Note:
This is a translation of the RSK statement entitled “Mindestwert von 0,1g (ca. 1,0 m/s²) für die maximale horizontale Bodenbeschleunigung bei Erdbeben”
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK statement
(457th meeting on 11 April 2013)

Minimum value of 0.1 g (approx. 1.0 m/s²) for earthquake peak horizontal ground accelerations

CONTENTS

1 Background

As a result of the EU (ENSREG) stress test, the Stress Test Peer Review Board[1] has formulated the following recommendations for the German plants:

"The PGA[2] values obtained for specific sites vary between 0.05 g and 0.21 g. For some sites, the PGA values are therefore below the IAEA SSG-9 recommended value of 0.1 g, which is explained by German experts to be due to the use of site specific response spectra. Nevertheless, the reviewers recommend that the German regulatory authority should consider the possible safety impact of using PGA that is below the internationally recommended value."

In response, in letter RS I 3 – 13042-3/2, RS I 5 – 13043/03.01 of 8 November 2012, the BMU asked the RSK Committee on PLANT AND SYSTEMS ENGINEERING (AST) to consult on the following questions:

1 What are the safety impacts of the difference between the two approaches to determining the minimum level for seismic design, on the one hand on the basis of IAEA NS-G-1.6 (2003) and SSG-9 (2010) and, on the other hand, on the basis of the German nuclear safety standards (KTA 2201.1, version 2011, version 1990, version 1975)?

2 To what extent does the peak ground acceleration (PGA) defined by the IAEA in SSG-9 (2010) and used in NS-G-1.6 (2003) correspond to the maximum acceleration described in KTA 2201.1, versions 1975, 1990, 2011 as well as in the documentation of KTA 2201.1, version 2011?

3 Do the three approaches referred to here achieve at least equivalent minimum levels for seismic design and what ranges of variation in the results can be identified in each case?

4 How can assessments on the minimum design level according to the previous acceleration-based approach in Germany (KTA 2201.1, version 1975 and version 1990) be transferred in terms of method and result to the intensity-based approach (KTA 2201.1, version 2011)?

2 Consultations

At its 84th meeting, the AST Committee began its consultations on the above-mentioned issues, was informed about the ground response spectra on which the seismic design of the plants is based and about the PGA value, using the example of an earthquake time history, and received the corresponding request for advice from the BMU. At its 85th meeting on 20 December 2012, the Committee began discussing the draft statement prepared by a drafting group. The Committee continued its consultations at its 87th meeting and concluded them at its 87th meeting on 14 February 2013. The RSK discussed the statement at its 456th meeting on 21 March 2013 and adopted it at its 457th meeting on 11 April 2013.

[1] ENSREG, Post Fukushima Accident, Stress Test Peer Review Board, Peer review report, Stress tests performed on European nuclear power plants, Germany

[2] Peak Ground Acceleration

3 Current situation

The term ‘peak horizontal ground acceleration’ or ‘PGA value’ mentioned by ENSREG is the maximum amplitude of an earthquake time history (seismogram). In the ground response spectrum (explanation in connection with question 2 of the BMU), it corresponds to the value in the high frequency range (rigid-body acceleration). The ground response spectrum (acceleration as a function of frequency) is the seismic load assumption on which engineering seismic safety demonstrations for structures, systems and components are based.

In Specific Safety Guide SSG-9 [1], Safety Guide No. NS-G-3.3 [6] and NS-G-1.6 [7] and Safety Reports Series No. 28 [12], the IAEA stipulates the use of a minimum value of 0.1 g for the peak horizontal ground acceleration in the seismic design of new plants or the seismic re-evaluation of existing plants. This specification is intended to take account of uncertainties in the seismological site evaluation.

