RSK STATEMENT

KTA Safety Standard 2201.1: "Design of Nuclear Power Plants against Seismic Events; Part 1: Principles"; as amended in 6/90 – Recommendations for the revision of the standard

1 Advisory request

With letter of 08.11.2002 [U 1], the BMU requested the RSK to prepare a statement on the need for a revision of KTA Safety Standard 2201.1, Part 1, and to make recommendations for contents of a revised version of the standard.

2 Background and assessment criteria

The design of nuclear power plants (and generally also of other nuclear facilities) against earthquake is based on KTA Safety Standard 2201 [R 1] "Design of Nuclear Power Plants against Seismic Events". The principles of seismic design, such as the specification of the design basis earthquake, the classification of plant components or the design requirements are laid down in KTA Safety Standard 2201.1, as amended in June 1990. Further, KTA Safety Standard 2201 is referred to for the verification of the seismic safety of existing plants. Within the frame of the discussions of the working group SEISMOLOGY[1] on the redefinition of the design earthquake for the Biblis site [U 2] it showed that the progressing state of knowledge in the fields of seismology and earthquake engineering (e. g. on probabilistics, the selection of the design response spectra and the fractiles) requires a revision of the standard according to the state of the art in science and technology. On behalf of the BMU, this statement addresses the required extent of revision for KTA Safety Standard 2201.1 and gives recommendations on contents of an amended version of this standard.

The discussions on the request of the BMU were held in the working group SEISMOLOGY of the RSK Committee on PLANT AND SYSTEMS ENGINEERING. The assessments and recommendations of the working group are based on the knowledge of the working group in research, education and practice in the field of seismology and earthquake engineering as well as on the state of the art in science and technology published in the relevant literature. In particular, the international status of the earthquake regulations was also referred to.

[1] Members of the working group: Dr. Brüstle, Dipl.-Ing. Gerding, Dipl. Phys. Hahn, Prof. Hinzen, Dr. Kaiser, Dr. Leydecker, Prof. Scherbaum, Dr. Schwarz, Dr. Waas, Dr. Zinn

3 Procedure

The working group SEISMOLOGY of the RSK Committee on PLANT AND SYSTEMS ENGINEERING addressed on its

- 12th meeting on 26.03.2003,
- 13th meeting on 04.06.2003,
- 14th meeting on 26.09.2003,
- 15th meeting on 04.11.2003,
- 16th meeting on 25.11.2003, and
- 17th meeting on 02.03.2004 (editorial meeting)

the following topics related to KTA Safety Standard 2201.1:

- Scope of application,
- terms and definitions,
- specification of the design basis earthquake,
- consideration of the seismic activity including paleoseismology,
- deterministic seismic hazard analysis,
- probabilistic seismic hazard analysis,
- seismic engineering data,
- classification, protection goals, and
- design, calculations.

In the following, the wording and contents of KTA Safety Standard 2201.1, as amended in 06/90, is presented as status quo[2]. This is followed by an assessment and corresponding recommendations for an amendment of KTA Safety Standard 2201.1.

The statement was discussed and adopted at the 371st and 372nd RSK meeting on 29.04.2004 and 27.05.2004, respectively.

4 Recommendations for an amendment of KTA Safety Standard 2201.1, Part 1

4.1 Title

Status quo

The title of KTA Safety Standard 2201.1 reads *"Design of Nuclear Power Plants against Seismic Events; Part 1: Principles"*.

[2] Quotations from KTA Safety Standard, Part 1, are italicised.

Assessment/recommendation

KTA Safety Standard 2201.1 is also referred to regarding the verification of the seismic safety of existing installations and, moreover, not only applied to nuclear power plants. The title of KTA Safety Standard 2201.1 should therefore be replaced by "Seismic Safety of Nuclear Installations; Part 1: Principles".

4.2 Scope of application

Status quo

This safety standard applies to nuclear power plants. However, there is also a note that *by analogy, this safety standard may also be used as a basis for all other kinds of nuclear facilities*.

