra is mostly neglected. The selection of an appropriate fractile can only be performed in coordination with the complete safety analysis, taking into account the uncertainties of all partial steps, and with the background of a general safety level which has been determined by societal consensus.

According to RSK [2002], both fractiles could be argued for, in combination with different probabilities of exceedance of the design basis earthquake. The question, which fractile actually should be selected, cannot be answered conclusively from the international state of science and technology alone [RSK 2002].

Furthermore, it is regarded as problematical to offset lower probabilities of occurrence (e.g. $10\text{-}^{5}$/yr instead of $10\text{-}^{4}$/yr) against the use of a less conservative fractile (e.g. the 50%- instead of the 84%-fractile), since the 50%- and the 84%-fractile spectra are characterized by different shapes [MAYER-ROSA in RSK 2002]. Occasionally, the selection of fractiles is also discussed in connection with or offset against the safety margin for general conservativity.

Apart from supporting the design values (seismic engineering data) by means of systematic uncertainty analyses, further probabilistic investigations have to be performed. Due to the large bandwidths of uncertainty for the frequencies of occurrence of the defined design values, it turns out that probabilistic results in the range smaller than $10^{-4}$/yr become less and less meaningful the smaller they are. Since the results of probabilistic analyses depend significantly on the deterministic definition of certain input parameters, probabilistic results are useful for comparisons and supplemental considerations only. In the relevant range of values, they are not sufficient as sole basis for decisions [ÖKO 1999].

### II.2.4 Uncertainty Analyses and Probabilistic Considerations:

It is the goal of uncertainty analyses to determine the uncertainty associated to the intensity and magnitude of the design basis earthquake, as well as to the seismic engineering date. The results of the uncertainty analyses are ranges for design basis parameters. The analysis of the uncertainty of a given value is part of the state of science and technology. Therefore, it is required and has to be performed by appropriate methods. For important parameters such as intensity and magnitude, this has already been indicated in section II.2.2 above; for the seismic engineering data, in section II.2.3.

As already pointed out in section II.1, the regulation KTA 2201.1 requires a deterministic procedure for the determination of the design values. Nevertheless, probabilistic calculations of the probability of exceedance of the design basis earthquake have been performed in Germany. Probabilistic analyses for the control and support of deterministic definitions of the design basis earthquake conform to the state of science and technology and are recommended by, among others, the International Atomic Energy Agency [IAEA 1991, 2002a].

The significance of probabilistic analyses for seismic design in Germany, however, is limited since it is not defined in the regulations which probability of exceedance is admissible. In this respect, the German regulations differ from those of some other countries. In Switzerland and the USA, for example, probabilities of exceedance of $10^{-4}$/yr and $10^{-5}$/yr, respectively, are proscribed.

The data base for a probabilistic hazard assessment consists mainly of the earthquake catalogue, the division into tectonic units, information on seismologic, geologic and tectonic characteristics of the site region as well as the attenuation law for the seismic soil ground movement and the intensity. When applying the probabilistic method, as in other comparable calculations, the accuracy of the results depends on the accuracy of the input data for the calculation model. Since the input data often are beset with considerable variations or are based on expert opinion, an uncertainty analysis of the input data is strictly required (for example, sensitivity analyses, e.g. determination of the degree in which variations of input data influences the exceedance probability calculated) [ÖKO 1997, 1999].

The exceedance probability as determined by probabilistic means depends strongly on the upper bound for the magnitude as assumed for the calculation. This upper bound can only be defined deterministically, according to the present state of science and technology. Insofar, the probabilistic method is thus coupled to the deterministic method and cannot be regarded as independent; its chief weakness is that it requires deterministic input data which are decisive for its application. At the present state, the probabilistic method should not be substituted for the deterministic assessment of seismic hazard. Probabilistic results are useful only as indicators for comparisons and supplementary confirmation of deterministic results [ÖKO 1999].

In summary, it can be stated that probabilistic methods should be applied as a supplement when analysing seismic hazards. The combination of deterministic and probabilistic assessments can result in a balanced analysis of seismic risk. It must be possible to integrate the results of probabilistic earthquake analyses and deterministic determinations, without contradictions, into the overall safety concept of a nuclear power plant [LIEMERSDORF 1997]. The result will be a mutual control and support regarding the estimation of hazard. This will be required, in particular, in areas of low seismicity [LEYDECKER 1999].

Although conservativity is not explicitly addressed in regulations, it is today generally recognized that a so-called conservativity addition (margin) is required. Some authors assume that such a margin is already sufficiently provided for if the 84%-fractile is used. Others, however, generally recommend a separate addition, to take into account the uncertainties of the data base. This addition in any case has to be quantified and must be chosen in a transparent and comprehensible way. Therefore, it should not be treated simply be implicit inclusion in other steps.

## *II.3 Seismic Design and Instrumentation:*

### II.3.1 Seismic Instrumentation:

In accordance with KTA 2201.1[1] seismic instrumentation shall be provided which will make it possible to determine whether 40 % of the design values of the design basis earthquake have been exceeded. When a value of this inspection level is exceeded, the nuclear power plant shall be subjected to a review.

The safety standard KTA 2201.5 specifies the requirements for a seismic instrumentation of nuclear power plants with light water reactors, that

- can be used to ascertain whether the parameters on which the inspection level has been based have been exceeded, and
- to obtain input parameters for an analytical verification by recording the earthquake time histories.

The seismic instrumentation is based on the principle of measuring of accelerations, which corresponds to current design practice and instrument technology.

The following requirements regarding number and location, instrumentation characteristics and actuation and signal are defined:

<u>Number and location:</u>

Three tri-axial acceleration sensors shall be installed in the reactor building: Two in the foundation and one above these at an elevation level. In addition, one tri-axial acceleration sensor shall be located in the open field. In the case of multi-unit plants each reactor building shall, basically, be equipped with seismic instrumentation. It is, however, sufficient to equip only one reactor building with seismic instrumentation if the floor response spectra of the reactor buildings do not vary by more than ± 10 % for any one frequency in the frequency range between 0.1 Hz and 30 Hz.

<u>Instrument Characteristic:</u>

The seismic instrumentation[2] shall be capable of rendering a reliable comparison, between the design basis spectrum and the response spectrum of the actual seismic ground movement.

The **acceleration sensors and recorders** shall be fully operational within 0.1 seconds after the seismic trigger has registered that the limit value has been exceeded; they shall not be switched off earlier than 30 seconds after the limit value has last been exceeded.

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[1] A seismic instrumentation is required if the maximum acceleration of the design basis earthquake was determined to be ≥ 1.0 m/s².

[2] A seismic instrumentation different from the type de-scribed in KTA 2201.5 may be used if it allows determining the parameters required in accordance with this safety standard.

The **seismic switch** shall be sensitive to frequencies in the range between 0.1 Hz and 30 Hz. Vertical as well as horizontal seismic excitations shall actuate the signal indicating that the limit value has been exceeded.

Actuation and Signal:

It shall be ensured that the actuation of any one seismic trigger starts all acceleration sensors and recorders. The **seismic triggers** in the reactor building shall be set for limit values of accelerations less than or equal to 0.1 m/s² (in the open field less than or equal to 0.2 m/s²).

Furthermore, the documentation of the results of the measurements, maintenance and tests on seismic instrumentation is required.

### II.3.2 Seismic Design:

The seismic design of safety-relevant components and buildings of nuclear facility must correspond to the Safety Standard KTA 2201.1[3]. For purposes of design against earthquakes the plant components are classified into two classes[4] (KTA 2201.1, 3). For Class I plant components, it is required that their safety-related functions are preserved during a design basis earthquake and that the stresses and/or deformations will remain within admissible limits if the seismic loads of the design basis earthquake occur together with other loads. For Class II plant components no such demonstration is required, but it shall be demonstrated that potential effects from and damage to these plant components will not affect the safety-related functions of any of the class I plant components.

Basically, the loads caused by a design basis earthquake shall be superposed with the loads of stationary full-power operation of the entire plant and, in addition, with the post-incident loads caused by the earthquake, taking into account their time history.

According to KTA 2201.4, the mechanical and electrical plant components shall be designed for seismic loading in such a way that

a) the shutdown of the reactor and the long term maintenance of sub-criticality are ensured,

b) the residual heat removal from the reactor core and the fuel pool is ensured,

c) any inadmissible radiological exposure of the environment is prevented.

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[3] Design of Nuclear Power Plants against Seismic Events, Part 1: Principles, 6/1990

[4] Class I: Plant components,
-which are required for shutting down the reactor safely, for maintaining it in a shutdown condition and for removing the residual heat,
-whose damage or failure can cause or result in an accident involving an impermissible release of radioactive materials,
-which are to prevent an impermissible release of radioactive materials to the environment, as well as all structures supporting or connecting these plant components.
Class II: All other plant components of the nuclear power plant.

The safety standard KTA 2201.4 describes the methods for the verification of the seismic safety of mechanical and electrical plant components. The required verifications are subdivided into individual verification steps:

a) Determination of the excitation at the place of installation,

b) mechanical system analysis and

c) loading analysis.

In KTA 2201.4, these verification steps are dealt with, with respect to each of the three possible verification methods: Verification by analysis, verification by experiments and alternative methods of verification (verification by analogy considerations, plausibility analysis). The seismic safety of a component can be verified on the basis of a single verification method or on the basis of a combination of verification methods.

The requirements for verification methods are specified for Class I and Class II plant components. The safety-related tasks comprise:

a) in case of Class I plant components: Support stability, integrity and functional capability

b) in the case of those Class II plant components which could jeopardize Class I plant components: Support stability and integrity.

The relevant regulations KTA 2201.1 (version of 06/1990), KTA 2201.4 (version of 06/1990) and KTA 2201.5 (version of 06/1996) have recently been re-examined. After this examination, the Nuclear Safety Standards Commission (KTA) came to the conclusion, in June 2000, that there was no need for revision and that the regulations will be valid further, in the versions as mentioned.

Regarding the seismic design of the pressure retaining boundary, section 18 of the RSK-Guidelines [RSK 1981/1996] is applied in addition to the Safety Standard KTA 2201.1. According to this section, it has to be guaranteed by analysis (taking into account the number of oscillations excited by the earthquake) that the loads to the piping system resulting in the case of the design basis earthquake do not exceed the admissible stress limits. If there are parts of the piping system which are particularly endangered and the failure of which could lead to a loss of coolant accident or other dangerous developments, a remedy has to be found by adapting materials and design as well as planning of appropriate tests.