According to the current German seismic safety standard KTA 2201.1 [2], an earthquake intensity VI shall be specified as the minimum design level for a nuclear installation against seismic impacts. This specification corresponds to the RSK recommendations for the revision of safety standard KTA 2201.1 of 27 May 2004 [4], according to which the design against earthquakes should be specified such that the seismic impacts at least correspond to intensity VI also in areas of low seismicity. The intensity describes the strength of the ground motion on the basis of observed effects on people, buildings or the earth's surface in a limited area (e.g. according to the MSK or EMS scale). In Germany, a minimum intensity was defined instead of a minimum acceleration since this represents an appropriate integral measure of the earthquake hazard. Due to the sound database and the low seismicity in Germany, a minimum intensity was specified that leads to lower minimum accelerations in the high frequency range than those specified by the IAEA. Uncertainties in determining the design basis earthquake are also taken into account in accordance with safety standard KTA 2201.1, generally by adding a certain value on the determined intensity of the earthquake.

In Germany, the PGA values of site-specific ground response spectra can also be less than 1.0 m/s^2 due to the low seismicity (see Table 2-1 of the BMU report on the EU stress test [9]). At eight of the 12 NPP sites in Germany, the peak horizontal ground acceleration determined in seismological reports for the design basis earthquake with a probability of exceedance of $\leq 10^{-5}$/a (once in 100,000 years) is less than 1 m/s^2, at the northern German sites in some cases 0.5 m/s^2.[3]

Within the framework of the peer review of the German stress test reports, justifications were provided for the minimum intensity approach followed in Germany and for the non-application of a minimum acceleration according to IAEA SSG-9. Irrespective of this, the review recommended the consideration of safety impacts using an acceleration of 0.1 g.

In order to comply with the recommendation of the peer review, existing differences between the requirements of the IAEA and the German regulations with regard to seismic impacts are therefore presented below, in reply to the BMU questions, and the resulting effects with regard to plant safety are assessed, taking into account the existing design (load side, resistance side, entire safety demonstration chain).

[3] For the northern German sites, the site-specific seismic hazard for an exceedance probability of 10^{-4}/a (84 % fractile) or 10^{-5}/a (median) is at least in some cases below 0.5 m/s^2. The 0.5 m/s^2 chosen as design basis only results from the minimum design requirement of the “old” KTA 2201.1 (1990 and earlier).

4 Answers to the BMU's questions

Based on its consultations, the RSK answers the BMU's questions in a modified order as follows:

1 *To what extent does the peak ground acceleration (PGA) defined by the IAEA in SSG-9 (2010) and used in NS-G-1.6 (2003) correspond to the maximum acceleration described in KTA 2201.1, versions 1975, 1990, 2011 as well as in the documentation of KTA 2201.1, version 2011? (BMU question 2)*

In IAEA SSG-9 (2010) [1], peak ground acceleration (PGA) is defined, on the one hand, as the maximum absolute value of ground acceleration displayed on a seismogram (accelerogram) and, on the other hand, as the greatest ground acceleration produced by an earthquake at a site. In a seismogram, the ground acceleration occurred over time is typically recorded in two orthogonal horizontal directions (often in the NS and EW directions) and one vertical direction. To characterise the intensity of an earthquake, the peak ground acceleration is generally given as a multiple of the acceleration due to gravity in ‘g’ (e.g. 0.1 g corresponding to approx. 1.0 m/s^2) and mostly only that for the horizontal component (PHGA), which, in general, is the decisive one. The PGA value is thus assigned to one of the two horizontal acceleration components. In the view of the RSK, the PGA value in IAEA SSG-9 is to be understood in this way.

The two horizontal acceleration components can also be combined to form a resultant. The resulting horizontal ground acceleration differs in magnitude from the value of the maximum acceleration of the individual horizontal components. Since experience has shown that the resulting horizontal ground acceleration is below the theoretical maximum value of 1.41 x PGA (experience has shown that the maximum values of the two individual horizontal components do not occur at the same time), it is necessary when using a resulting horizontal ground acceleration to define the mathematical relationship between the individual component and the resulting horizontal component via a resultant factor.