Assessment/recommendation

In the practice of the licensing procedures and inspections, KTA Safety Standard 2201.1 is not only taken as a basis for nuclear power plants but also for other nuclear installations, as e. g. interim storage facilities, repositories and nuclear fuel production facilities. Its application particularly refers to the specification of the design basis earthquake. Regarding the classification of plant components to be protected and specification of the loads to be considered, plant-specific features take effect for other nuclear installations. This applies to some extent also to the requirements on design and verification procedures.

It is therefore recommended to generally apply KTA Safety Standard 2201.1 to nuclear installations in terms of the definition "nuclear installation" as defined in Appendix 1 of the Atomic Energy Act (AtG) and to the installations and facilities which are subject to the RSK safety requirements [U 3].

For the application of the standard, the different hazard potentials and plant-specific features of nuclear power plants and other nuclear installations shall be taken into consideration.

The assessment of the hazard potentials of nuclear installations other than nuclear power plants and the type of seismic design derived from it may be determined, e. g., analogously to the RSK recommendation [U 3], Chapter 2.7.1. In case of repositories for radioactive wastes, KTA 2201.1 should only be applied to the part of the facility above ground.

4.3 Terms

Status quo

In the current version of KTA Safety Standard 2201.1, no terms related to nuclear engineering, civil engineering and (engineering) seismology are defined, apart from a few exceptions (intensity, maximum acceleration).

Assessment/recommendation

In a revised version of KTA Safety Standard 2201.1, definitions of relevant technical terms should be included according to the following recommendations.

Plant components: The term “plant components” is defined as electrical and mechanical systems and equipment installed in the buildings.

Response spectrum: Graphical display of the maximum amplitudes of the oscillations of damped oscillators with a single degree of freedom (accelerations, velocities, displacements) with different natural frequency in response to a base excitation, plotted against the natural frequencies or periods of the oscillators. The excitation is described by a s*eismogram*; this usually refers to the free field. If not otherwise stated, reference is made to the response spectrum of acceleration (spectral accelerations). For the purpose of this statement, response spectrum is defined as the response spectrum of an elastic oscillator, not including effects of ductile deformation.

Structural components: According to the definitions in the building regulations of the *Länder*, “structural components” (also referred to as “structures”) are components connected with the ground, made of building products (building materials and structural parts). For a “structural component”, the verification of seismic safety both for the whole component and in parts (“structural parts”) may be required.

Design earthquake: The earthquake relevant to the design of a nuclear installation against seismic events. On the basis of the design earthquake, the *seismic engineering data* are specified. Design earthquake may also be defined as several quakes or the ground motions at the site of the installation relevant to the design.

Design spectrum: Response spectrum on which the seismic design for the design earthquake is based.

Deaggregation: Determination of the contributions of earthquakes with discrete magnitude and distance intervals to the total hazard of a site, to be performed within the framework of the PSHA.

Deterministic Seismic Hazard Analysis (DSHA): Specification of the *design earthquake* with deterministic methods. It is not possible to specify an *exceedance probability* with it.

Epicentral intensity: *Intensity* of the earthquake in the *epicentre*.

Epicentre: Projection of the location of rupture initiation (*hypocentre*) of an earthquake on the earth's surface; defined by geographical co-ordinates.

Free field: Ground surface whose oscillation properties are not influenced by structures.

Largest seismic events: Defined as those *seismic events* which include the largest spectral acceleration values for the frequency range relevant to the structural and plant components to be designed (about 0.2 Hz to 25 Hz).

Focal depth: Depth of the *hypocentre* of an earthquake below the earth's surface.

Hypocentre: Point on the rupture surface of an earthquake where the rupture starts; defined by the geographical co-ordinates of the *epicentre* and the *focal depth*.

Seismic engineering data: Parameters derived from the *design earthquake*: *Response spectrum, strong-motion duration* and other parameters of ground movements at the site.

Intensity or macroseismic intensity: Describes the local effects of seismic waves and dislocations at the earth's surface on man, objects, structures and landscape. The classification of the intensity takes place qualitatively on the basis of observed and felt effects in a limited area. In Germany, the 12-grade scale MSK 1964 (MEDVEDEV - SPONHEUER - KARNIK) has been used so far for the classification. The European Macroseismic Scale 1998 (EMS) was newly introduced. When specifying intensities, the scale used always shall be mentioned.