The safety of German nuclear power plants is re-evaluated regularly. This includes a re-evaluation of the seismic design. For example, in the context of the safety analysis for the Biblis A nuclear power plant, shortcomings were found regarding seismic design which led to the requirement of various backfitting measures, among them [BMU 2000]:

- Upgrading of accumulators and the water storage tank to ensure resistance against the design basis earthquake, and
- Strengthening of the support structure for cable routes belonging to the emergency power system.

In Germany, research is continuously under way to improve the seismic design of nuclear power plants. New analytic developments make possible re-qualification of different components. At the Annual Meeting on Nuclear Technology 2000, a new model (Whole-Pool-Multi-Rack-Model) was presented, which permits calculation of the seismic loads to the fuel storage rack with high precision [STABEL 2000].

### *II.4 Summary of Section on German State of the Art:*

The German regulations, in particular KTA 2201.1, require deterministic determination of the design basis earthquake. It is not excluded, however, to use probabilistic analyses as supplement and support to the deterministic results.

Occasionally, probabilistic target values for the design basis earthquake are employed (in the range $10^{-4}$/yr to $10^{-5}$/yr). There is no basis for the use of such values to be found in regulations or legal precedent.

German regulations do not lay down methods and criteria in detail. They demand conformity with the current state of science and technology. Thus, the dynamic process of development of the state of science and technology is taken into account.

When determining intensity and magnitude of the design basis earthquake, the earthquake with the highest intensity which was observed in historical time in the seismo-tectonic unit relevant for the site has to be taken into account. An extended area around the site with a radius of about 200 km has to be studied. In case of doubt, a re-evaluation of significant historical earthquakes has to be performed. Furthermore, the maximum possible earthquake for this area has to be defined. The design basis earthquake has to be chosen with an intensity between the maximum historical earthquake and the maximum possible earthquake. In a given case, the choice will depend strongly on the quality and reliability of the available data.

For intensity and magnitude of the design basis earthquake as determined, bandwidths of uncertainty have to be estimated. They are to be derived from the quality of the earthquake data in the area under study. Paleoseismic results have to be taken into account. An uncertainty analysis has to be performed to determine the probability distribution of intensity and magnitude.

Seismic engineering data (free field response spectra, strong motion duration and maximum acceleration) have to be derived from strong motion data. Site-specific response spectra must be taken into account. When selecting the appropriate fractiles (50%- or 84%-fractiles), the 84%-fractiles are often regarded as appropriately and sufficiently conservative. The discussion of this point, however, is not yet concluded. In any case, the design values have to be supported by systematic uncertainty analyses and error estimations.

Probabilistic methods should be employed, in a supplementary manner, for the assessment of seismic hazards. They should not only be used as support for deterministic assumptions. The results of probabilistic seismic analyses and deterministic assumptions have to fit without internal contradictions into the overall safety concept of a nuclear power plant. Thus, mutual control and support of hazard assessment is achieved. This is particularly required in areas of low seismicity.

All in all, the seismic hazard assessment consists of several individual steps, the results of which are interlinked. Therefore, it is absolutely required that all steps together form a “chain of proof” consistent in itself. Within this framework, it is obligatory to take into account the conservatisms required and to perform uncertainty analyses.

The margin of conservativity has to conform to the uncertainty of the data. It has to be comprehensible and transparent and should not be dealt with by implicit inclusion in other steps.

# III. State of the Art of Seismic Hazard Assessment in France:

## *III.1 Survey of Regulations:*

The first fundamental safety rule (RFS, règle fondamentale de sûreté) associated with the determination of the seismic risk for nuclear reactors was adopted and published in 1982, on the basis of the seismic knowledge acquired before 1975. In 1997, because of the major progresses made in 20 years, to comprehend and model phenomena linked with earthquakes, the French safety authority initiated a revising process including major French official expertise. Working groups led by the National Institute for Nuclear Safety and Radioprotection (IRSN, Institut de Radioprotection et de Sûreté Nucléaire[5]) included the Geological and Mining Researches Board (BRGM, Bureau des Recherches Géologiques et Minières), nuclear and chemical plants operators representatives, and the French ministry of Environment.

Before 2001, two fundamental safety rules were dedicated to seismic studies: RFS n°I.2.c and RFS n°I.1.c (a presentation of the two former RFS can be found in appendix 2). The first one was specifically dedicated to nuclear power plants, the second one to other nuclear facilities except of long-term storage of radioactive wastes.

In May 2001, a new RFS (RFS 2001-01) was published and replaced both former RFS [DSIN 2001]. However, this RFS is only destined to be applied to the future nuclear facilities which could be built (see below for an extensive presentation of RFS 2001-01). If the safety authority announced that "*it can be also used to reassess the safety of the existing facilities*"[6], it also specifies that it will not be used in a constraining way, but only as an indicative reference, for such facilities.

The new RFS keeps the same general framework and approach developed in the former rules, but is more precise on several points. It proposes especially to take into account and integrate the seismic studies, progress and methods related to seismic knowledge, that have occurred during the past twenty years (the oldest RFS, I.2.c., has been published in 1982, and the second one, I.1.c, published in 1992, is a carbon-copy of the first RFS). It also gives to the operator the opportunity to use the latest development of geology regarding earthquakes, as much as it can.

The potential problem of such an approach to the seismic risk is the freedom given to the operator regarding to what he should (or should not) take into account in his seismic study. Although the latest RFS is more detailed, treatment of the different aspects of the seismic risk is very unequal, and the choice of seismic study parameters and therefore the safety level, is to some extent left into the hands of the operator.

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5 The IRSN was previously known – before March 2002 – as IPSN (Institut de Protection et de Sûreté Nucléaire).

6 See the announcement of the adoption of the RFS 2001-01 on the authority website: http://www.asn.gouv.fr/data/information/decision12.asp

### *III.2 General Framework of Seismic Hazard Assessment:*

Before the 1990s, information on seismic parameters of earthquakes resulted only from the interpretation of very few historical archives on earthquakes, describing recorded damages in France, and essentially some direct Californian and few French instrumental records. Since the early 1990s, a historical library covering 1000 years, called SISFrance, was created, and largely upgraded compared with the former database. As of the end of 2002, SISFrance contained around 6,000 earthquakes observed on the French territory, with 1,700 epicenters with intensities greater or equal to 4 on the MSK scale, for which localization, magnitude and depth have been determined[7].

The instrumental records started in 1962 with the CEA (Commissariat à l'Énergie Atomique) network called LDG, the first purpose of which was to observe nuclear tests explosions abroad. Since the 1960s, accelerometric networks were not developed at a national scale, even if regional networks developed in the 80s. The IRSN accelerometric network, managed by its specific department, the BERSSIN (Bureau d'évaluation des risques sismiques pour la sûreté des installations nucléaires), possesses its own monitoring stations installed as soon as 1978. It was included in a national network which was created in December 2000[8], on the basis of several institutional and academic networks [BERSSIN 1999]. As of the end of 2002, the instrumental library on which is based the RFS (together with the SISFrance database), contained 965 vertical records and 485 horizontal records, or around 485 earthquakes, of which 83% of European data and 17% if Californian data[9].

Development of paleoseismology during the 90s showed that traces could be found of earthquakes that had occurred a few thousands years ago and which presented magnitudes higher than the magnitudes deducted from the SISFrance library. The development of this specific approach to the seismic risk to a mature knowledge, led to include the possibility of paleoseismic studies in the RFS 2001-01. However, one should note that paleoseismic studies are only required in the case of new nuclear installations, covering a period of few 100,000 years. In this case, magnitude is estimated on the ground of observed surface displacements, and epicenter depth is taken on the basis of the distance between the paleoseism and the ground surface.

Moreover, characterization of important earthquakes of the 80s, like Mexico in 1985 or Loma Prieta in 1989, showed the importance of surface geology in determination of the engendered surface motions. In particular, localization of soft geologic layers, like alluvium type, presented a close relation with damages repartition. Later earthquakes, like Kobe in 1995 and Izmit in 1999, confirmed the importance of superficial layers in what is called "site effect".

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7 The SISFrance database is available on internet at: http://www.sisfrance.net/

8 The national network, the permanent accelerometric network, called GIS-RAP (Groupement d'Intêret Scientifique-Réseau Accélérométrique Permanent), is available on internet at: http://www-rap.obs.ujf-grenoble.fr/

9 Personal communication with P. Volant, seismologist at BERSSIN, 4 March 2003

These recent developments of the understanding of earthquakes mechanisms were integrated in the 2001 revised RFS, in particular in the mean spectral acceleration attenuation law, thanks to cooperation at the European level between IRSN, United Kingdom (Imperial College of London) and Italy (Ente Nazionale per l'Energia Ellettrica, Ente Nazionale per la Ricerca e per lo Slivuppo de l'Energia Nucleare e delle Energie Alternative). Former attenuation laws were essentially based on Californian data, although the latest are mainly based on European data. However, latest attenuation laws are not applicable for very slow waves speeds (less than 300 m/s), linked with the presence of very soft geological layers or very specific geometry like sedimentary basins. In this case, categorized as "particular site effect", specific studies are recommended by the new RFS.

Considering the seismic risk, the basic design of each French nuclear facility has been elaborated with the same general approach:

- a case study (including an historical part) is led, to evaluate all the seismic parameters linked to the site;
- these parameters are then applied to with the corresponding RFSs, which are the basis of the French regulation, published by the French safety authority; this enables to integrate the seismic parameters to the facility design.

The RFS globally develop two different approaches to integrate the risk of external hazards:

- a probabilistic approach: each event has a certain probability to occur, and the RFS gives the probabilistic threshold below which the event can be excluded. Only the more probable event is taken into account for the design (for example: fire, aircraft crash, ...);
- **a deterministic approach**: the event taken into account for the design is the most extreme recorded event, which intensity is increased by an additional factor; **this method is used for the seismic studies**.

RFS are not absolute rules that have to be applied strictly by the operator to design its facility. According to the safety authority, "*those are recommendations that define safety purposes and describe practices that the Safety Authority considered as satisfying to respect these purposes. They are not regulatory texts strictly speaking. An operator is likely not to have to follow the RFS provisions if he proves the alternative means he proposes enable him to reach the purposes defined by the RFS.*"[10]

Three RFS are dedicated to seismic issues in the French regulation:

- RFS n°2001-01 (May 2001), on seismic studies[11];

- RFS n°I.3.b, (June 1984), on seismic instrumentation [MINISTRIES 1999];

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[10] General Directorate for Nuclear Safety and Radioprotection (DGSNR, the French safety authority name since February 2002), on its web site: http://www.asn.gouv.fr/Textes/lrfds.asp

[11] RFS n°2001-01 (May 2001) can be found on the safety authority's web site: http://www.asn.gouv.fr/data/information/decision12b.asp

- RFS n°V.2.g, (December 1985) on building calculation codes [MINISTRIES 1999].

