Transactions, **SMiRT-22**
San Francisco, California, USA - August 18-23, 2013
Division VII

DESIGN OF NUCLEAR POWER PLANTS AGAINST SEISMIC EVENTS IN GERMANY - SEISMIC INSTRUMENTATION AND POST-SEISMIC ACTIONS

Matias Krauß[1], Björn Elsche[2] and Gebhard Roth[3]

[1] Section Head, Department of Nuclear Safety, Section Safety Assessment, Federal Office for Radiation Protection, Salzgitter, Germany (mkrauss@bfs.de)
[2] Senior Engineer, Eon Kernkraft, Hannover, Germany
[3] Senior Engineer, EnBW Kernkraft, Philippsburg, Germany

ABSTRACT

The design principles of German nuclear power plants base on the recommendations of the Nuclear Safety Standards Commission (KTA). [Kerntechnischer Ausschuss (KTA), http://www.kta-gs.de/welcome_engl.htm], where the standard series KTA 2201 describes the general requirements for design against earthquakes. The series KTA 2201 consists of six parts and will be reviewed as part of the regular revision process of KTA at the time. The parts KTA 2201.1 "Principles", KTA 2201.2 "Subsoil" and KTA 2201.4 "Components" have been finally adopted by KTA. The parts KTA 2201.3 "Civil Structures", KTA 2201.5 "Seismic Instrumentation" and KTA 2201.6 "Post-Seismic Measures" are still in various stages of revision. All standards can usually be obtained under the above stated address.

This paper presents the drafts of the parts KTA 2201.5 and KTA 2201.6, in this process, were the authors involved. Starting from the description of the seismic hazard situation in Germany, the design concept "design earthquake - inspection level" is briefly explained with reference to the KTA rule. A special importance is given to plant-walk-downs and inspections. The recommendations proposed by the working committee KTA 2201.6 are briefly presented here and compared with international standards. In particular it describes developments within the rule. Finally, an outlook on the next steps of the revision is given.

DESIGN BASIS OF GERMAN NPPS AGAINST EARTHQUAKE

The sites of German nuclear power plants (NPP) are located in areas of low to moderate seismicity. Typical macro-seismic intensities for events with exceedance probabilities of 10^{-4}/a - 10^{-5}/a are in the range of $I_{site}(EMS) \approx V$ to $I_{site}(EMS) \approx VIII$. Due to the generally low seismicity seismic measurement data for hazard assessment are scarce. On the other hand abundant information on historic earthquakes dating back to as early as the year 800 A.D. is available. Therefore, the leading parameter for the seismic hazard assessment in Germany is the macro-seismic intensity.

A site specific deterministic seismic hazard assessment is required for NPP sites in Germany according to Part 1 of the nuclear safety standard KTA 2201 (2011-11). In the new revision of this standard (published in 2012) the application of probabilistic methods for the hazard assessment will be required additionally. In practice, such probabilistic approaches have already been part of the seismic hazard assessment for all German NPP sites. The exceedance probability of the so called "Bemessungserdbeben"(design base earthquake DBE) according to the revised KTA 2201.1 is 10^{-5}/a (median). Basis for the deterministic determination of the design basis earthquake are the strongest earthquakes that have occurred within the surrounding area of the site up to the radius at least of 200 km. Paleoseismic findings are be taken into account. In the past also an exceedance probability of 10^{-4}/a in combination with the 84th percentile of the ground motion parameters has been used.

NPPs at sites where the site specific hazard is very low (I_{site}(EMS) < VI) are designed to withstand at least an earthquake with I_{site}(EMS) = VI. The seismic hazard assessments performed on behalf of the licensees are typically subject to a review by the authority.

All NPPs in Germany are designed in such a way that they can be safely brought to a cold shutdown state after a DBE. A shutdown is not triggered by seismic instrumentation automatically, but has to be initiated manually if deemed necessary.

The information listed in the Table 1 is a short summary of the main DBE characteristics in different regions of Germany in terms of maximal values. The site specific values could be significant lower, c.f. BMU (2011-10).