Magnitude: In 1935, C. F. RICHTER introduced the term "magnitude" (M). It is an instrumentally determined measure for the strength of an earthquake. The method for magnitude determination proposed by RICHTER is still used today under the term "local magnitude". As is the case with all magnitude scales (body wave magnitude, surface wave magnitude, moment magnitude) established later, it is a logarithmic scale.

Magnitude/intensity - frequency relation: The average number of earthquakes per year for a certain magnitude or intensity interval. A frequency relation is determined for one *seismic source* each. The presentation in form of normal and cumulative magnitude or intensity frequency curves is recommended.

Maximum acceleration (peak ground acceleration – PGA): Maximum amplitude value of the horizontal and vertical acceleration components of the earthquake time history (*seismogram*); equivalent to the rigid body acceleration of the *free-field* response spectrum ("suspension value").

Paleoseismology: Study of prehistoric earthquakes with geological and geophysical methods with regard to location, strength and age of the quakes.

Probabilistic seismic hazard analysis (PSHA): Calculation of *exceedance probabilities* per year of, e. g., intensities and spectral acceleration values and their uncertainties with probability theoretical models.

Seismic impacts: Impacts of seismic waves at the site resulting from an earthquake. In general, the seismic impacts are described by the *response spectrum*, the associated *strong-motion duration* and the *intensity*.

Seismic source: Area (volume, surface or line) with quasi-homogeneous seismicity. A seismic source is described by relevant seismological parameters (type, geometry and spatial distribution of earthquakes, frequencies of earthquakes of different strengths, rupture types and propagation characteristics, rupture surfaces, maximum magnitudes, etc.) as well as by a statistical model for the time distribution of future quakes.

Seismicity: Earthquake activity in the broadest sense.

Seismogram: Recording of the translatory ground motion (proportional to dislocation, velocity or acceleration) at a location when seismic waves pass; also referred to as registration or time history. Mostly recorded in three orthogonal components, two of them in horizontal direction.

Seismotectonic unit (also referred to as **seismotectonic region):** Region where homogeneity is postulated with regard to *seismicity*, the geological structure and development and the tectonic and, in particular, the neotectonic conditions. A seismotectonic unit may also be a *seismic source*.

Strong-motion duration (also referred to as **duration of the strong-motion phase**)**:** The strong motion duration is defined through the length of time in which a certain percentage of the cumulative seismic wave energy is reached at a site (e. g. the 70% criterion where the wave energy increases from 5 % to 75 % of the total energy).

Strong-motion seismogram: *Seismogram* of strong seismic ground motions (mostly acceleration seismogram) which may potentially cause damages to structures and technical facilities due to their amplitudes, their frequency content and their duration.

Tectonics: Study of the structure of the earth's crust and the movements and forces by which it was formed. Tectonic structures are lineaments, faults, grabens, etc. Neotectonics is the tectonics of the quaternary and the late tertiary.

Probability of exceedance: Probability that a certain seismic ground motion (*maximum acceleration*, spectral values of the acceleration, etc.) or *intensity* at a location is reached or exceeded within a given period of time (usually 1 year). The reciprocal of the annual exceedance probability is also referred to as mean return period.

Uncertainties: There are two types of uncertainties: epistemic and aleatory uncertainties. Epistemic uncertainties are uncertainties due to incomplete scientific knowledge which can be reduced by collecting new information. Aleatory uncertainties are due to the randomness of the processes themselves and cannot be further reduced.

4.4 General requirements on the specification of the design earthquake

Status quo

Current wording of KTA 2201.1:

(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).

N o t e :
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.

The current procedure is not explicitly defined as deterministic in KTA 2201.1, but it is, de facto, based on a deterministic approach.

Since KTA 2201.1, as amended in 06/90, does not include regulations on the probabilistic procedure for the specification of the design earthquake and the procedure pursued with the principles is not explicitly defined as deterministic approach, there are consequently no regulations on the specification of the design earthquake after performance of deterministic and probabilistic analyses. The same applies with regard to regulations on the exceedance probability and the selection of the fractiles (50% and 84%, resp.) of the design response spectrum.