A brief summary of RFS n°I.3.b and RFS n°V.2.g can be found in section III.4.

The full text of regulation RFS 2001-01 as well as of the two regulations preceding it can be found in appendix 2.

### *III.3 The New Seismic Hazard Regulation RFS 2001-01:*

The general purpose of RFS 2001-01 is described as follows: "*The French regulatory practice provides for the maintenance of the important safety function of a nuclear facility above the surface, including and according to its precise features, the safe shutdown, the fuel cooling and the containment of the radioactive material, should be ensured during and/or after plausible earthquakes on the considered facility site.*"[12]

More precisely, it defines the method that should be taken into account to determine the seismic intensity that has to be considered for the design of a nuclear facility, and the method to convert this intensity into usable data.

It is important to notice that this RFS is a new one (published in May 2001), replacing two former RFS, as mentioned above. RFS 2001-01 will mainly be applied to the potential nuclear facilities to be built. The safety authority only specifies that "*it can be also used to reassess the safety of the existing facilities*", and anyway not as a constraining rule, but as a reference.

RFS 2001-01 underlines the fact that in metropolitan France, the frequency of high-intensity earthquakes is low and that the earthquakes are difficult to link to the known faults. It also underlines that it is difficult to identify the potentially seismogenic faults and the features of their associated earthquakes. Consequently, the RFS suggests to take into account all the possible direct and indirect elements that are relevant (including data from other areas around the world), and proposes an approach of the seismic risk determination described below.

#### III.3.1 The Maximum Historically Probable Earthquake:

To determine the seismic risk, a Maximum Historically Probable Earthquake (SMHV, Séisme Maximal Historiquement Vraisemblable) is defined as the maximum earthquake that is likely to happen on a period of time comparable to the "historical period", which corresponds to about 1,000 years. Wherever this historical seism really took place, the SMHV is chosen to be located at the epicenter position that implies the maximum effects on the site, considering this position has to remain compatible with the geological and seismic data.

To evaluate the SMHV:

[12] Paragraph 1 of RFS n°2001-01 (May 2001).

- a synthesis of the latest documents on geology, geophysics and seismicity has to be led[13];
- based on the existing macroseismic databases and on the latest knowledge on seismo-tectonics and instrumental and historical seismicity, the features of the earthquakes likely to be used to determine the SMHV have to be defined, and especially intensity at the epicenter, isoseists, epicenter location, magnitude and local intensity attenuation laws[14].

### III.3.2 Response spectrum:

The intensity of a seism is not a data directly usable for the design study of a facility. For the site under consideration, each given intensity has to be linked to an oscillator response spectrum, including the acceleration frequency, the horizontal and vertical speeds and motions at ground level (taking into account the epicenter depth, the intensity, the features of the local soil, etc.), and summarizing the potential effects of the seism.

As the response spectra associated to real earthquakes are very complex, a general standardized spectrum is used. It is based on empirical calculation codes, and on numerous recordings of the “earthquakes library”. The shape of the mean attenuation law used to calculate the response spectrum (PSA for “pseudo-acceleration”) is the following[15]:

$$\log_{10} PSA = aM + bR - \log_{10} R + c \qquad (I)$$

M: magnitude.

R: shortest distance to rupture zone.

The coefficients a, b and c depend on the frequencies and the acceleration rates, and are valid for 7 kms < R < 100 kms and for 4.5 < M < 7.3. They are functions of the frequency and at least calculated between 0.25 and 33 Hz. These correlation coefficients are obtained by a regression calculation operated on the instrumental database, frequency per frequency. The c coefficient permits to include “site effects” in the attenuation law.

The law used to calculate the response spectrum is the **mean law**, which corresponds to a **confidence interval of 50%**. In fact, locations of different monitoring stations give, for a definite earthquake, a large variation for the measured acceleration. Therefore, the regression calculation presents a considerable dispersion of the recorded data around the calculated curve. An interval of 50% is taken for the calculated a, b and c coefficients, which induces a ‘maximum’ and ‘minimum’ attenuation curve. The curve then actually chosen is the mean curve between these

13 A short specific method to delimit the seismo-tectonic areas (based on seismicity, deformations and stress) is given in Annex 1 of the RFS.

14 An operational way to define each of these features is given in Annex 2 of the RFS.

15 According to the RFS, it is possible to calculate only the response spectrum for the horizontal motions, $PSA_{Horiz}$,, and then to postulate the vertical response spectrum as being, for all frequencies: $PSA_{Vertic} = (2/3)*PSA_{Horiz}$

two extremes (50%-fractile). It seems that there have been intense discussions between IRSN, DGSNR and other participants in the elaboration process of the RFS 2001-01, concerning the determination of the confidence interval and the choice of fractile.

In fact, the attenuation law increased by its standard deviation presents a confidence interval of 84% (84%-fractile). However, a mean law has been finally chosen, which signifies that the corresponding confidence interval has been restricted to 50%. This choice is not conservative; it has not been subject to any open debate.

For distances smaller than 7 km, it is postulated that R = 7 km, but with an increased magnitude to obtain the same effect over the site as the considered seism (the SMHV intensity is then considered as constant). Moreover, the maximal acceleration of the ground is considered to be equal to the response spectrum value for an acceleration corresponding to a frequency fixed at 33 Hz.

The RFS evokes other parameters that can be potentially taken into account for the response spectrum calculation (accelerograms, maximal speed at ground level, ...).

### III.3.3 The Design Basis Earthquake:

**The seism that has finally to be taken into account for the design study is not directly the SMHV, but the Design Basis Earthquake** (SMS, Séisme Majoré de Sécurité), based on the SMVH intensity up one unit on the MSK scale[16]:

$I_{SMS} = I_{SMVH} + 1$ (MSK units)

Considering the relation (I), this definition of the SMS conventionally implies for the SMVH magnitude to be increased from 0.5, to obtain the SMS response spectrum.

It is moreover postulated that SMS level earthquakes can be preceded or followed by earthquakes which can reach the SMHV level.

Both the addition of one unit MSK to the SMHV and the postulation of pre- and aftershocks are conservative elements of the French approach.

To complete the seismic study, two more parameters may have to be taken into account:

- if active faults with surface break are located close to the facility, a method for their integration in the study is given in Annex 3 of the RFS;
- the site effects (amplification of the seismic motion due to mechanical and geometric particularities of the subsoil layout located close to the surface) has to be specifically studied if the subsoil is not known enough in the 30 meters under the facility. The response spectrum is then calculated for two site conditions, depending on the shear waves speed under the facility, and the design spectrum has to “include” the response spectra for both site conditions. For some other particular site effects not precisely specified, the response spectrum *“can be usefully completed by other indicators”*...

[16] Medvedev-Sponheuer-Karnik scale (1964), which classifies earthquakes in function of their observed impacts. This is the scale used in France to measure the seism intensity.

According to Philippe Saint-Raymond, deputy director of the French nuclear safety authority, "*there is [...] no explicit probabilistic consideration linked to the notion of SMS, because it is not really known what the extrapolation in the time could be, at these very low frequency levels. We estimate however, but this cannot be demonstrated, that the frequency of the SMS could be of about 1/10.000*"[17].

[17] P. Saint-Raymond, personal communication, 21 February 2003. M. Saint-Raymond commented upon its declaration that it has not been reviewed internally and therefore "*cannot however be taken as an official position*" of the safety authority.

### *III.4 Seismic Design and Instrumentation:*

The general purpose of the two RFS (RFS n°I.3.b and RFS n°V.2.g) which apply specifically to nuclear power plants is described as follow: "*The French regulatory practice provides for the safe shutdown of an NPP, the fuel cooling and the containment of the radioactive material to be ensured even in case of or after plausible earthquakes on the facility site that is considered.*"[18]

III.4.1 Seismic instrumentation:

The purpose of the RFS n°I.3.b is "*to define the nature, the location and the operating conditions of the seismic instrumentation required to know quickly the seismic motions applied to the building structure including important safety systems and components, in order to compare them to the seismic motions taken into account in the design study of the facility.*"[19] This instrumentation aims at knowing as quickly as possible the decisions that have to be taken and the actions that have to be done after a seism.

Each site has to be equipped by:

- an alarm, in each control room, and the accelerograms obtained during each significant seism (acceleration of at least 0.01g);
- mechanical recordings of the acceleration peeks, to compare with and confirm the previous recordings.

According to the RFS, the recorders (tri axial accelerometers) should have a band-width from 0.1 to 35Hz, and should be able to measure accelerations from at least 0.01 to 1g. The recordings last 30 seconds after the last tremor whose acceleration in more than 0.01g.

To determine the location of the seismic instrumentation, two kinds of sites are defined:

- "homogeneous" sites have homogeneous geological and mechanical soil features, and a regular topography;
- the other sites are called "heterogeneous".

For homogeneous sites, accelerometers have to be set up:

- at the reactor building raft's level;
- at one or several level(s) of the reactor building, approximately on the same vertical, high enough to know the effects on certain components important for safety located above the raft;
- at the raft level of another building including components important for safety and whose foundations are different from the reactor building's ones;
- in clear field.

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[18] Paragraph 1.1 of RFS n°I.3.b (June 1984) and RFS n°V.2.g (December 1985)

[19] In article 1.1 of the RFS n°I.3.b (June 1984).

For heterogeneous sites, the same locations are chosen, and also:

- one more accelerometer has to be set up in clear field in an area with different geological and topological features;
- one has to be set up in each reactor building, at raft's level.

If the measured spectrum of the seism is higher than a reference spectrum (half the design spectrum), the operator has to organize a "withdrawal" to the place considered as the safest for each reactor.

The re-starting of the plant will finally occur only after the safety authority will authorize it.

III.4.2 Building calculation codes:

The RFS n°V.2.g, more technical, aims at "*defining acceptable methods*" to determine and evaluate the motions and stress induced in the buildings by seismic actions. To achieve this purpose, it takes into account:

- the "design seismic motions" corresponding to the design spectrum (see above);
- the ground mechanical features of the foundation;
- the features of the civil engineering building and the potential interactions between buildings;
- the features of the devices linked to these buildings, if they are likely to modify their motions.