A response spectrum can be determined from the earthquake acceleration time history recorded in a seismogram. For this purpose, the maximum amplitudes (absolute value) of the oscillations of damped, single-degree-of-freedom oscillators with different natural frequencies and a constant degree of damping are plotted against the natural frequency of the single-mass oscillator as a response to excitation at the base of the single-degree-of-freedom oscillator by the earthquake time history.

In such an acceleration response spectrum, the value in the high frequency range corresponds to the maximum amplitude (absolute value) of the acceleration time history on which the response spectrum is based, i.e. the PGA value. In KTA 2201.1, version 2011 [2], this value is also referred to as ‘rigid-body acceleration’ or ‘peak ground acceleration’. The term ‘rigid-body acceleration’ or ‘peak ground acceleration’ in KTA 2201.1, version 2011 thus corresponds to the ‘peak ground acceleration’ of IAEA SSG-9 [1].

By evaluating a large number of earthquake time histories and subsequently smoothing the associated response spectra, so-called standardised response spectra can be determined. By specifying an ‘anchor point’, i.e. the PGA value for such a standardised response spectrum, it can be scaled to the respective site hazard (expressed by the rigid-body acceleration of the underlying design basis earthquake).

In SSG-9 [1], the IAEA specifies a minimum value of 0.1 g as an anchor point for a horizontal standardised response spectrum. According to [1], this approach should also be applied to existing nuclear power plants.

Methods for carrying out seismic re-evaluations of existing nuclear power plants are contained in IAEA Safety Guide NS-G-2.13 [8] (see answer to question 4).

In KTA 2201.1, versions 1975 and 1990, the term ‘maximum acceleration’ was understood as the maximum value of the resultant of the horizontal acceleration components or the absolute value of the vector sum of the peak horizontal accelerations. KTA 2201.1, version 2011 [2] defines the peak ground acceleration as the “maximum amplitude (absolute value) of the horizontal or vertical acceleration components of the earthquake time history (seismogram)”. It corresponds to rigid-body acceleration (peak ground acceleration – PGA) of the ground response spectrum (‘anchor point’). In addition, 3.5(4) of KTA 2201.1, version 2011, states: “The response spectrum for the horizontal resultant earthquake excitation may be specified by multiplying the response spectrum for one horizontal component by a factor of 1.2.” The ‘maximum acceleration’ within the meaning of KTA 2201.1, versions 1975 and 1990, thus refers to the horizontal resultant earthquake excitation and differs from the ‘peak ground acceleration’ of KTA 2201.1, version 2011, which refers to one of the two horizontal components of the earthquake excitation, by the above mentioned factor. The application of a PGA value of 0.1 g in accordance with the requirement of IAEA SSG-9 thus results in a peak horizontal ground acceleration of 0.12 g when applying the approach according to KTA 2201.1, version 2011.

2 *Do the three approaches referred to here achieve at least equivalent minimum levels for seismic design and what ranges of variation in the results can be identified in each case? (BMU question 3)*

The minimum design level specified in IAEA SSG-9 [1] leads to the use of a standardised horizontal ground response spectrum with an anchor point at 0.1 g. As stated in the answer to question 4 (see below), a spectrum suitable for the site conditions is to be used. The determination of the minimum design level in accordance with KTA 2201.1, version 2011 [2] leads to a site-specific response spectrum that corresponds to an intensity of I = VI. The resulting PGA value – depending on the site-specific subsoil conditions – has a value in the order of 0.5 m/s^2 (approx. 0.05 g).

With regard to the approach of the older versions of KTA 2201.1, reference is made to answer under 3 (see below).

As a result, the PGA value of the site-specific response spectrum according to KTA 2201.1, version 2011, is about a factor of two below the PGA value according to IAEA SSG-9 [1]. The same factor applies to the accelerations in the entire spectral range (see answer to question 4 below).

Overall, the different approaches at the impact side do not lead to equivalent minimum design levels since the minimum values for the peak horizontal ground acceleration resulting from the German regulations are approximately two times lower than the minimum value for the peak horizontal ground acceleration of 0.1 g (approx. 1.0 m/s^2) required according to the IAEA and this also applies to the accelerations in the entire spectral range.