Table 1: Main characteristics – maximum values – of the DBE in Germany

region	Characteristics of DBE			
	peak ground acceleration	macro-seismic intensity at the site	exceedance probability in terms of the median value	$t_{strong\ motion}$
Schleswig-Holstein	$pga_{hr} \approx 0.50$ m/s^2 $pga_v \approx 0.25$ m/s^2	V ½ (EMS)	$\leq 10^{-5}$/a	≤ 4 s
Lower Saxony	$pga_{hc} \leq 0.75$ m/s^2	≤ VII (MSK)	$\leq 10^{-5}$/a	≤ 4 s
Hesse	$pga_{hr} = 1.5$ m/s^2	VII ¾ (MSK)	$\leq 10^{-5}$/a	-
Baden-Württemberg	$pga_h \leq 2.1$ m/s^2 $pga_v \leq 0.85$ m/s^2	≤ VIII (MSK)	$< 10^{-5}$/a	≤ 4 s
Bavaria	$pga_{hk} \leq 0.83$ m/s^2 $pga_h \leq 1.0$ m/s^2	≤ VII (EMS)	$p < 10^{-4}$/a	≤ 10 s

Abbreviations used in the table:
pga_{hr} = horizontal resultant of the peak ground acceleration
pga_{hc} = horizontal component of the peak ground acceleration
pga_h = horizontal peak ground acceleration (information about type not provided)
pga_v = vertical component of the peak ground acceleration

REGULATORY BASIS

The German safety concept for nuclear power plants gives priority to the deterministic approach, i.e. deterministic analysis and good engineering judgement, are primary tools of design evaluation. Basis for this approach are the standards of the Nuclear Safety Standards Commission (KTA).

The KTA standards have the task of specifying those safety related requirements which shall be met with regard to precautions to be taken in accordance with the state of science and technology against damage arising from the construction and operation of the plant (Sec. 7 para. 2 subpara. 3 Atomic Energy Act – AtG) in order to attain the protective goals specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the “Safety Criteria” , in the “Design Basis Accident Guidelines” and in the recently issued “Safety Requirements for NPPs”.

In accordance with Criterion 2.6 of the Safety Criteria, protective measures against the seismic events are required, provided earthquakes must be taken into consideration. Table I of the Design Basis Accident Guidelines classifies earthquakes as belonging to that group of design basis accidents that requires taking preventive plant engineering measures against damage and which are relevant with respect to radiological effects on the environment. The basic requirements of these preventive measures are dealt with in safety standard series KTA 2201.

Probabilistic safety assessment is seen as a supplementary tool to the deterministic approach which provides quantitative information on the occurrence of incidents and thus can be used to check deterministic design assumptions, to evaluate desired plant and system modifications, to optimize corrective measures and to identify existing safety margins, e.g. in the frame of comprehensive (periodic) safety reviews. Guidelines are published 2005 by BMU and they are available online (BMU 2005), (FAK PSA 2005).

The safety standards of KTA applies to nuclear power plants with light water reactors and, in particular, to the design of components and civil structures against seismic events in order to meet the protective goals of a) controlling reactivity, b) cooling fuel assemblies, c) confining radioactive substances, and d) limiting radiation exposure, cf. BMU (2012) and KTA 2201.1 (2011-11).

SEISMIC INSTRUMENTATION AND POST-SEISMIC ACTIONS ACCORDING TO KTA 2201

General requirements

The present safety standard KTA 2201.1 (2011-1) describes the general requirements for the design and defines the general terms for all other parts. The standard KTA 2201 will be applied under the presumption that the geology and tectonics of the plant site has been investigated with special emphasis on the existence of active geological faults and lasting geological ground displacements.

KTA 2201.1 defines a design basis earthquake (DBE) as following.

"The design basis earthquake is the decisive earthquake for the design against seismic events. The design basis earthquake is the basis for the specification of the seismoengineering parameters. The design basis earthquake may also be understood as being a combination of a number of decisive earthquakes or as being the design-decisive ground motions at the site of the facility."

