Specific Requirements – External Events - Earthquakes

Earthquakes

The seismological and geological conditions in the region and the engineering geological aspects and geotechnical aspects of the proposed site area shall be evaluated. Information on prehistorical, historical and instrumentally recorded earthquakes in the region shall be collected and documented. The hazards associated with earthquakes shall be determined by means of seismotectonic evaluation of the region with the use to the greatest possible extent of the information collected. Hazards due to earthquake induced ground motion shall be assessed for the site with account taken of the seismotectonic characteristics of the region and specific site conditions. A thorough uncertainty analysis shall be performed as part of the evaluation of seismic hazards.

The potential for surface faulting (i.e. the fault capability) shall be assessed for the site. The methods to be used and the investigations to be made shall be sufficiently detailed that a reasonable decision can be reached using the definition of fault capability. A fault shall be considered capable if, on the basis of geological, geophysical, geodetic or seismological data, one or more of the following conditions applies:

1- It shows evidence of past movement or movements (significant deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to infer that further movements at or near the surface could occur. In highly active areas, where both earthquake data and geological data consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults.





FAULTS PROPERTIES

Section of a dipping fault (length L) which strikes at an angle $\phi~$ east of north and dips at an angle $\delta.$

🕇 ← 🛛 length L→

Surface of rupture S=LxW

width W

K = bulk or incompressibility modulusd= fault slipS = fault surface rupture

SEISMIC MOMENT Mo =K•d •S (dyne•cm)

2- A structural relationship with a known capable fault has been demonstrated such that movement of the one may cause movement of the other at or near the surface.

3- The maximum potential earthquake associated with a seismogenic structure is sufficiently large and at such a depth that it is reasonable to infer that, in the geodynamic setting of the site, movement at or near the surface could occur.

Where reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation, an alternative site shall be considered.



The view southeast along the San Andreas fault in the Carrizo Plain of California. The San Andreas is a transform fault, forming a portion of the sliding boundary between the Pacific and North American plates. *R. E. Wallace, USGS*.

IAEA SSG- 9 - General

The current version of the Safety Guide NS-G-3.3 on "Evaluation of Seismic Hazards for Nuclear Power Plants", was issued in 2002.

IAEA Specific Safety Guide SSG-9 supersedes Evaluation of Seismic Hazards for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.3 (2002).

The objective of this Safety Guide is to provide recommendations and guidance on evaluating seismic hazards at a nuclear installation site and, in particular, on how to determine: (a) the vibratory ground motion hazards, in order to establish the design basis ground motions and other relevant parameters for both new and existing nuclear installations; and (b) the potential for fault displacement and the rate of fault displacement that could affect the feasibility of the site or the safe operation of the installation at that site.

IAEA SSG- 9 - General

The geological, geophysical and seismological characteristics of the region around the site and the geotechnical characteristics of the site area should be investigated. Where necessary, the site region should include areas extending beyond national borders.

The database acquired should be homogeneous for the entire region to the extent possible or, at a minimum, should be sufficiently complete for characterizing, from a seismotectonic point of view.

The general approach to seismic hazard evaluation should be directed towards reducing the uncertainties at various stages of the evaluation process in order to obtain reliable results driven by data. Experience shows that the most effective way of achieving this is to collect a sufficient amount of reliable and relevant data. There is generally a trade-off between the time and effort necessary to compile a detailed, reliable and relevant database and the degree of uncertainty that the analyst should take into consideration at each step of the process.

IAEA SSG- 9 - Uncertainty

The collection of site specific data tends to reduce uncertainties. However, part of the data used indirectly in seismic hazard evaluation may not be site specific; for example, in many cases the strong motion data used to develop the attenuation relationships. There may be, therefore, a part of the uncertainty which is irreducible with respect to site specific investigations. This should be recognized and taken into consideration by including aleatory uncertainty (i.e. uncertainty that is intrinsic or random in nature) and epistemic uncertainty (i.e. uncertainty that is extrinsic in nature or is associated with modelling) within the framework of seismic hazard evaluation.

IAEA SSG- 9 - Database

The integrated database should include all relevant information; that is, not only geological, geophysical, geotechnical and seismological data, but also any other information that is relevant to evaluating the ground motion, faulting and geological hazards at the site.

Investigations should be conducted on four spatial scales — regional, near regional, site vicinity and site area — leading to progressively more detailed investigations, data and information.