The rules defines:

- the characteristic parameters of the design seismic motions (definition of the "control point", the components and the wave nature of the design seismic motions);
- the calculation methods (usually spectral or temporal; a static calculation can be use for the vertical component. For each method, the sensibility to the hypothesis of the results has to be studied);
- the principles of mathematical schematizations of these calculations (modeling of the ground-structure interaction by impedance functions or discretization; modeling of the buildings by discretization);
- the use of seismic response to check the buildings;
- the documents to be presented to justify that the rules has been taken into account (description and justification of the foundations, building drawings and their justifications, parameters related to the soil, dynamic analysis of each building, ...).

## *III.5 Case Study: The Closure of the Cadarache Facility Because of Seismic Risk[20]:*

The MOX production facility at Cadarache, called ATPu (Plutonium technology facility) is a very interesting case showing how seismic risk has been re-evaluated and managed by the French nuclear safety authority and the operators, CEA and COGEMA[21].

ATPu was created in 1961 to produce mixed oxide (MOX) fuel for the fast breeder (FBR) and light water (LWR) reactors experimental programs, and was the first MOX production facility built in France. It was created in a regulatory context were no specific seismic rules were defined, and when operators could construct nuclear installations on the basis of a voluntary declaration to be compared with the current public inquiry process.

It is therefore comprehensible why ATPu's design did not include the seismic risk and why the question of the resistance of this installation raised with the development of seismic concern during the 90s.

In March 1994, an IPSN (former IRSN) report [IPSN 1994] established that seismic activity in the Cadarache region "*shows significant recurrence since the end of December 1993*". The document stated moreover that a segment of the Durance fault, a few kilometers from the center, "*has experienced notable activity on several occasions, not only since the setting up of the Cadarache unit (in 1966-67 and in 1985-86 especially), but also historically: it was the seat of intense activity throughout a large part of the 19th century beginning with an event of intensity VII-VIII on 20 March 1812*". This had been determined, thanks to the IRSN accelerogram network installed around the Durance fault, one of the most active faults in France. The area around Cadarache has been the seat of destructive seismic disturbances (maximum intensities reach VIII on the MSK scale) with a return period of around one century. The last event of this type occurred in 1913.

The question was therefore, taking into account a seismic study conducted by IPSN on the basis of the 1992 RFS I.1.c, dedicated to nuclear installations other than nuclear reactors (but formulated exactly like the RFS dedicated to nuclear reactors), to estimate the resistance of the ATPu to a SMS estimated to be IX on the MSK scale. On the basis of the 1992 RFS only, it became clear that the ATPu wasn't dimensioned to resist to the SMS.

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20 For more information on this case, see WISE-Paris' Briefing "ATPu (Plutonium Technology Facility) at Cadarache", 21 August 2000. On Internet: http://www.wise-paris.org/english/ourbriefings_pdf/000821BriefCAD1v4.pdf.

21 COGEMA has been the industrial operator of the ATPu since 1991. CEA Cadarache's management indicates on its website that "having become a COGEMA establishment in 1991, CEA Cadarache (the CFCa) has found its place naturally in the COGEMA Group's fuel production cycle". However, the CEA remains the operator where safety is concerned. In the list of BNIs established by the DSIN, no change in the authorization of the ATPu (INB n° 32) has been reported since its declaration of 27 May 1964 by the CEA. Decree n° 63-1228 of 11 December 1963, setting the rules applicable to BNIs and especially their regime of authorization, nevertheless stipulates that a new authorization is necessary for a BNI to change operator.

On 27 January 1995, following IPSN arguments, the DSIN (Directorate for Safety of Nuclear Facilities, the French safety authority name at this time) informed CEA and COGEMA that ATPu had to be closed due to its non-conformity to anti-seismic norms and the impossibility for the facility to be modified to meet French seismic standards. "*[...] to conclude, DSIN asks COGEMA to propose a plan for ATPu's future, including [...] a definitive and non-negotiable closing date of the facility, just after the year 2000*" [DSIN 1995].

As a consequence, and after intense discussions between DSIN and COGEMA, which lasted 7 years because of COGEMA reluctance to close its plant, the French Government decided as of October 2002, of the closure of the ATPu. Although the shutdown process will be long – COGEMA announced in January 2003 the end of commercial production at the end of July 2003, but some more time will be needed to effectively close the plant – it will be the first time a French nuclear installation is closed on the ground of seismic risk consideration.

### *III.6 Summary of Section on French State of the Art:*

The French regulations require deterministic determination of the design basis earthquake.

It is estimated in-officially that the probability of the design basis earthquake (the so-called SMS) is about $10^{-4}$/yr, but it is emphasized that this cannot be demonstrated.

The procedure for the determination of the design basis earthquake is similar to that employed in Germany. The "Maximum Historically Probable Earthquake" (SMHV) has to be determined in an extended area around the site, taking into account a broad database on geology, geophysics and seismicity. The most recent regulation (from 2001) explicitly includes the possibility of paleoseismic studies.

The design basis earthquake (SMS) is derived from the maximum historical earthquake (SMHV). In contrast to German procedure (where the difference between design basis earthquake and maximum historical earthquake has to be determined on a case-by-case basis), there is a generic rule for this derivation: 1 MSK unit has to be added to the SMHV's intensity in each case to arrive at the SMS.

Concerning seismic engineering data, the French regulations focus on free field response spectra. General standardized spectra are used, which are based on empirical calculation codes and numerous records compiled in an earthquake library.

French regulations clearly specify that the 50%-fractile values have to be selected in case of the response spectra.

Probabilistic methods are of even less importance for seismic hazard analysis in France than they are in Germany. Similar to the German approach, the seismic hazard assessment has to consist of well interlinked and consistent individual steps.

In contrast to German regulations, French regulations explicitly postulate that design-basis earthquakes can be preceded or followed by earthquakes of SMHV-intensity (weaker by one MSK unit).

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## Appendix 1: Full Text of German Regulation KTA 2201.1:

The text was downloaded from www.kta-gs.de on March 5, 2003.

# Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

**KTA 2201.1** (June/1990)

**Design of Nuclear Power Plants against Seismic Events;**
**Part 1: Principles**

(Auslegung von Kernkraftwerken gegen seismische Einwirkungen;
Teil 1: Grundsätze)

A previous version of this Safety Standard
was issued 6/75

If there is any doubt regarding the information contained in this translation, the German wording shall apply.

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# KTA SAFETY STANDARD

| June 1990 | Design of Nuclear Power Plants against Seismic Events;<br>Part 1: Principles | KTA 2201.1 |
|---|---|---|

## Contents



PLEASE NOTE: Only the original German version of this safety standard represents the joint resolution of the 50-member Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA). The German version was made public in Bundesanzeiger No. 194a on October 14, 2000. Copies may be ordered through the Carl Heymanns Verlag KG, Luxemburger Str. 449, 50939 Koeln (Telefax +49-221-94373-603).
All questions regarding this English translation should please be directed to:
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**Comments by the editor:**

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

| | |
|---|---|
| **shall** | indicates a mandatory requirement, |
| **shall basically** | is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of **shall normally** - are specified in the text of the safety standard, |
| **shall normally** | indicates a requirement to which exceptions are allowed. However, the exceptions used, shall be substantiated during the licensing procedure, |
| **should** | indicates a recommendation or an example of good practice, |
| **may** | indicates an acceptable or permissible method within the scope of this safety standard. |

## Basic Principles

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the task of specifying those safety-related requirements which shall be met with regard to precautions to be taken in accordance with the state of science and technology against the damage arising from the construction and operation of the facility (Sec. 7 para. 2 no. 3 Atomic Energy Act), in order to attain the protective goals specified in the Atomic Energy Act and the Radiological Protection Ordinance and further detailed in the "Safety Criteria for Nuclear Power Plants" and the "Guidelines for the Assessment of the Design of Nuclear Power Plants with Pressurized Water Reactor against Incidents pursuant to Sec. 28 para. 3 of the Radiological Protection Ordinance (Incident Guidelines)".

(2) In order to attain these protective goals, Safety Standard KTA 2201.1 - as part of KTA 2201 entitled "Design of Nuclear Power Plants against Seismic Events" - deals with the principles governing the design of nuclear power plants against seismic events. KTA 2201 also contains the following parts:

Part 2: Subsurface Materials (Soil and Rock)

Part 3: Design of Building Structures

Part 4: Requirements to be Met by Methods for the Demonstration of the Aseismic Safety of Mechanical and Electrical Components

Part 5: Seismic Instrumentation

Part 6: Post-Seismic Measures

## 1 Scope

This safety standard applies to nuclear power plants.

Note: By analogy, this safety standard may also be used as a basis for all other kinds of nuclear facilities.

## 2 Specification of the Design Basis Earthquake

(1) The design basis earthquake is the earthquake of maximum intensity at a specific site which, according to scientific knowledge, may occur at the site or within a larger radius of the site (up to approx. 200 km from the site).

Note:
The "intensity" of an earthquake is a measure of its impact on man, structures and the surface of the earth. In this safety standard, the term intensity is defined as the numerical value on the MEDVEDEV-SPONHEUER-KARNIK scale (MSK 1964).

(2) The specification of the design basis earthquake shall include statements of the expected maximum accelerations, the duration of excitation, response spectra, etc. on the basis of seismic assessment taking into account the prevailing geological conditions.

(3) The following principles shall constitute the basis for these assessments:

a) All historic earthquakes which have affected, or are assumed to have affected, the site shall be listed according to their frequency of occurrence and strength.

b) Historic earthquakes were characterized by various parameters such as magnitude, intensity and impacts on the ground, on structures and on man. As these parameters are not suited as input data for a design analysis, they shall be replaced by seismic engineering data using adequate relationships in accordance with the state of the art.

c) Horizontal and vertical accelerations shall be assumed to act simultaneously. The maximum vertical acceleration shall be assumed to be 50% of the maximum horizontal acceleration.

d) If epicenters or areas of maximum intensity of earthquakes are located in the same tectonic unit as the site; these earthquakes shall be assumed to occur in the vicinity of the site when determining the acceleration at the site.

e) If epicenters or areas of maximum intensity of earthquakes are located in a tectonic unit other than that of the site, the accelerations at the site shall be determined on the assumption that the epicenters or areas of maximum intensity of these earthquakes are located at a point on the boundary of their tectonic unit which is closest to the site.

f) The characteristics of ground movements shall be determined on the surface of the soil (free field) of the site.

g) The maximum acceleration of the design basis earthquake shall be assumed to be max a = 0.5 m/s² even if max a was determined to be smaller than 0.5 m/s².

h) The maximum acceleration of the design basis earthquake shall be assumed to be max a = 1.0 m/s² if max a was determined to be between 0.5 m/s² and 1.0 m/s².