3 *How can assessments on the minimum design level according to the previous acceleration-based approach in Germany (KTA 2201.1, version 1975 and version 1990) be transferred in terms of method and result to the intensity-based approach (KTA 2201.1, version 2011)? (BMU question 4)*

The 1975 and 1990 versions of KTA 2201.1 contained the minimum design level requirements that

- 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, and

- 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.

In this approach, it was assumed that a standardised response spectrum for the resulting horizontal ground acceleration is scaled with an anchor point at at least 0.5 m/s². The earlier KTA specifications for raising the accelerations in the range between 0.5 m/s² and 1.0 m/s² to the minimum value of max. a = 1.0 m/s² had, due to an RSK recommendation [10], no longer been considered justified according to the BMU letter of 23 October 1998 to the *Land* authorities (AG RS I 4-14200/7, -14300/7) when using site-specific response spectra and were then no longer used in KTA 2201.1 of 2011 [2].

The intensity-based approach according to KTA 2201.1, version 2011, specifies an intensity of at least I = VI for the design basis earthquake, irrespective of the actual site-specific hazard. Based on the design basis earthquake, the seismic impacts are to be described using seismo-engineering parameters, in particular ground response spectra with the associated rigid-body accelerations (peak ground accelerations). In Germany, site-specific ground response spectra determined within the framework of site evaluations are used for this purpose.

This means that a ground response spectrum is used for an intensity of at least I = VI depending on the site-specific subsoil (rock, solidified sediments, loose sediments), from which the corresponding peak ground acceleration results directly as an acceleration value in the high frequency range (rigid-body range). Here, intensity I = VI correlates approximately with a peak ground acceleration of 0.5 m/s² (e.g. [11]).

Thus, the intensity-based approach of KTA 2201.1, version 2011, leads to minimum accelerations that correspond approximately to the minimum value of KTA 2201.1, versions 1975 and 1990, of 0.5 m/s². The 2011 version of KTA 2201.1 no longer includes an increase in the maximum acceleration in the range between 0.5 and 1.0 m/s² to a value of 1.0 m/s² corresponding to a minimum intensity of approximately I = VII (e.g. [11]), as provided for in the old versions of KTA 2201.1.

4 What are the safety impacts of the difference between the two approaches to determining the minimum level for seismic design, on the one hand on the basis of IAEA NS-G-1.6 (2003) and SSG-9 (2010) and, on the other hand, on the basis of the German nuclear safety standards (KTA 2201.1, version 2011, version 1990, version 1975)? (BMU question 1)

The requirement of a minimum design against earthquakes with a component-related rigid-body acceleration of 0.1 g (PGA) according to IAEA NS-G-1.6 (2003) [7] for new plants as well as for the re-evaluation of existing plants according to IAEA SSG-9 (2010) [1] and IAEA NS-G-2. 13 [8] is complied with for the nuclear power plants KKE, KWB-A and -B, KKP-1 and -2 and GKN-I and -II due to the ground response spectrum on which their design is based with a rigid-body acceleration ≥ 1.0 m/s². The seismic design of the KKB, KBR, KKK, KKU, KWG, KKG, KKI-1 and -2 and KRB-II-B and -C plants is based on ground response spectra for the design basis earthquake with a component-related rigid-body acceleration of < 1.0 m/s². For the latter plants, no seismic safety demonstrations were provided that fulfil the IAEA requirement of a minimum value of 0.1 g for the component-related rigid-body acceleration. According to RSK-SÜ [3], the design basis earthquake has an intensity ≥ VI for all German plants.