In practice, a procedure is often applied which already was described in 1986 within the framework of the research project [L 1] according to which the exceedance probability 10^{-5}/a is combined with the 50% fractiles spectra.

Assessment/recommendation

The RSK recommends to amend the general text on the definition of the design earthquake because the specification of influencing factors with reference to exceedance probabilities cannot be sustained and to choose, in lieu thereof, the following wording:

(1) The design earthquake and the associated impacts shall be specified on the basis of the results of deterministic **and** probabilistic analyses. For the deterministic specification of the design earthquake, an

earthquake of maximum seismic intensity at a specific site which, according to scientific knowledge, may occur at the site within a larger radius up to at least 200 km from the site shall be postulated. The probabilistic specification of the design earthquake shall be based on an exceedance probability within the range of 10^{-4} to 10^{-5} per year.

(2) The results of the probabilistic and deterministic procedures shall be compared and differences explained. The design earthquake is specified under consideration of the reliability of the results of the deterministic and probabilistic analyses. In case of doubt, the larger seismic impacts shall be referred to as design parameters. The specification of the relevant parameters shall be substantiated.

(3) Decisions on the uncertainty fractiles of the spectral ground motion parameters shall be substantiated. The fractile value of the design spectrum may be postulated to be 50% if the exceedance probability of the design earthquake is shown with 10^{-5}/a; the fractile value shall be postulated to be 84% if an exceedance probability of 10^{-4}/a is postulated.

(4) Within the framework of the seismological analysis, site intensity, strong motion duration and site-specific response spectra shall be stated for the design earthquake, also under consideration of the local and regional geological and tectonic conditions.

(5) Also in areas of low seismicity, the design earthquake shall be specified for nuclear installations, which are to be designed against earthquakes due to their hazard potential (cf. 4.2), such that the seismic impacts at least correspond to intensity VI of MSK/EMS.

(6) Seismological surveys shall be traceable and reviewable. The data used shall completely be enclosed, unless not generally accessible, to the survey in a suitable manner.

4.5 Consideration of earthquake activity

Status quo

For the specification of the design earthquake ... *The following principles shall constitute the basis*:

3a) 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.

Paleoseismology is not mentioned in KTA Safety Standard 2201.1, as amended in 06/90.

Assessment/recommendation

The RSK recommends to amend the text on the consideration of the previous earthquake activity and to choose, in lieu thereof, the following wording:

All earthquakes relevant for the seismic hazard at the site shall be considered for the specification of the design earthquake. The earthquakes with the maximum impact for the site shall be subjected to a separate analysis. In cases of doubt it may be required to re-assess historic sources on earthquakes and/or to perform paleoseismological studies.

The assessment of historical earthquakes should be performed according to the following steps:

- Collection and processing of historical sources (as the case may be, examination of damages still existing at buildings)

The collected and processed source texts shall be documented in full.

- Criticism of historical sources

The aim of source criticism is to assess the accuracy and reliability of historical information from the point of view of historical science.

- Seismological interpretation of the historical sources

The historical descriptions shall be converted into intensity values, the uncertainty range shall be specified for each intensity point. Based on the distribution of the intensities, further hypocentre parameters of the earthquake (e. g. epicentral intensity, hypocentre co-ordinates, focal depth, magnitude) can be estimated.

Paleoseismology involves the study of prehistoric earthquakes, especially with regard to their location, strength and age. The characterisation and dating of strong prehistoric earthquakes may supplement the historical and instrumental earthquake catalogue. Published paleoseismological data shall be considered for the site-specific hazard analysis. If the size seismicity cannot be assessed adequately with other methods and if it seems to be promising, the site shall be subjected to paleoseismological studies. This can be realised as follows:

- Geological interpretation of aerial photographs and other remote sensing data regarding the identification of solid rock, faults and other tectonic lineaments, soil condition and signs of landslides or soil liquefaction.

- Mapping of the topographical, geological, geomorphological and hydrological characteristics in scales and contour intervals suitable for the stratigraphic analysis, identification of tectonic surface structures, such as fault zones and quaternary geomorphological characteristics.

- Identification and assessment of vertical movements of the earth’s crust by geodetic measurements and geological analysis.