Note:
The term "maximum acceleration" is defined as
- the rigid body horizontal acceleration of the free field response spectrum (suspension value),
- the maximum value of the resultant of the horizontal acceleration components during the strong-motion phase of the time history of an earthquake (amplitude value).

## 3 Classification of Plant Components

Taking the safety aspects of the total plant into consideration, plant components shall be divided into two classes for purposes of design against earthquakes:

Class I: Plant components

- which are required for shutting down the reactor safely, for maintaining it in a shutdown condition and for removing the residual heat,
- whose damage or failure can cause or result in an accident involving an impermissible release of radioactive materials,
- which are to prevent an impermissible release of radioactive materials to the environment, as well as all structures supporting or connecting these plant components.

Class II: All other plant components of the nuclear power plant.

Note: The term "plant components" also refers to buildings.

## 4 Loads

(1) For the design of plant components, the following loads shall be distinguished in connection with earthquake loads:

a) External loads during operation, for example dead weight, permanent loads, live loads, operational loads (considering operating conditions such as scram or refuelling), snow loads, wind loads, soil pressure, water pressure, slow-down and start-up forces.

b) Reactions from constraint during operation, for example forces and moments caused by temperature, creep, shrinkage and support displacements.

c) Reactions from earthquakes and consequential effects.

d) External loads caused by damage to plant components, which have not been designed against earthquakes, for example pressure build-up, pressure differential, forces from steam or water jets, temperature, missiles and debris.

(2) When combining the loads and reactions listed in para. (1) above, it shall be investigated whether a simultaneous or a sequential occurrence of these loads shall be taken into consideration.

(3) Non-permanent loads which favourably counteract the seismic loads shall not be taken into consideration.

(4) Combinations of loads resulting from earthquakes and earthquake-induced incidents and consequential incidents shall be taken into consideration.

## 5 Design

(1) All Class I plant components shall be designed in accor-dance with this safety standard and in such a way that their safety-related functions are preserved during a design basis earthquake. The seismic design of all plant components shall be coordinated.

(2) All Class I plant components shall be designed in such a way that the stresses and/or deformations will remain within admissible limits if the seismic loads of the design basis earthquake occur together with other leads (see Section 4).

Note:

The admissible limits are specified in KTA 2201.3 (being pre-pared) and KTA 2201.4.

(3) For Class II plant components, no demonstration in accordance with this safety standard is required. However, it shall be demonstrated (in accordance with Section 6) that potential effects from and damage to these plant components will not affect the safety-related functions of any of the Class I plant components.

## 6 Calculations

### 6.1 Dynamic Calculation

The calculations required for the design against seismic events shall be carried out by means of such methods (spectral methods, time histories) as will sufficiently account for the earthquake characteristics as well as the behaviour of the ground and of the plant components.

### 6.2 Simplified Calculation

For nuclear power plants at sites for which the maximum accelerations of the design basis earthquake were determined to be less than 1.0 m/s², simplified calculations may be substituted for the dynamic calculation.

### 6.3 No Calculation Required

If a sufficient degree of safety is either provided for by the design or demonstrated by experimental tests, a calculation need not be carried out.

## 7 Seismic Instrumentation

If the maximum acceleration of the design basis earthquake was determined to be max a k 1.0 m/s2 a seismic instrumentation shall be provided in accordance with KTA 2201.5 which will make it possible to determine whether 0.4 times the de-sign values of the design basis earthquake as determined by the calculation have been exceeded. When a value of this inspection level is exceeded, the nuclear power plant shall be subjected to a review.

Note:

The term "design value" is understood as the maximum acceleration determined in the calculation for the location where the acceleration pickup is installed (KTA 2201.5: Seismic Instrumentation).

## 8 Effects on the Site

### 8.1 Foundation

Changes to the - possibly improved - ground conditions that may result from an earthquake shall not adversely affect the safety-related function of Class I plant components.

### 8.2 Environment

Changes in the environment and destruction of engineered facilities such as they may result from an earthquake (e.g. bursting of darns or dikes) shall not adversely affect the safety-related function of Class I plant components.

## Appendix

**Regulations Referred to in this Safety Standard**

(Regulations referred to are only valid in the version cited in this Appendix)

| | | |
|---|---|---|
| KTA 2201.5 | (6/90): | Design of Nuclear Power Plants against Seismic Events;<br>Part 5: Seismic Instrumentation |

# Appendix 2: Full Text of French Regulation RFS 2001-01:

A brief summary of preceding regulations is also given here for reference.

## Appendix 2.1: RFS 2001-01:

The following text was downloaded from www.asn.gouv.fr/texte on March 5, 2003:

### Règles fondamentales de sûreté relatives aux installations nucléaires de base

**Règle fondamentale de sûreté n°2001-01**

**Domaine d'application :** Installations nucléaires de base à l'exception des stockages à long terme de déchets radioactifs

**Objet :** Détermination du risque sismique pour le sûreté des installations nucléaires de base de surface.



### 1. OBJET DE LA REGLE

La pratique réglementaire française prévoit que le maintien des fonctions importantes de sûreté d'une installation nucléaire de base en surface, notamment et selon ses caractéristiques précises, l'arrêt sûr, le refroidissement et le confinement des produits radioactifs, puissent être assurés pendant et/ou à la suite de séismes plausibles pouvant affecter le site de l'installation considérée. La présente règle a pour objet de définir une méthode acceptable pour la détermination des mouvements sismiques qui doivent être pris en compte pour la conception de l'installation à l'égard du risque sismique.
Dans les régions où les taux de déformation sont faibles, comme en France métropolitaine, la période de retour des forts séismes est grande et il peut être malaisé de rattacher certains séismes à des failles connues. De plus, malgré d'importants progrès dans les dernières années, il est difficile, dans le contexte sismotectonique français, d'identifier les failles potentiellement sismogéniques* et de déterminer les caractéristiques des séismes qu'elles pourraient produire. Aussi, la démarche proposée dans cette Règle Fondamentale de Sûreté vise à pallier cette

difficulté en prenant en compte tous les éléments directs et indirects qui peuvent jouer un rôle dans l'apparition de séismes ainsi que toutes les connaissances de la sismicité.
Par ailleurs, dans le domaine du calcul du mouvement sismique, la rareté des enregistrements de mouvements forts sur le territoire métropolitain nécessite de faire appel à des données provenant d'autres régions du monde.

## 2. ENONCE DE LA REGLE

Pour satisfaire aux objectifs énoncés en 1, la démarche de base explicitée ci-après est déterministe, dans le sens où les mouvements de référence sont associés à des séismes de référence. Dans une première étape, la règle se fonde sur la définition des caractéristiques de "Séismes Maximaux Historiquement Vraisemblables" (SMHV) considérés comme les séismes les plus pénalisants susceptibles de se produire sur une période de durée comparable à la période historique, soit environ 1000 ans. Dans une seconde étape, on définit les "Séismes Majorés de Sécurité" (SMS). La définition du mouvement de référence est, elle, basée sur l'utilisation d'une "sismothèque"*.
Pour certains sites, la prise en compte des données de paléosismicité peut conduire à compléter les mouvements associés aux SMS. Le principe de ces études est esquissé au 2.3.5 et développé dans l'annexe III.
Pour chaque site, une évaluation de ces séismes est effectuée selon les procédures définies en 2.2 et 2.3.
Les études correspondantes doivent être menées de façon aussi précoce que possible. Les rapports de sûreté de l'installation nucléaire de base doivent présenter les éléments principaux permettant de caractériser le (ou les) SMHV, le (ou les) SMS et les mouvements sismiques correspondants.

### 2.1. Définition et principes de détermination des caractéristiques des séismes représentatifs de la sismicité du site

La démarche de base consiste à supposer que des séismes analogues aux séismes historiquement connus sont susceptibles de se produire dans l'avenir avec une position d'épicentre* qui soit la plus pénalisante quant à ses effets (en termes d'intensité*) sur le site, tout en restant compatible avec les données géologiques et sismologiques.
A cet effet, la démarche est fondée sur la prise en considération autour du site, d'une part de zones sismotectoniques, d'autre part des données sismiques, suivant une méthode qui sera précisée au paragraphe 2.2. L'investigation doit être poussée géographiquement aussi loin que nécessaire pour être sûr que tous les séismes pouvant avoir un effet significatif sur la définition du ou des SMHV ont bien été retenus.
Cette opération permet de définir, pour le site envisagé, un ou plusieurs Séismes Maximaux Historiquement Vraisemblables qui sont le ou les séismes, résultant de la démarche précédente, susceptibles de produire sur le site les effets les plus importants en termes d'intensité macrosismique. On détermine ainsi sur le site une intensité ISMHV. Afin de tenir compte des incertitudes inhérentes à la détermination des caractéristiques des SMHV, une marge de sécurité est forfaitairement fixée de la manière définie ci-après.
Pour chacun des SMHV, on définit un "Séisme Majoré de Sécurité" (SMS), déduit du SMHV par la relation simple suivante en termes d'intensité sur le site :
I SMS = ISMHV+1 (1)
Sauf cas particulier traité en 2.3.5., les SMS sont considérés comme les séismes les plus agressifs à retenir pour l'évaluation de l'aléa sismique à prendre en compte pour le dimensionnement d'une installation.
On postule que les SMS peuvent être précédés ou suivis de séismes pouvant atteindre le niveau du SMHV.

### 2.2. Procédure d'évaluation des SMHV

Elle se fonde sur la délimitation de zones sismotectoniques. Celles-ci sont des volumes de la croûte terrestre homogènes du point de vue de leur potentiel sismogénique. On postule qu'un séisme qui s'est produit en un point d'une zone sismotectonique peut se produire en tout point de celle-ci.

#### 2.2.1. Détermination des zones sismotectoniques

Une synthèse des documents les plus récents concernant la géologie, la géophysique et la sismicité devra être menée. Une étude détaillée, prenant en compte les caractéristiques statiques et dynamiques de la croûte ainsi que la sismicité devra être présentée en complément. Une méthode pour la détermination des zones sismotectoniques est présentée dans l'annexe I.