With regard to the safety significance of the deviation from the IAEA requirements for the above-mentioned German plants, the RSK considers that the following should first be noted:

- The seismic hazard for a plant depends on the intensity of the earthquake to be postulated at the site. The greater the seismic impact to be assumed, the greater the potential damage. In areas with high seismicity, the seismic design is therefore much more important with regard to the overall design of the plant than in areas with low seismicity. The above-mentioned ENSREG recommendation only applies to areas with low seismicity. Based on the current state of knowledge of the earthquake risk in Germany – as it results from the current site-specific seismic hazard assessments – the IAEA requirement of a minimum acceleration of 0.1 g in these areas, e.g. in northern Germany, leads to values that are significantly higher than the value to be taken as a basis for an earthquake with an exceedance probability of 10^{-5}/a (median value) according to KTA 2201.1 [2].

- The required minimum design against earthquakes also provides basic protection of the plants against dynamic loads. The German nuclear power plants in operation are also designed to withstand the dynamic loads of an aircraft crash and a blast wave with regard to the vital functions.

- In its plant-specific safety review of German nuclear power plants in the light of the events in Fukushima (RSK-SÜ [3]), the RSK found that in some cases there are considerable margins with regard to the seismic design and that the arguments put forward by the operators in this regard are generally plausible. The background to this judgement was, among other things, the conservative assumptions in the calculation chains and the knowledge gained from the seismic PSAs performed so far for individual plants. The RSK estimated the potential for safety margins in the order of one intensity level.

Following these basic statements on the seismic design of German nuclear power plants, the implications of the IAEA requirements for the plants are addressed in more detail below.

The question of the safety-related implications of the different definitions of the minimum design in the German regulations and IAEA safety standards is at first answered by a direct comparison of the peak ground accelerations. The direct comparison of the peak ground accelerations shows – applying empirical relationships (e.g. according to Murphy/O`Brien, 1977 [11]), according to which intensity I = VI correlates approximately with the peak ground acceleration of 0.5 m/s² – that both the specifications on the minimum design on the basis of accelerations in the versions of KTA 2201.1 of 1975 and 1990 as well as on the basis of the intensity in the 2011 version of KTA 2201.1, the IAEA requirement of a minimum value for the peak horizontal ground acceleration (PGA) of 0.1 g (approx. 1.0 m/s²) is not met. The IAEA requirement of using a PGA value of 0.1 g (approx. 1.0 m/s²) as an anchor point for the ground response spectrum leads to an impact that is approximately twice as high as the minimum design required by the German regulations.

The spectrum to be scaled to a PGA value of 0.1 g is relevant for impacts in the low frequency range. According to IAEA Guide SSG-9 [1], a standardised response spectrum is to be used. The requirements in IAEA safety guides SSG-9 [1], NS-G-3.3 [6], NS-G-1.6 [7] and IAEA Safety Reports Series No. 28 [12] indicate that a spectrum suitable for the site conditions is to be used. The ground response spectra that are currently used for the seismic hazard of the relevant German sites with regard to the minimum design correspond to the IAEA definition of the standardised response spectrum in [1] [4]. Thus, when implementing the IAEA specification, the site-specific[5] ground response spectra determined within the framework of site evaluations are to be scaled to a PGA value of 0.1 g. This results in higher spectral accelerations for the respective plants in all frequency ranges – corresponding to the scaling with the anchor point – than those on which the design was previously based.

The correspondingly expanded ground response spectra result in greater impacts on the plant. Their safety-related effects can only be assessed on the basis of analyses of the structures, systems and components.

With regard to the methods used to analyse and assess the impacts resulting from the minimum site hazard to be applied, a distinction can be made in the context of the IAEA safety standards between the design of a new plant and the re-evaluation of an existing plant. The issue of reassessing the seismic resistance of existing plants is dealt with in IAEA Safety Guide NS-G-2.13 [8] and Safety Report No. 28 [12]. Reassessments can be carried out on the basis of existing margins. Using the 'seismic margin assessment' or 'seismic PSA' methods mentioned in [8] and [12], it is to be demonstrated for plants with a peak ground acceleration of < 0.1 g that the plant is also sufficiently resistant to a ground acceleration of 0.1 g. If necessary, structures, systems and components are to be upgraded accordingly.