- Analysis of abnormal landscape formations, such as shifted profiles of water flows, sudden changes in fluviatile sediments or at terraces.

- Analysis of quaternary sedimentation in or near to tectonic fault zones.

- Identification and analysis of quake-induced deformation features, including seismic-induced soil liquefaction features.

- Analysis of displacements on faults, including the application of adequate dating methods.

- Assessment with regard to coseismic and non-seismic movements.

4.6 Deterministic specification of the design earthquake

Status quo

The current procedure is not explicitly defined as deterministic in KTA 2201.1, but it is, de facto, based on a deterministic approach:

3d) 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.

3e) 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.

Assessment/recommendation

The RSK recommends to amend the text on the specification of the design earthquake and to choose, in lieu thereof, the following wording:

The design earthquake should be determined deterministically as follows under specification of the seismotectonic units used:

If the epicentre of a significant earthquake is located in the same seismotectonic unit as the site, a similar earthquake shall be assumed to occur below the site when determining the seismic impact.

If the epicentre of a significant earthquake is located in a tectonic unit other than that of the site, the seismic impact at the site shall be determined on the assumption that the epicentre of a similar earthquake is located at the point on the boundary of the seismotectonic unit which is closest to the site.

For the specification of the design earthquake, the uncertainties shall be considered in the assumptions and their influences on the extent of the design earthquake be presented. For the final specification of the strength of the design earthquake, an additional margin shall be considered which covers, for example, the incompleteness and the limited time span of the earthquake catalogue referred to.

If reference is made to more than one quake for the specification of the seismic impacts, a corresponding procedure shall be applied.

4.7 Probabilistic specification of the design earthquake

Status quo

KTA 2201.1, as amended in 06/90, does not include regulations on the probabilistic procedure for the specification of the design earthquake.

Assessment/recommendation

In addition to the deterministic seismic hazard analysis (DSHA) and taking into account the safety significance of the nuclear installation under consideration, a probabilistic specification shall be performed, as far as it is possible to derive an activity model for the relevant seismic sources. For this purpose, a probabilistic seismic hazard analysis (PSHA) shall be performed.

Goals of the PSHA

The PSHA determines possible earthquake ground motions at the site in a probability-oriented form. All known seismological, geophysical and geological data are used in an appropriate manner for it. The annual exceedance probabilities of the seismic impacts at the site and uncertainties of these data are determined with it.

In the following, a description is given of the procedure, elements and results of a complete PSHA following [R 3], as they are according to the scientific state of the art. For clarification, the English terms mentioned in the SSHAC Report [R 3] are listed. After revision of the KTA safety standard they should be deleted again.

The RSK is of the opinion that a probabilistic seismic hazard analysis shall be required in the amended version of KTA 2201.1 as a basic principle. In some sub-areas, scientific investigations are still required for the application of a hazard analysis according to the international state of the art in science and technology to German conditions, e. g. according to the specifications of the Senior Seismic Hazard Analysis Committees (SSHAC) on behalf of the US Nuclear Regulatory Commission [R 3, R 4], the PEGASOS Project in Switzerland [L 2] or the International Atomic Agency (IAEA) in Vienna [R 2].

Besides the PSHA method described here, there are also other probabilistic methods. Their applicability shall be specified according to 4.2 within the framework of the further development of rules and regulations.

PSHA procedure

- The PSHA includes an explicit and quantitative consideration of epistemic (logic-tree approach) and aleatory uncertainties.

- The PSHA identifies type and extent of the influence of the data, models and procedures applied on the result (sensitivity, deaggregation).

- The PSHA considers the existing diversity of opinion among the scientific experts in an adequate manner, e. g. by establishment of an expert committee (representation of scientific community). Here, a special opinion formation and interaction process of the experts involved in the analysis is used (expert interaction, ellicitation, feed back). Their different assessments are explicitly considered in form of epistemic uncertainties.

Elements of the PSHA

The elements of the PSHA comprise the earthquake catalogues used, the seismic sources with their characteristic parameters, transfer function in solid rock (ground motion prediction equation) on the propagation path of the seismic waves from the source to the site under consideration of site effects as well as the procedures, calculation methods and computer codes applied.