The first three scales of investigation lead primarily to progressively more detailed geological and geophysical data and information. The site area investigations are aimed at developing the geotechnical database

IAEA SSG-9 – Seismological Database

The compilation of the seismological database will normally be less dependent on the regional, near regional and site vicinity scales than that of other databases. However, seismogenic structures in the near region and in the site vicinity will usually be more important for seismic hazard evaluation, depending on the rates of activity, the expected maximum potential magnitudes and the regional attenuation of ground motion.

Regional Investigation

The size of the relevant region may vary, depending on the geological and tectonic setting, and its shape may be asymmetric in order to include distant significant seismic sources of earthquakes. Its radial extent is typically 300 km

The purpose of obtaining data on a regional scale is to provide knowledge of the general geodynamic setting of the region and the current tectonic regime, as well as to identify and characterize those geological features that may influence or relate to the seismic hazard at the site.

The most relevant among these geological features are structures that show potential for displacement and/or deformation at or near the ground surface; that is, capable faults. The data obtained from any type of published and unpublished geological and geophysical source (e.g. data derived from existing galleries, road cuts, geophysical surveys or boreholes) should be presented on maps with appropriate cross-sections.

The data are typically presented on maps at a scale of 1:500 000 or larger, and with appropriate cross-sections.

Near regional investigations

Near regional studies should include a geographical area typically not less than 25 km in radius, although this dimension should be adjusted to reflect local conditions. The objectives of these studies are to:

- 1) Define the seismotectonic characteristics of the near region on the basis of a more detailed database than that obtained from the regional study;
- (2) Determine the latest movements of faults;
- (3) Determine the amount and nature of displacements, rates of activity and evidence related to the segmentation of faults.

To supplement the published and unpublished information for the near regional area, specific investigations typically should include a definition of the stratigraphy, structural geology and tectonic history of the near region.

In addition to field mapping, other sources of data should be used if necessary, for example:

Subsurface data derived from geophysical investigations (such as seismic reflection, refraction, gravimetric, electric and magnetic techniques), to characterize spatially the identified structures considered to be relevant in terms of their geometry, extent and rate of deformation.

Investigations should be made in sufficient detail so that the causes of each recent (in terms of the pertinent time window for the specific local tectonic environment) geological and geomorphological feature that is relevant (e.g. linear topographic or structural features as found photographs, remote sensing imagery or geophysical data) can be properly included in a reasonable model of the recent geological evolution of the area.

The data are typically presented on maps at a scale of 1:50 000 and with appropriate cross-sections.

Investigations should be made in sufficient detail so that the causes of each recent (in terms of the pertinent time window for the specific local tectonic environment) geological and geomorphological feature that is relevant (e.g. linear topographic or structural features as found photographs, remote sensing imagery or geophysical data) can be properly included in a reasonable model of the recent geological evolution of the area.

The data are typically presented on maps at a scale of 1:50 000 and with appropriate cross-sections.

As a minimum, the following data sets should be provided:

a) A geological map with cross-sections;

- (b) Age, type, amount and rate of displacement of all the faults in the area;
- (C) Identification and characterization of locations potentially exhibiting hazards induced by natural phenomena (e.g. landslide, subsidence, subsurface cavities or karstic processes) and by human activities.

Typically, the data are presented on maps at a scale of 1:5000 and with appropriate cross-sections.

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Typically, the data are presented on maps at a scale of 1:5000 and with appropriate cross-sections.

The following investigations of the site area should be performed, by using field and laboratory techniques:

a) Geological and geotechnical investigations to define the stratigraphy and the structure of the area: Investigations using boreholes or test excavations (including in situ testing), geophysical techniques and laboratory tests should be conducted to define the stratigraphy and structure of the site area and to determine the thickness, depth, dip, and static and dynamic properties of the different subsurface layers as may be required by engineering models (e.g. Poisson's ratio, Young's modulus, shear modulus, density, relative density, shear strength and consolidation characteristics, grain size distribution).