A corresponding approach has been recommended by the RSK as part of its robustness assessments in [5]. The results of existing probabilistic seismic safety analyses (PSA) can be referred to for this purpose. For plants for which no such PSA results are available, the safety implications of the IAEA requirement may be assessed by applying results for other plants by analogy. In [5], the RSK states that it considers it appropriate that at least a robustness level 1 is targeted as a result of a robustness analysis for beyond design basis seismic impacts. For the earthquake load case, this would correspond to the demonstration of design margins in the order of one intensity level. In the case of a design intensity (minimum intensity according to KTA 2201.1) of I = VI (PGA approx. 0.5 m/s^2), design margins for intensity I = VII (PGA approx. 1.0 m/s^2) would therefore have to be demonstrated. If a site-specific PGA value < 0.1 g should be determined for an assumed intensity corresponding to robustness level 1, the RSK recommends determining the design margins for an assumed PGA value of 0.1 g.

5 Conclusions and recommendations

The IAEA requirement of a minimum design against earthquakes using a minimum value for the peak horizontal ground acceleration (PGA) of 0.1 g (approx. 1.0 m/s^2) as an anchor point for the ground response spectrum leads to impacts that are about twice as high as the minimum design level required by the German regulations.

[4] The Committee on PLANT AND SYSTEMS ENGINEERING COMMITTEE understands that current site-specific ground response spectra are based, among other things, on

- Hosser spectra that are suitable for the ground conditions,
- fractiles of a set of response spectra for earthquake time histories from worldwide strong-motion registrations that correspond to the site in terms of site conditions and earthquake characteristics (e.g. magnitude, focal depth, etc.) since strong-motion registrations do not exist for the site,
- empirical relationships,
- modified US spectra.

[5] A site-specific ground response spectrum is a spectrum that has been determined taking into account the subsoil conditions and the seismicity of the site.

All German plants fulfil the minimum design level of intensity VI required by safety standard KTA 2201.1 [2], although for some German NPP sites no seismic safety demonstrations were provided that meet the IAEA requirement of a minimum acceleration of 0.1 g.

However, no reliable conclusions can be drawn from this deviation regarding the actual seismic robustness of the relevant structures, systems and components. The safety impacts of increased ground response spectra can only be assessed on the basis of analyses of the structures, systems and components.

Compliance with the IAEA requirement to apply a PGA value of 0.1 g can be demonstrated by reassessing the seismic resistance of the respective plants using the methods of IAEA Safety Guide NS-G-2.13 [8]. Using the 'seismic margin assessment' method mentioned in NS-G-2.13 (data from an existing seismic PSA may be used), it would have to be demonstrated for plants with a peak ground acceleration of < 0.1 g that the plant is also sufficiently resistant to a ground acceleration of 0.1 g. This approach is, in principle, already included in the recommendations of the RSK statement on robustness [5].

If a site-specific PGA value < 0.1 g should be determined for an assumed intensity corresponding to robustness level 1, the RSK recommends determining the design margins for an assumed PGA value of 0.1 g.

In the opinion of the RSK, this approach to robustness assessments for the plants does not call into question the design-oriented approach of the KTA safety standard [2] with the intensity-oriented approach deviating from the IAEA safety standards and its validity.

References

[1] IAEA Safety Standards
Seismic Hazards in Site Evaluation for Nuclear Installations
Specific Safety Guide No. SSG-9
2010

[2] Sicherheitstechnische Regel des KTA
KTA 2201.1
Auslegung von Kernkraftwerken gegen seismische Einwirkungen
Teil 1: Grundsätze
Fassung 2011-11

[3] RSK-Stellungnahme
Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ) deutscher Kernkraftwerke unter Berücksichtigung der Ereignisse in Fukushima-I (Japan)
11. – 14.05.2011 (437. RSK-Sitzung)

[4] RSK – Stellungnahme
KTA-Regel 2201.1: „Auslegung von Kernkraftwerken gegen seismische Einwirkungen; Teil 1: Grundsätze"; Fassung 6/90 - Empfehlungen für die Überarbeitung der Regel
vom 27.05.2004