The transfer functions of the ground motions shall be presented as function of the distance, itemised according magnitudes, frequencies and uncertainty fractiles. All elements of the PSHA shall be described and documented in an adequate manner.

PSHA results

The results of the PSHA contain information on the horizontal and vertical ground motions at the site to be expected with different probabilities without interaction with structures (free field) and, as far as possible, on site intensities to be expected. The ground motion is to be described in form of the spectral acceleration values with 5 % of the critical damping:

- in the frequency range from 0.2 Hz to 25 Hz (as far as possible),
- for exceedance probabilities from 10^{-1}/year to 10^{-5}/year and smaller (in order to present uncertainties), and
- for the six discrete uncertainty fractiles: average value, median and ± 1 and ± 2 standard deviations.

The results shall, among other things, be itemised in the following forms:

- Presentation of the annual exceedance probabilities against the amplitudes of the spectral accelerations considered for different uncertainty fractiles, separated for discretely specified frequencies each (total hazard curves) and, as far as possible, presentation of the annual exceedance probability against site intensity,

- presentation of the response spectra: amplitude of the spectral acceleration against the frequency for different uncertainty fractiles, separated for discretely specified annual exceedance probabilities (uniform or equal hazard spectra),

- above presentations in the same form, but separately itemised for the seismic sources with the largest influences (hazard by source), and

- presentation of the relative contributions of all sources to the total hazard, separated, e. g., according to contributions in magnitude-distance-interval pairs for discretely specified annual exceedance probabilities and frequencies each and, where applicable, other forms of deaggregation (hazard deaggregation).

4.8 Seismic engineering data

Status quo

3b) 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.

3c) 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.

3f) The characteristics of ground movements shall be determined on the surface of the soil (free field) of the site.

3g) 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.

3h) 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).*

Assessment/recommendation

The RSK is of the opinion that 3b) and 3f) still comply with the state of the art in science and technology, but that 3c), 3g) and 3h) are no longer up-to-date. In particular, the seismic engineering parameters of the design earthquake should not be specified via the maximum acceleration but via the seismic impacts in form of response spectra and strong-motion durations. The seismic engineering parameters should be specified as follows:

The free field response spectrum for 5 % and, if applicable, further suitable values of the critical damping shall be specified as response spectrum; this reflects the seismic impacts of the design earthquake at the size as relevant seismic engineering parameter. A response spectrum shall be presented each for the horizontal and vertical component. The spectrum for the resulting horizontal vibration can be estimated, for this purpose, the response spectrum is multiplied for a/an (arbitrarily oriented) horizontal component with the factor 1.2.

The strong-motion duration for the design earthquake shall be stated, also specifying the energy criterion. If possible, a window function for the generation of synthetic seismograms should also be given.

4.9 Classification of plant components

Status quo

In the current version of KTA 2201.1, the plant components are divided into two classes for the design against earthquake under consideration of the safety aspects of the overall plant as follows:

<u>*Class I*</u>*: 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.

<u>*Class II*</u>*: All other plant components of the nuclear power plant.*

According to a corresponding note ... *The term "plant components" also refers to buildings.*

Assessment/recommendation

The term “plant components” is generally defined as mechanical and electrical systems and components of an installation, whereas “structural components” form a separate class according to their type and function. KTA Standards 2201 also make distinction between the two classes with its KTA Safety Standards 2201.3 and KTA 2201.4. In an amended version of KTA Safety Standard 2201.1, plant components and structural components should be mentioned.

The safety requirements with regard to earthquakes mentioned so far (safe shut-down, residual-heat removal, no impermissible activity release) primarily refer to nuclear power plants. They should be generalised and adjusted to the current terminology. As general safety requirements with regard to the seismic design of nuclear installations the following should be mentioned: reactivity control, fuel element cooling, confinement of the radioactive materials, and limitation of radiation exposure.