The general requirements for a DBE acc. KTA 2201.1 are

(1) *"The DBE is described by the seismic actions at the location of the site that are characterized, essentially, by the intensity and ground motions. The DBE shall be determined and specified based on deterministic and probabilistic analyses. The surrounding area of the site out to a radius of at least 200 km shall be taken into account; however, it shall be examined whether data is available that would make it necessary to consider even larger radii from the site in the analyses."*

(2) *"The deterministic approach to specifying the design basis earthquake shall be based on historic earthquakes, taking the earthquake with the largest seismic actions into consideration that would have to be assumed at the site in light of current scientific knowledge."*

(3) *"The probabilistic approach to specifying the characteristics of the design basis earthquake shall be based on a probability of exceedance of 10-5 per annum."*

(4) *"The DBE shall be specified by evaluating the deterministic and the probabilistic analyses. The corresponding seismic actions may be specified for the 50 %-fractile value, provided, the probability of exceedance of the characteristics of the design basis earthquake is in the order of 10^{-5} per annum."*

(5) *"The DBE shall be specified with an intensity of at least VI."*

Further information's are given in KTA 2201.1.

Regarding the instrumentation and the post-seismic measures KTA 2201.1 defines the following requirements:

"A seismic instrumentation shall be installed that it will display the exceedance of any acceleration limit values related to the inspection level of the plant. Furthermore, the seismic instrumentation shall be designed such that it allows comparing the response spectra derived from the registered earthquake time histories with the underlying response spectrum of the inspection level. The inspection level of the plant corresponds to 0.4 times the rigid-body accelerations and it corresponds to the ground or building response spectra of the design basis earthquake scaled down by factor 0.4. A higher limit value of the

inspection level is permissible, provided, it is verified that specified normal operation of the plant is still possible even after the occurrence of an earthquake of this higher level."

"Whenever the seismic instrumentation registers an earthquake in the plant, a plant inspection shall be carried out. Whenever the acceleration limit values of the inspection level are exceeded, the loadings caused shall be investigated more extensively to help evaluate the earthquake effects with regard to a continuation of plant operation. In case the inspection level is decisively exceeded or the plant is not anymore in a specified normal condition, then the plant shall be shut down."

Details regarding seismic instrumentation are specified in safety standard KTA 2201.5 and regarding the inspection level / post-seismic actions in safety standard KTA 2201.6.

Seismic Instrumentation

According to KTA 2201.1 at a nuclear power plant a seismic instrumentation is installed. The objective of this seismic instrumentation is to identify and record an earthquake. In KTA 2201.5 the locations of the seismic instrumentation and characteristics are fixed. The data is recorded in the free field and at three points in the reactor building. To capture the different vibrations in buildings, the three measuring equipment in the reactor building should be arranged as follows. Two instruments are installed on the bottom plate of the reactor building with a large distance. To capture the vibration characteristics of the building level, another sensor is installed in the upper level of the building. The instrumentation in the free field is situated far away from the buildings; the buildings have no effect on the measured data.

The seismic instrumentation must be able to determine the response spectrum of the earthquake that occurred in the acceleration time histories, in order to allow a comparison with the response spectrum of the inspection levels. This inspection level, demanded in KTA 2201.1 and defined in KTA 2201.6, is specified as 0.4 times of the DBE. For the comparison on the respective installation locations the respective response spectrum of the design earthquake has to be multiplied by a factor of 0.4. This provides a conservative level, in order to be able to take the necessary measures after an earthquake.

Compared to the previous version of 1996, the requirements on the characteristics of the measuring instruments have changed significantly. By the transition from analog to more efficient digital measurement technology, the requirements have been adapted to the state of the art. For the plants in operation, these results in metrology hardly need to adjust because the analog measurement technology has been in most cases already switched to digital. The number of measuring instruments has been maintained. It also responds to the international requirements, as they are recommended for example by the IAEA (2011-05).

Post-seismic actions

To define this level safety standard KTA 2201.6 uses the verification concept "design basis earthquake versus inspection level".