### 2.2.2. Etude de la sismicité

Les données de la sismicité historique comportent des imprécisions tant sur le degré de connaissance des faits que sur l'appréciation des intensités macrosismiques. Les caractéristiques des séismes qui sont susceptibles d'intervenir dans la définition du ou des SMHV doivent être établies avec la meilleure précision possible, compte tenu des connaissances sur la sismotectonique et sur la sismicité historique et instrumentale.
Il convient de s'appuyer sur l'ensemble des informations rassemblées dans une base de données macrosismiques* actualisée (par exemple la base évolutive SISFRANCE*) en tant que source d'informations de base. Des informations complémentaires peuvent être nécessaires et un travail d'interprétation est indispensable.
Les caractéristiques qui sont susceptibles d'intervenir dans la définition des SMHV sont les suivantes :

- intensité à l'épicentre,
- isoséistes*,
- épicentre, foyer* et profondeur focale*,
- magnitude*,
- lois d'atténuation* régionales de l'intensité.

Une méthode pour déterminer ces caractéristiques est présentée en annexe II.
Les données de la sismicité instrumentale les plus actualisées doivent aussi être considérées pour compléter la connaissance de la sismicité.

### 2.2.3. Détermination des SMHV

Après la détermination des zones sismotectoniques, on retient comme SMHV le ou les séismes historiquement connus qui, déplacés à l'intérieur de leur zone, produisent sur le site les intensités les plus fortes, c'est-à-dire :
a) les séismes de la zone à laquelle le site appartient sont considérés comme pouvant se produire au droit du site,
b) les séismes des autres zones sont considérés comme pouvant se produire au point le plus proche du site de la zone à laquelle ils appartiennent.

## 2.3. Calcul des mouvements sismiques

Le mouvement* sismique est défini par les spectres de réponse* des composantes horizontale et verticale du mouvement à la surface des terrains du site. Cette définition peut être complétée par d'autres paramètres évoqués au paragraphe 2.3.3.

### 2.3.1. Calcul des spectres correspondant à un SMHV donné

Le calcul des spectres est fondé sur l'étude d'un grand nombre d'enregistrements rassemblés dans une "sismothèque". A partir des valeurs de la magnitude M et de la distance focale R* du SMHV considéré, les spectres de réponse correspondant aux composantes horizontales et verticale du mouvement sont calculés selon une loi moyenne* d'atténuation de la forme :
$\log10\ PSA = aM + bR - \log10R + c$ (2)
où PSA est la valeur du spectre de réponse (pseudo-accélération) pour une fréquence et un amortissement donnés.
Pour ce qui concerne la composante verticale, il est acceptable d'utiliser le spectre de réponse des composantes horizontales affecté d'un coefficient 2/3 pour toutes les fréquences.
Les coefficients de corrélation a, b et c, fonction de la fréquence et du taux d'amortissement considérés, sont évalués pour deux catégories de site (cf. 2.3.4). Ces coefficients sont valides dans un intervalle de distance et de magnitude fonction des enregistrements de la sismothèque et de l'analyse sismologique (soit une distance R comprise entre 7 km et 100 km et une magnitude M comprise entre 4,5 et 7,3). Les spectres sont calculés au moins pour la gamme de fréquence 0,25 - 33 Hz.
Pour les distances focales inférieures à 7 km, la méthode conventionnelle suivante pourra être adoptée : le calcul des spectres est effectué en considérant que R est égale à cette distance minimale et en majorant la magnitude M pour que le séisme produise les mêmes effets sur le site (ISMHV et ISMS constantes).
Dans le domaine de validité de la loi (2), l'accélération à fréquence infinie (égale à l'accélération maximale du mouvement du sol) est considérée égale à la valeur du spectre de réponse en accélération à la fréquence de 33 Hz.
La sismothèque, la méthode de détermination des coefficients de corrélation et leur domaine de validité sont décrits dans le rapport IPSN/DPRE/SERGD/2000/0053 établi sous assurance de la qualité.

#### 2.3.2. Calcul des spectres correspondant à un SMS donné

Le spectre du SMS est calculé à partir de la relation (2), dans son domaine de validité, en considérant que l'augmentation d'intensité de un degré entre le SMHV et le SMS correspond à une augmentation de la magnitude conventionnellement fixée à 0,5.

#### 2.3.3. Calcul d'autres paramètres du mouvement du sol

La définition du mouvement sismique sous forme de spectre de réponse pourra être complétée notamment par les données suivantes :
- durée de la phase forte,
- accélérogrammes,
- vitesse maximale du sol,
- A/V*,
- CAV*,
- Intensité d'Arias*.

Ces données doivent être compatibles avec les caractéristiques physiques du séisme (SMHV ou SMS) et les conditions de site définies au paragraphe 2.3.4.
La base de données ayant permis la détermination des coefficients de l'équation (2) peut être utilisée pour le calcul de ces différents paramètres.

#### 2.3.4. Prise en compte des effets de site

Les effets de site sont généralement dus à une amplification du mouvement sismique créée par une couche de sol de faible résistance mécanique à géométrie plane située près de la surface.
L'équation (2) permet de calculer les spectres pour deux conditions de site, à partir des caractéristiques dynamiques du sol déterminées conformément à la RFS I.3.c :
- les sites caractérisés par une vitesse moyenne des ondes de cisaillement* dans les 30 premiers mètres de profondeur supérieure à 800 m/s,
- les sites pour lesquels la vitesse moyenne des ondes de cisaillement dans les 30 premiers mètres est comprise entre 300 m/s et 800 m/s.

Lorsque le sol d'assise au droit de l'installation manque de caractérisation, a minima jusqu'à une profondeur de 30 m, ou présente de fortes variations latérales, le spectre de dimensionnement devra envelopper les spectres calculés avec les deux conditions de site.
Dans certains cas particuliers, la géométrie complexe des couches sédimentaires (présence d'une topographie ou d'une cuvette sédimentaire) ou leur grande épaisseur peut conduire à une amplification ou à un allongement de la durée du mouvement sismique. Ces effets particuliers ne sont pas dus simplement aux propriétés superficielles du sol (30 derniers mètres sous l'installation).
Dans ces cas d'effets de site particuliers ou dans les cas où la vitesse moyenne des ondes de cisaillement dans les 30 premiers mètres de profondeur est inférieure à 300 m/s, des études spécifiques seront nécessaires pour tenir compte de ces particularités dans l'estimation des mouvements sismiques associés aux SMHV et SMS. Dans ces situations, l'utilisation du spectre de réponse calculé avec la loi 2 peut être complétée utilement par d'autres indicateurs du mouvement sismique spécifiques au site considéré.

#### 2.3.5. Prise en compte des failles actives avec rupture de surface*

Dans le cas d'un site localisé à proximité immédiate d'une faille active avec rupture de surface, une étude visant à déterminer les mouvements sismiques associés aux séismes ayant pu se produire sur cette faille, et pouvant avoir un effet sur le site, sera effectuée. Des précisions sur la manière dont peuvent être conduites ces études sont fournies dans l'annexe III.

### 2.4. Prise en compte des mouvements sismiques

#### 2.4.1. Pour la conception des installations ou des parties d'installation à dimensionner aux séismes, les mouvements en champ libre définis en 2.3 doivent être utilisés comme suit.

**2.4.1.1** Le dimensionnement de l'installation doit être réalisé pour des sollicitations sismiques enveloppes de celles induites par les mouvements associés aux Séismes Majorés de Sécurité. Ce caractère enveloppe est établi en fonction des paramètres décrivant les mouvements du sol associés aux SMS. Il sera effectué, pour un amortissement réduit de 5%, une comparaison entre les spectres retenus pour la conception de l'installation et les spectres de réponse associés aux Séismes Majorés de Sécurité. Il sera suffisant de vérifier que les spectres retenus pour la conception de l'installation enveloppent les spectres de réponse associés aux Séismes Majorés de

Sécurité. L'emploi des données mentionnées au point 2.3.3. n'est pas systématique et se fera au cas par cas selon le type de site ou d'ouvrage considéré.

**2.4.1.2.** La prise en compte des spectres correspondant aux séismes déduits de l'étude des failles actives avec rupture de surface pour le dimensionnement de l'installation se fera au cas par cas en fonction de la période de retour* de ces séismes, du degré de certitude attaché à la connaissance de leurs caractéristiques et de la comparaison des spectres obtenus aux spectres associés au SMS.
**2.4.1.3.** Le spectre retenu par l'exploitant pour le dimensionnement de son installation ne pourra pas être inférieur à un spectre minimal forfaitaire calé en accélération à 0,1 g à la fréquence infinie. En fonction des conditions de site, les valeurs d'accélération de ce spectre sont définies par:

Vitesse des ondes de cisaillement inférieure à 800 m/s
Fréquence 0,25 Hz 2,5 Hz 8 Hz 30 Hz 33 Hz
Pseudo accélération 0,02 g 0,21 g 0,23 g 0,1 g 0.1 g

Vitesse des ondes de cisaillement supérieure à 800 m/s
Fréquence 0,35 Hz 3,5 Hz 9 Hz 30 Hz 33 Hz
Pseudo accélération 0,02 g 0,21 g 0,23 g 0,1 g 0.1 g

2.4.2. Pendant la phase de construction ou d'exploitation de l'installation, des progrès dans les données et les méthodes peuvent conduire l'administration à demander une réévaluation des mouvements sismiques correspondant à un site donné.

## ANNEXE I

### METHODE POUR LA DELIMITATION DES ZONES SISMOTECTONIQUES

Les zones sismotectoniques sont des volumes de la croûte terrestre homogènes du point de vue de leur potentiel sismogénique. L'objectif est de caractériser chaque zone par sa géométrie et la sismicité qui s'y produit. Une zone sismotectonique peut être constituée par plusieurs volumes distincts ayant les mêmes caractéristiques structurales et sismotec-toniques. Une faille ou un ensemble de failles peut à ce titre définir une zone.
La caractérisation des zones tient compte de toutes les données géologiques, géophysiques et sismiques disponibles.

### 1. Données à retenir

#### 1.1. Etat statique
Pour définir des zones sismotectoniques on peut considérer, par exemple :
- l'épaisseur de la croûte ;
- l'épaisseur de la couverture sédimentaire ;
- la nature lithologique des terrains ;
- la structure de la croûte qui résulte des principaux épisodes tectoniques. La géométrie des structures est essentielle pour la définition des zones. La direction des paléo-contraintes de ces différents épisodes tectoniques contribue aussi à l'identification des zones ayant eu la même histoire tectonique ;
- les données géophysiques.