For the construction of the installations, the design against earthquakes was generally based on more or less standardised procedures, first of all by classifying a building or technical system to be in need of protection (Class I) and demonstrating its design by corresponding dimensioning or structural design against seismic events. Here, no differentiation was made regarding the safety significance of the individual structural or plant components during earthquake-induced accidents. Compared with this, the seismic safety of structural and plant components is verified within the framework of the periodic safety review (PSR) or licensing procedures for modifications regarding the necessary safety functions, depending on the safety significance of the components in case of design-basis accidents. In this respect, distinction is made between requirements on stability, integrity and functional reliability. Instead of a general classification of structural and plant components, the requirements on the verification of the seismic safety of structures (load bearing capacity, usability) and plant components (stability, integrity, functional reliability) should be defined with regard to the safety functions required in case of demand.

For the analysis of the earthquake-induced accident sequence at nuclear power plants, the following should be specified in an amended version of the standard:

- Consideration of limited coolant leakages after the ground-motion phase,
- maintenance of the containment integrity and availability of the containment isolation functions,
- the longer-term control of design-basis accidents after the event and event combinations to be postulated in this respect, and
- the requirements of the single-failure concept.

Further, a reference should be included in the regulations in KTA 2101.1 with regard to the event combinations postulated for fire.

Structural and plant components not fulfilling safety-related functions themselves (currently Class II), but which may impair the function of safety-significant plant components due to damages and impacts on them shall be considered in the accident analyses. According to current practice, these structural and plant components are classified as Class IIa. For the new classification, the requirements on the verification of seismic safety of structural and plant components classified as Class IIa according to the current standard should also be mentioned explicitly regarding the necessary safety functions in dependence of the results of plant-specific accident analyses.

4.10 Impacts (loads)

Status quo

Regarding the design of plant components, loads are listed for which distinction is to be made in connection with seismic loads as follows:

- *External loads during operation ...,*
- *reactions from constraint during operation ...,*
- *reactions from earthquakes and consequential effects*, and
- *external loads caused by damage to plant components, which have not been designed against earthquakes ... .*

(2) When combining the loads ... 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.

Assessment/recommendation

The term “loads” is no longer up-to-date and should be replaced by the term “impacts”, which is used in standards and guidelines of recent date.

For the verification of seismic safety of the structural and plant components, earthquake impacts shall be combined with permanent and varying impacts according to the assumptions of the accident analysis and the technical rules; thus, the detailed listing in KTA Safety Standard 2201.1 may be dispensed with.

4.11 Verification of seismic safety (design)

Status quo

(1) All Class I plant components shall be designed in accordance 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 loads.

(3) For Class II plant components, no demonstration in accordance with this safety standard is required. However, 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.

Assessment/recommendation

In accordance with the recommendation to change the title of the KTA Safety Standard 2201.1 into “Seismic Safety of Nuclear Installations”, the current chapter heading “Design” should be replaced by “Verification of Seismic Safety”.

The verification of seismic safety shall be performed for all structural and plant components whose seismic safety is required to comply with the safety requirements due to the results of plant-specific accident analyses such that their respective safety-related functions (structural components: load bearing capacity, usability; plant components: stability, integrity, functional reliability) are maintained in case of a design earthquake.

4.12 Verification methods (calculations)

Status quo

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 behavior of the ground and of the plant components.

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.

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.

Assessment/recommendation

In addition to calculation procedures, verification by experiments, compliance with construction rules and empirical may also be taken into account for the verification of the seismic safety of structural and plant components. The chapter heading should therefore be changed into “Verification Procedures”.

As calculation procedures, dynamic calculations generally come into consideration. The admissibility of simplified calculations for structural and plant components shall be justified in the individual case.

Essential principles for the verification of seismic safety of structural and plant components from the Standards 2201.3 and 2201.4 should already be mentioned in KTA Safety Standard 2201.1. The following should be mentioned in particular:

- For the dynamic calculation, the structural component and the foundation are modelled by means of a mathematical-mechanical model which shall be able to cover the frequency range of the structure excited by the earthquake.

- The excitation of structures shall be defined in the three orthogonal directions as being effective at the same time or a resulting horizontal and the vertical excitation shall be used each. The superposition of unidirectional load parameters may take place according to the square root method.

- The influence of the interaction between structure and ground (ground-structure interaction) may be considered in a simplified form by frequency-dependent parameters if the parameters are varied in an adequate range for verification; however, frequency-dependent ground-structure interaction models shall be preferred.