IAEA SSG- 9 – Seismological Database

Prehistoric and historical earthquake data (pre-instrumental data)

To the extent possible, the information on each earthquake should include:

(a) Date, time and duration of the event;

(b) Location of the macroseismic epicentre;

(c) Estimated focal depth;

(d) Estimated magnitude, the type of magnitude (e.g. moment magnitude, surface wave magnitude, body wave magnitude, local magnitude or duration magnitude;) and documentation of the methods used to estimate magnitude from the macroseismic intensity;

(e) Maximum intensity and, if different, intensity at the macroseismic epicentre, with a description of local conditions and observed damage;

(f) Isoseismal contours;

IAEA SSG- 9 – Seismological Database – Instrumental Earthquake Data

The information to be obtained for each earthquake should include:

- (a) Date, duration and time of origin;
- (b) Coordinates of the epicentre;

(c) Focal depth;

(d) All magnitude determinations, including those on different scales, and any information on seismic moment;

(e) Information on observed foreshocks and aftershocks, with their dimensions and geometry where possible;

(f) Other information that may be helpful in understanding the seismotectonic regime, such as focal mechanism, seismic moment, stress drop and other seismic source parameters;

IAEA SSG-9 – Seismological Database – Instrumental Earthquake Data

To acquire more detailed information on potential seismic sources, it is recommended that a network of sensitive seismographs having a recording capability for micro-earthquakes be installed and operated. The minimum monitoring period necessary to obtain meaningful data for seismotectonic interpretation is at least several years for regions of high seismicity, and is much longer for regions of low seismicity.



IAEA SSG-9 – Seismological Database – Instrumental Earthquake Data





Modern seismic monitoring

Seismographic recording of P, S and surface waves

SSR-1

Seismographs record (a) vertical or (b) hori-

Seismic hazard

IAEA SSG-9 – Seismological Database – Instrumental Earthquake Data



Distance (km) ~ S-P (sec) X 7

Epicenter location



(a) Seismograms of the same earthquake as recorded by seismographs located at A, B, and C. The time interval between the passage of the P wave and that of the S wave allows the calculation of the distance between the seismograph and the earthquake, because the speeds of P waves and S waves are known. (b) This is shown on a map as the radius of a circle with the seismograph at the center. The earthquake is located where the three circles intersect. Modified from Press and Siever (1994).



IAEA SSG-9 – Earthquake Measuring

Measuring the size of an earthquake

Approximate correlation between epicentral intensity (Io-MCS) and Richter magnitude



INTENSITY (Mercalli scale) Empirical scale measuring the effects of an earthquake on the environment, people, and buildings

MAGNITUDE (Richter scale) Instrumental scale measuring the amplitude of the ground motion recorded by a seismograph. It's proportional to the energy released

IAEA SSG- 9 – Seismotectonic Model

CONSTRUCTION OF A REGIONAL SEISMOTECTONIC MODEL

The link between the geological, geophysical, geotechnical and seismological databases and the calculation of the seismic hazard is a regional seismotectonic model, which should be based on a coherent merging of the databases.

The standard procedure is to integrate the elements of the seismological, geophysical and geological databases in order to construct a coherent seismotectonic model (and alternative models) consisting of a discrete set of seismogenic structures.

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IAEA SSG- 9 – Seismotectonic Model

Magnitude and Energy

The magnitude is proportional, through a <u>logaritmic</u> <u>scale</u> to the energy released at the focus log(E)= 1.5M + 11.8 (erg) For each unit of M the amplitude of ground motion increases by a factor of 10 and the energy by a factor of 32



The magnitude is also proportional to the length of the fault rupture M= 5.08 + 1.16 log(Lfr) (Wells & Coppersmith, 1994)



IAEA SSG- 9 – Magnitude

ML Local magnitude(Richter 1935)log. of max amplitude (micron) of a seismogram recorded by a Wood-Anderson seismograph at 100Km from the epicenter. For different seismographs and distance appropriate calibrations are used.
ML= log A - log A°ML= log A - log A°(log A° calibration factor)(wave period 1-2 sec)

mbBody waves magnitude
mb= log(A/T) + Q(h,R)(wave period 1 -10 sec)A/T ratio of max. amplitude and period calculated on body waves;
Q(h,R) calibration factor depending on distance R and depth h of the earthquake.

IAEA SSG- 9 – Magnitude

MS Surface waves magnitude

calculated as a mean of the recordings of several seismographs generally located at large distances from the epicenter (thousands of km)

MS= log(A/T) + 1.66 log D° + 3.3 + Ci (w A/T ratio of max. amplitude and period calculated on surface waves; D° epicentral distance in degreees; Ci calibr. station coefficient

(wave period ~ 20 sec)

Mw Moment magnitude

the only type of magnitude not affected by saturation problems; calculated on the basis of the seismic moment Mo derived from the Fourier spectra of the seismometric recordings

<u>Mw</u> = 2/3log(Mo) -10.7

Seismic Hazard - PSHA MAPS in Italy





Seismic hazard

Seismic Hazard - PSHA MAPS in Italy



Seismic hazard