[5] RSK-Empfehlung
Empfehlungen der RSK zur Robustheit der deutschen Kernkraftwerke
450. Sitzung am 26./27.09.2012

[6] IAEA Safety Standard
Evaluation of Seismic Hazards for Nuclear Power Plant
Safety Guide No. NS-G-3.3
2002

[7] IAEA Safety Standard
Seismic Design and Qualification for Nuclear Power Plants
Safety Guide No. NS-G-1.6
2003

[8] IAEA Safety Standard
Evaluation of Seismic Safety for Existing Nuclear Installations for protecting people and the environment
Safety Guide NS-G-2.13
2009

[9] BMU
EU Stresstest; National Report of Germany, Dezember 2011

[10] Anlage 1 zum Ergebnisprotokoll der 320. Sitzung der RSK am 16.09.1998

[11] J.R. Murphy und L.J. O´Brien
The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and Other Physical Parameters
Bulletin of the Seismological Society of America, Vol. 87, 877-915, June 1977

[12] IAEA Safety Reports Series No. 28
Seismic Evaluation of existing nuclear power plants
2003

Annex A: Definitions

Nuclear safety standard KTA 2201.1, version 2011-11

Response spectrum

The response spectrum is the graphical representation of the largest oscillation amplitudes (values) of dampened single degree-of-freedom oscillators (accelerations, velocities, displacements) with various eigenfrequencies and a constant damping ratio in response to an excitation described by a time history at the base point. Unless indicated otherwise, the response spectrum relates to the acceleration (spectral acceleration). In this safety standard, the response spectrum is considered to be that of an elastic oscillator that shows no effects from ductile deformation

Peak ground acceleration

The peak ground acceleration (PGA) is defined as the maximum amplitude (absolute value) of the horizontal or vertical acceleration components of the earthquake time history (seismogram). It corresponds to the rigid-body acceleration of the ground acceleration response spectrum (anchor point).

Rigid-body acceleration

The rigid-body acceleration is the maximum amplitude (absolute value) of the acceleration time series on which the response spectrum is based; it corresponds to the value of the response spectrum in the high frequency range.

Seismogram

A seismogram is the graphic display of the ground motion (proportional to displacement, velocity or acceleration) at a certain location during the earthquake. It is also called earthquake registration or earthquake time history and is usually recorded in three orthogonal directions, two of these in the horizontal plane.

Nuclear safety standard KTA 2201.1, version 1990

The ‘maximum acceleration’ is understood to mean

- the rigid-body horizontal acceleration of the free field response spectrum (anchor point),
- the maximum value of the resultant of the horizontal acceleration components in the strong ground motion phase of the earthquake time history (maximum absolute value).

Nuclear safety standard KTA 2201.1, version 1975

Referring to ground motion at foundation height, the ‘maximum acceleration’ is understood to mean

- the peak acceleration in the strong motion phase of an earthquake, and
- the absolute value of the vector sum of the peak horizontal accelerations.

IAEA, SSG-9

accelerogram. A recording of ground acceleration, usually in three orthogonal directions (i.e. components), two in the horizontal plane and one in the vertical plane.

peak ground acceleration. The maximum absolute value of ground acceleration displayed on an accelerogram; the greatest ground acceleration produced by an earthquake at a site.

response spectrum. A curve calculated from an accelerogram that gives the value of peak response in terms of the acceleration, velocity or displacement of a damped single-degree-of-freedom linear oscillator (with a given damping ratio) as a function of its natural frequency or period of vibration.

Standardized response spectra

9.5. A standardized response spectrum having a smooth shape is used for engineering design purposes and to account for the contribution of multiple seismic sources represented by an envelope incorporating adequate low frequency and high frequency ground motion input. The prescribed shape of the standardized response spectrum is obtained from various response spectra derived on the basis of earthquake records and engineering considerations. This standardized response spectrum is scaled to envelop the mean ground motion levels at low and high frequencies.