4.13 Seismic instrumentation

Status quo

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 design 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.

N o t e :
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).

Assessment/recommendation

In order to establish whether measures are to be initiated after occurrence of a seismic event, all nuclear power plants and all other nuclear installations with increased hazard potential should generally be equipped with seismic instrumentation. Deviations shall be justified in the individual case.

Design parameters for establishment of the inspection level may also be response spectra.

4.14 Effects on the site

Status quo

- ***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.

- ***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.

Assessment/recommendation

Changes to the foundation or the environment resulting from earthquake must not impair the required safety functions of the plant components and the structural components.

5 Additional comment

In addition to the recommendations for the revision of KTA Safety Standard 2201.1, the RSK recommends to implement the following recommendations, substantiated in [U 2]:

- Performance of a probabilistic seismic hazard analysis for a site in Germany under consideration of the recommendations stated in [R 3] (a corresponding analysis has recently been performed in Switzerland referred to as PEGASOS [L 2]),

- specification of the selection criteria regarding the strong-motion recordings for the identification of the design response spectrum (magnitudes, site intensity, epicentral distance/Joyner-Boore distance, focal mechanisms, subsurface).

6 Consultation documents [U], Guides, guidelines, standards [R], Literature [L]

Consultation documents

[U 1] Schreiben des BMU an die RSK-Geschäftsstelle (Az.: AG RS I 3-17018/1) vom 08.11.2002, Beratungsauftrag an die RSK, Thema: Stellungnahme der RSK zur KTA-Regel 2201.1

[U 2] Stellungnahme der AG SEISMOLOGIE des RSK-Ausschusses ANLAGEN- UND SYSTEMTECHNIK: Bemessungserdbeben am Standort Biblis, 07.03.2002.

[U 3] Empfehlung der RSK: Sicherheitsanforderungen an die längerfristige Zwischenlagerung schwach- und mittelradioaktiver Abfälle, Fassung vom 05.12.2002 mit Neuformulierung in Abschnitt 2.7.1 (dritter Spiegelstrich) vom 16.10.2003.

Guides, guidelines, standards

[R 1] KTA 2201, Auslegung von Kernkraftwerken gegen seismische Einwirkungen
Teil 1: Grundsätze, Fassung 6/90
Teil 2: Baugrund, Fassung 6/90
Teil 3: Auslegung der baulichen Anlagen, Regelvorlage 6/91
Teil 4: Anforderungen an Verfahren zum Nachweis der Erdbebensicherheit für maschinen- und elektrotechnische Anlagenteile, Fassung 6/90
Teil 5: Seismische Instrumentierung, Fassung 6/90
Teil 6: Maßnahmen nach Erdbeben, Fassung 6/90

[R 2] IAEA-Safety Guide-NS-G-3.3-2002 (2002):
Evaluation of Seismic Hazards for Nuclear Power Plants.

[R 3] Senior Seismic Hazard Analysis Committee (SSHAC) (1997):
Recommendations for Probabilistic Seismic Hazard Analysis - Guidance on Uncertainty and Use of Experts. Main Report.
US Nuclear Regulatory Commission, NUREG/CR-6372

[R 4] Lawrence Livermore National Laboratory (2002): Guidance for Performing Probabilistic Seismic Hazard Analysis for a Nuclear Plant Site:
Example Application to the Southeastern United States
U.S. Nuclear Regulatory Commission, NUREG/CR-6607, UCRL-ID-133494, October 2002.

Literature

[L 1] IfBt-Bericht (1986) (König und Heunisch (eds.)):
Realistische Lastannahmen für Bauwerke mit erhöhtem Sekundärrisiko. Abschlußbericht im
Auftrage des Instituts für Bautechnik Berlin, Frankfurt/M., 1986.

[L 2] Abrahamson, Birkhäuser, Koller, Mayer-Rosa, Smit, Sprecher, Tinic, Graf: PEGASOS – A Comprehensive Probabilistic Seismic Hazard Assessment for Nuclear Power Plants in Switzerland, Paper Ref. 633 of 12th European Conf. on Earthquake Engineering, London, 2002.