#### 1.2. Etat dynamique
Chaque zone sismotectonique doit présenter une homogénéité de son régime de déformation (type et intensité de déformation sismique et asismique). Celui-ci est étudié en utilisant les données sur la sismicité, la déformation et les contraintes.

**1.2.1.** Sismicité
La sismicité est un indice de la déformation actuelle. Elle intervient à plusieurs titres pour la définition de zones sismotectoniques. Son analyse contribue à la connaissance du régime de déformation (type et intensité de la déformation sismique et asismique). Elle permet aussi la mise

en évidence de caractéristiques locales. Il convient de porter une attention particulière aux points suivants :
- la localisation des épicentres ;
- l'intensité à l'épicentre ou la magnitude des différents séismes, leur distribution quantitative en fonction de ces paramètres ;
- la profondeur de leurs foyers ;
- la géométrie des aires d'intensités les plus élevées des séismes majeurs ;
- la répartition spatiale et temporelle des séismes instrumentaux (principalement des répliques de forts séismes) ou des essaims d'épicentres historiques ;
- les mécanismes au foyer des séismes.

**1.2.2.** Déformations
Tous les indices de déformation néotectoniques*, qu'il s'agisse d'indices directs (ruptures dans les terrains récents, plis, manifestations volcaniques, etc.) ou indirects (anomalies morphologiques) doivent être répertoriés et étudiés. En particulier, les failles actives avec rupture de surface seront identifiées et les données les concernant seront quantifiées dans la mesure du possible. Dans le cas de décalages de marqueurs morphologiques, il convient de les dater.
Pour la période la plus récente, c'est à dire datant de moins d'un siècle environ, il convient de tenir compte des données des comparaisons de nivellements successifs, ainsi que des données de la géodésie classique (triangulation) et de la géodésie spatiale (Global Positionning System).
Les éléments présentés ci-dessus contribuent à la définition de zones homogènes quant à leur régime de déformation caractérisé par son type et son intensité.

Type de déformation. Dans la mesure du possible, il convient de déterminer pour chaque faille le type de déformation potentielle, à partir des données de la déformation récente et des directions de contraintes.

Intensité de déformation. Avec les données actuellement disponibles, l'intensité de déformation ne peut être définie que de manière qualitative en tenant compte des vitesses de déformation, de l'intensité du relief... L'étude de la sismicité peut aussi apporter des informations sur le taux de déformation sismique.

**1.2.3.** Contraintes
L'état de contraintes actuel du secteur retenu est examiné en considérant :
- les mesures de contraintes in situ ;
- les mécanismes au foyer des séismes ;
- les mesures microtectoniques dans les terrains récents et les alignements volcaniques.

**2. Délimitation des zones sismotectoniques**

Une synthèse des éléments présentés ci-dessus permet de définir des zones sismotectoniques constituées de volume de la croûte terrestre homogènes du point de vue de leur potentiel sismogénique. On postule qu'un séisme qui s'est produit en un point d'une zone sismotectonique peut se produire en tout point de celle-ci.
Une zone sismotectonique peut être constituée par une faille, voire même par une famille de failles présentant les mêmes caractéristiques géométriques et dynamiques, et les mêmes potentialités sismiques. Lorsqu'une zone est constituée d'une ou de plusieurs failles, sa délimitation doit tenir compte du pendage de ces structures.
Pour chaque zone, les caractéristiques statiques et dynamiques doivent être détaillées. En outre, pour les zones constituées par un ou des accidents, il convient de préciser les caractéristiques géométriques, la chronologie des différents mouvements et la sismicité associée.

## ANNEXE II

### METHODE POUR LA DETERMINATION DES CARACTERISTIQUES DES SEISMES REPRESENTATIFS DE LA SISMICITE DU SITE

Les caractéristiques utilisées dans la définition des séismes représentatifs de la sismicité du site sont :
- les coordonnées de l'épicentre ;
- l'intensité épicentrale ;
- les isoséistes ;
- la profondeur focale ;
- la magnitude ;
- les lois régionales d'atténuation de l'intensité.

En règle générale, les coordonnées de l'épicentre, la profondeur focale et la magnitude sont déduites des données macrosismiques. Cependant, pour les séismes récents, ces caractéristiques calculées à partir des données instrumentales peuvent être disponibles. Les valeurs doivent être comparées et leurs différences explicitées. Si les justifications sont insuffisantes pour choisir l'une de ces valeurs, la valeur la plus contraignante pour le site sera retenue.

**1. Coordonnées de l'épicentre et intensité épicentrale**
Les coordonnées de l'épicentre et l'intensité épicentrale sont déduites de la répartition en zone proche des observations ponctuelles des intensités estimées dans les localités. La localisation de l'épicentre correspond, en général, au barycentre de l'aire de la plus forte intensité, mais lorsque cette dernière est mal définie (par exemple, cas des épicentres en mer), la localisation approximative de l'épicentre peut être faite par des méthodes appropriées (loi d'atténuation de l'intensité, par exemple).
L'intensité épicentrale ne correspond pas nécessairement à l'intensité maximale observée (effet de site, épicentre en mer, zone montagneuse) et peut être déduite de la répartition des intensités ponctuelles en zone proche ou de l'utilisation de méthodes appropriées (loi d'atténuation de l'intensité, par exemple).

**2. Isoséistes**
Des courbes isoséistes peuvent être tracées si le nombre d'intensités ponctuelles de même valeur est suffisant et présente une distribution assez homogène. Ces courbes, qui lissent les effets locaux, permettent d'avoir une vue d'ensemble rapide des effets (niveau et extension). Lorsque leur qualité est reconnue, les courbes isoséistes permettent, au terme de l'analyse sismotectonique, de définir l'intensité sur le site des séismes représentatifs de la sismicité du site.

**3. Profondeur focale**
L'intensité, quand elle est estimée sur un nombre suffisant de points, peut présenter un schéma régulier de décroissance avec la distance à partir d'un point source explicable par un modèle énergétique très simple (relation de Sponheuer par exemple). Cette hypothèse est justifiée pour les séismes de magnitude moyenne à faible, représentatifs de la sismicité modérée de la France. La distribution des intensités peut alors être utilisée, après élimination des points particuliers (effets de site et phénomènes associés), pour estimer la profondeur du foyer du séisme. Le calcul doit être fait en utilisant de préférence l'ensemble des données macrosismiques, plutôt que des rayons de courbes isoséistes qui résultent d'une interprétation. L'estimation de la profondeur est d'autant plus précise que le nombre des intensités ponctuelles est abondant et que leur distribution est homogène, notamment en zone proche de l'épicentre. En l'absence de données macrosismiques suffisantes, la profondeur pourra être déduite de celles des séismes instrumentaux ou historiques bien documentés, localisés dans le même domaine sismotectonique ou à partir d'autres méthodes. Si des différences significatives apparaissent et que les justifications ne permettent pas de choisir l'une ou l'autre valeur, la valeur la plus contraignante pour le site sera retenue.

**4. Magnitude**
La magnitude des séismes historiques doit être déterminée à partir des corrélations disponibles les mieux adaptées au contexte français, liant la magnitude à l'intensité et à la distance focale établies à partir d'ensembles de données macrosismiques homogènes. Ces corrélations calées sur des séismes pour lesquels on dispose à la fois des magnitudes instrumentales (M) et des

intensités macrosismiques (I) sont de la forme courante :
M = a I + b log R + e, dans lequel R est la distance focale (km).
On évitera l'utilisation de telles corrélations établies uniquement sur la seule valeur de l'intensité épicentrale. A l'épicentre, la distance focale est la profondeur du foyer.

**5. Lois d'atténuation régionales**
Dans la mesure du possible, il convient d'utiliser des lois d'atténuation régionales fondées sur un modèle de décroissance de l'intensité avec la distance (relation de Sponheuer par exemple) ; ces lois peuvent servir pour définir l'intensité sur le site d'un séisme, en l'absence de courbes isoséistes. Les lois seront établies sur l'ensemble des données macrosismiques d'un nombre suffisant de séismes contenues dans la base ayant servi à l'évaluation de l'aléa sur le site, ou bien issues d'autres ensembles de données, à condition d'apporter la preuve que ces lois sont bien adaptées au contexte régional du site.

## ANNEXE III

### PRISE EN COMPTE DES FAILLES ACTIVES AVEC RUPTURE DE SURFACE

Dans le cadre de l'étude visant à déterminer les mouvements sismiques associés aux séismes ayant pu se produire sur une faille active avec rupture de surface, la méthode suivante, en trois étapes, peut être utilisée.

La première étape consiste à décrire les observations qui permettent de conclure à l'occurrence d'une ou plusieurs ruptures de surface d'origine co-sismique* et de déterminer l'âge de ces ruptures et la valeur du glissement unitaire. La prise en compte des indices de paléosismicité est étayée par les éléments suivants :

§ une observation directe d'une ou plusieurs ruptures de surface (photo, dessin, description d'affleurement) ou évidence morphologique claire d'un décalage de marqueurs géologiques datés et identifiés (terrasses fluviatiles, cours d'eau, horizons repère, etc ...). Chaque rupture de surface doit être en relation avec une faille dont les dimensions (géométrie, aire, longueur) sont compatibles avec la magnitude estimée du ou des paléoséismes ;
§ une étude du caractère tectonique de la déformation. Les autres hypothèses permettant d'expliquer les déformations observées doivent être examinées (processus gravitaires, diapyrisme, halocinèse, arglocinèse, glaci-tectonique, glaciel, karstique, processus lié aux déformations superficielles dans l'environnement périglaciaire...) ;
§ une évaluation de l'âge du dernier niveau affecté (quelle que soit la méthode de datation) et si possible la valeur du temps de retour entre deux ou plusieurs événements.

La seconde étape consiste à évaluer le temps de retour des paléoséismes à partir de la vitesse moyenne de glissement de la faille. Cette vitesse est estimée en utilisant les données géologiques, géodésiques ou la distribution en fréquence et en magnitude des séismes de la région. Les indices paléosismiques montrant des événements séparés par un temps de retour inférieur ou égal à quelques dizaines de milliers d'années doivent être pris en compte.

La troisième étape consiste à déterminer la gamme de magnitudes associées à la rupture de surface à partir de l'étude de la longueur, de la segmentation et de la profondeur sismogénique* de la faille. Dans le contexte français, ces paramètres sont difficiles à déterminer et on peut, le cas échéant, se reporter aux relations empiriques publiées et couramment utilisées liant la valeur du glissement et la magnitude.

La magnitude des paléoséismes doit être évaluée à l'aide de la magnitude de moment que l'on considère égale à la magnitude Ms entre Mw=6,5 et Mw=7,5. Le mouvement sismique associé à chacune des hypothèses concernant la magnitude du paléoséisme est calculé en utilisant l'équation (2) du paragraphe 2.3.1.

## GLOSSAIRE

**A/V :** Ce paramètre exprimé en s-1, où A et V désignent respectivement l'accélération et la vitesse maximales d'un signal, donne une information sur le contenu fréquentiel de ce signal.

**CAV :** On appelle CAV (Cumul en valeur Absolue de la Vitesse) la quantité suivante :

**CAV :** |g(t)| dt

Il s'agit de l'intégrale, sur la durée du séisme, de la valeur absolue de l'accélération g(t). Elle s'exprime en m/s.

**Co-sismique :** caractère lié à l'occurrence d'un séisme. Une rupture co-sismique est créée par la rupture tectonique instantanée de la faille qui génère le séisme. Elle se distingue d'une rupture créée par un phénomène différent de la tectonique (effondrement, glissement de terrain, etc...) ou bien de la déformation a-sismique (glissement lent le long d'une faille).

**Distance focale :** distance entre le foyer d'un séisme et un point donné.

**Donnée macrosismique :** information déduite de l'observation en surface des effets des séismes.

**Durée de phase forte :** La durée de la phase forte d'un signal sismologique est généralement définie par l'intervalle de temps entre le moment où le signal a atteint 5% de l'intensité d'Arias et le moment où il en a balayé 95%.

**Epicentre :** point de la surface du sol situé à la verticale du foyer d'un séisme.

**Faille active avec rupture de surface :** faille montrant l'évidence de mouvements récurrents à proximité de la surface dans une période de plusieurs dizaines de milliers d'années.

**Foyer :** point à l'intérieur de la terre considéré comme l'origine de l'énergie dissipée par le séisme.

**Intensité :** évaluation en une zone limitée de la surface du sol des effets d'un séisme, sur des bases statistiques, par référence aux critères d'une échelle descriptive.

Dans la présente règle, il est fait usage de l'intensité macrosismique MSK (Medvedev-Sponheuer-Karnik, 1964) qui a servi à évaluer l'intensité des séismes contenus dans la base de données SISFRANCE (ex-SIRENE) et, pour les séismes récents, de l'échelle EMS 1998 (European Macroseismic Scale, version 1998) prolongement de l'échelle MSK, plus adaptée aux constructions actuelles. Ces échelles comportent douze degrés; l'intensité peut s'exprimer sous forme de degré ou de demi-degré.

**Intensité d'Arias :** l'intensité d'Arias est définie par l'expression suivante

I = g2(t)dt

Il s'agit de l'intégrale, sur la durée du séisme, du carré de la valeur de l'accélération g(t). Elle s'exprime en m/s

**Isoséiste :** courbe qui enveloppe des points de même intensité et sépare deux aires dans lesquelles les intensités observées pour un même séisme sont différentes.

**Loi d'atténuation :** loi décrivant la décroissance d'un paramètre en fonction de la distance. Dans la présente règle, il est fait référence, d'une part à l'atténuation de l'intensité en fonction de la distance focale, d'autre part à l'atténuation des ordonnées spectrales du spectre de réponse en fonction de la distance et de la magnitude.

**Loi moyenne :** les valeurs du spectre de réponse obtenues à partir des enregistrements suivent une distribution log-normale (les logarithmes de ces valeurs sont distribués de façon normale). La régression aux moindres carrés en deux étapes utilisée pour déduire les coefficients de la loi d'atténuation (2) a été établie sur le logarithme des valeurs d'accélération. La valeur moyenne du logarithme des accélérations spectrales est donc égale à la valeur médiane du fait de cette distribution normale. Cela signifie que la valeur donnée par la loi (2) représente un intervalle de confiance de 50% et celle prédite par la loi (2) augmentée de son écart type un intervalle de confiance de 84%.

**Magnitude :** grandeur obtenue par la mesure de l'amplitude des ondes enregistrées par un sismographe ; la magnitude fournit une estimation de l'énergie dissipée au foyer sous forme d'ondes sismiques. Il existe plusieurs définitions de la magnitude :

**La Magnitude locale (Ml)** est définie à partir de l'amplitude maximale soit des ondes P, soit des ondes S. Le LDG utilise l'amplitude maximum de la phase S mesurée sur la composante verticale de la vitesse (Plantet, 1978). Pour une distance épicentrale D :

**ML(LDG)** = log(A/T) + B(D) + C

**A :** amplitude maximum en déplacement des ondes S,
**T :** période associée,
**B(D) :** coefficient d'atténuation moyen,
**C :** correction de station.

La magnitude d'un séisme est la moyenne des valeurs calculées dans les stations situées de 100 à 1500 km de l'épicentre.

**La magnitude de surface (Ms)** est mesurée à partir des ondes de surface de Rayleigh. Une définition générale de la magnitude de surface Ms est la suivante :

**Ms =** log10 (A/T) + s (D,h) + s(Ms)

**A :** amplitude du déplacement du sol,
**T :** période associée,
**s (D,h) :** fonction de calibration empirique amplitude-distance,
**s (Ms) :** terme correctif permettant de prendre en compte les effets de site, les trajets et les mécanismes au foyer (Wilmore, 1979).

**La magnitude de moment (Mw)** est reliée au moment sismique Mo du séisme. Mo s'exprime de façon simple en fonction de la surface S de la faille qui a joué, du déplacement (ou dislocation) moyen D sur cette faille et de la rigidité m du milieu, par la relation Mo= m S D. La magnitude Mw est alors reliée à Mo par l'expression :

**Mw =** 2/3log Mo - 6,0

Pour les magnitudes inférieures à 7,5, les valeurs trouvées pour Mw, Ms et Ml sont quasi-identiques (Madariaga et Perrier, 1991).

**Mouvement sismique :** mouvement d'un point de la surface du sol en champ libre, c'est-à-dire en l'absence de toute installation.

**Néotectonique :** relatif à la déformation actuelle de la croûte terrestre.

**Période de retour :** intervalle de temps moyen entre deux séismes, dans une gamme de magnitude donnée, se produisant sur une même faille ou dans une zone spécifique.

**Potentiel sismogénique :** capacité d'une zone à produire des séismes de caractéristiques données.

**Profondeur focale :** distance entre le foyer d'un séisme et l'épicentre.

**Profondeur sismogénique :** profondeur maximale atteinte par les ruptures cosismiques.

**SISFRANCE :** base de données sur la sismicité historique (BRGM/EDF/IPSN) anciennement dénommée SIRENE. Cette base de données macrosismiques comprend des informations (dates, positions des épicentres, valeurs d'intensité ponctuelles, ...) sur les séismes historiques et contemporains en France.

**Sismothèque :** ensemble d'enregistrements accélérométriques obtenus à la surface du sol lors de séismes.

**Spectre de réponse :** courbe correspondant à l'amplitude maximale, en fonction de la fréquence, de la réponse d'oscillateurs simples pour un amortissement donné, lorsqu'ils sont sollicités par le mouvement du sol.

**Vitesse moyenne des ondes de cisaillement :** vitesse moyenne de propagation des ondes de cisaillement en se plaçant dans le cas des faibles déformations.

## App. 2.2: French seismic regulations for nuclear facilities built before 2001:

Seismic studies for nuclear power plants (built before 2001)[22]:

The RFS n°I.2.c is the former RFS that defines the method which should be used for the determination of the seismic intensity for the design of a nuclear power plant, and the method to convert this intensity into usable data.

To determine the seismic risk, a Maximum Historically Probable Earthquake (SMVH, Séisme Maximal Historiquement Vraisemblable) is defined as the maximum earthquake that has been historically found around the site. Wherever this historical seism really took place, the SMVH is chosen to be located at the epicentre position that implies the maximum effects on the site, considering this position has to remain compatible with the geological and seismic data.

The seism that has to be considered for the design study is called the Safe Shutdown Earthquake (SMS, Séisme Majoré de Sécurité), based on the SMVH "increased" to 1 unit on the MSK scale[23]:

$I_{SMS} = I_{SMVH} + 1$ (MSK units)

The intensity of a seism is not a datum directly usable for the design study of a facility. For the considered site, each intensity has to be linked to an oscillator response spectrum giving the acceleration frequency and the horizontal and vertical speeds and motions at ground level (taking into account the epicenter depth, the intensity, the features of the local soil, etc.), and summarizing the potential effects of the seism.

The oscillator response spectrum for the SMS is extrapolated from the SMHV effects. As the response spectra associated to real earthquakes are very complex, a general standardized spectrum is used, except for nearby earthquakes (focal center at less than 10km; see below). This standardized spectrum is based on an empirical calculation, and on numerous recordings of a "library of earthquakes" managed by the CEA[24].

Nearby earthquakes (focal center at less than 10 km) with a magnitude higher than 5 imply specific studies that are not taken into account in the RFS. For the other nearby earthquakes, the observations are not numerous enough to elaborate an empirical response spectrum. In this case the operator has to propose a response spectrum adapted to the knowledge of the site.

If this method cannot be applied, the RFS gives the parameters to be taken into account by the operator. Anyway, such a seism has not to be taken into account if the SMHV intensity is below or equal to VI.

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22 In comparison to RFS 2001-01, the approach of this RFS is also deterministic, except for the case of "nearby earthquakes" (less than 10 km), for which both probabilistic and deterministic methods can be used.

23 Medvedev-Sponheuer-Karnik scale (1964), which classifies earthquakes in function of their observed impacts. This is the scale used in France to measure the seism intensity.

24 Only a few nuclear reactors located in the Paris Basin are given a special response spectrum, as this area is *"an almost non-seismic one"*.

Seismic studies for nuclear installations other than power plants (built before 2001):

The RFS n°I.1.c applied to the nuclear facilities, except the power plants and the facilities dedicated to the long term storage of the radioactive wastes. The purpose of this RFS is "*to define a method to determine the seismic motions to take into account for the design of each workshop [inside each facility] that can lead to unacceptable radioactive release*". It follows actually exactly the same method as RFS n°I.2.c on seismic studies for nuclear reactors to evaluate the seismic risk and its potential effects on the facility (see above, RFS n°I.2.c).

The only difference is that the administrative authority has to decide "*case by case*" which dispositions have to be taken to appreciate the resistance of each facility.