KTA 2201.6 defines the measures that are to take place immediately after the detection of an earthquake by the operating personnel. KTA 2201.1 demanded an inspection level 0.4 times of the DBE. If the acceleration does not exceed the inspection level significantly, it can be assumed that the plant is in normal operation state, but it is a inspection required. The scope of the examination depends on the seismic action occurred. With the review of the system, structure and components possible changes due to seismic action are examined. If the acceleration does exceed the inspection level significantly the plant is shut down and further measures are specified in each individual case.

According to KTA 2201.6 measures to be taken after an earthquake correspond to defined levels of the earthquake occurred. KTA 2201.6 distinguishes between three earthquake levels in terms of scaled DBE and defines three corresponding categories of actions. The levels and categories are described in Table 2. Here, between the "first", "recessed" and "resulting" measures and the levels "plant-walk-down-level", "inspection level", "shut down level" and "design level" must be distinguished.

As seen in Table 2, in response to the strength of the earthquake plant walk-downs, inspections and dedicated actions depending on plant status are carried out.

To get a quick overview of the consequences of the earthquake on the plant, the system state must be determined by short-term measures. For this purpose, check of control room records of plant parameters and fault indication system and plant inspections are carried out. If the classification of the earthquake shows, that the inspection level was exceeded significantly, then a shut-down inspection has to be performed and the plant has to shut-down.

The measures to be taken after an earthquake correspond to defined levels of the earthquake occurred. When the earthquake instrumentation has recorded an earthquake and the inspection level, which corresponds to 0.4 times the DBE, is not exceeded, then plant inspections have to be performed (operator walk down level), in order to confirm the specified normal operation state of the plant.

Above the inspection level in addition to the system checks an enhanced inspection has to be carried out. This includes more comprehensive actions than the operator walk down inspections. If the earthquakes exceed $f \cdot 0.4 \cdot \text{DBE}$ with a plant specific safety factor f (normally 1.5), which defines the shut-down-level, then a shut-down inspection and measures are demanded specified in dependence of the system status. Compared with previous version of KTA 2201.6 the expiry of the measures to be taken has been clarified.

So now, a plant walk is demanded below the inspection level, and plant walk is demanded below the level of inspection. If Shutdown of the plant should be necessary, in addition to being pre-plant walk down, at least one shut-down inspection has to be performed. This approach is also in line with international requirements EPRI (1989-12), NUREG (1997).

Table 2: Graded approach for post-seismic actions according to KTA 2201.6.

earthquake level	plant status	actions
1.0 · DBE	design level	
f · 0.4 up to 1.0 · DBE	shut-down operation	shut-down-inspection and dedicated actions depending on plant status
f · 0.4 · DBE	shut-down level	
0.4 up to f · 0.4 · DBE	continue normal operation	extended walk-down and review of plant status
0.4 · DBE	inspection level	
	continue normal operation	standard walk-down
threshold for data-logging according KTA 2201.5	plant-walk-down level	
	normal operation	no

DBE: design base earthquake
normally f = 1.5

The classification of the earthquake is regulated as follows. If an earthquake occurs, the data generated from the recorded time histories response spectra are evaluated. Because of today's modern seismic instrumentation technology, this can be done without significant delay, so that all necessary information is immediately available. The earthquake is classified according to Table 2. Here, the factor must be applied with f = 1.5. The use of a factor f greater than 1.5 has to be verified.

At least one frequency of a determined response spectrum (component or resultant) 40% response spectrum which is the underlying design by more than 10% is exceeded, the inspection level is considered as exceeded. A higher level is to KTA 2201.1 admissible if normal operation status of the plant is verified even after the occurrence of such an earthquake (Operating Basis Earthquake OBE). At least one frequency exceeds more than 10% of a determined response spectrum (component or resultant) the f·0.4-times response spectrum, which is the underlying design, then the inspection level is considered as exceeded significantly and the shut-down level is reached.

Required actions and measures

In summary, the required actions and measures can be described with the following of nine points. For this purpose, some supplementary notes are given.

(1) Verification of the seismic event
The group alarm "seismic event" shall be triggered in the control room. If at least two seismic triggers have responded it shall be assumed that an earthquake has occurred. Upon detection of a fault excitation, the cause must be determined.

(2) Classification of the Earthquake
The inspection level at the location of the seismic instrumentation is reached when the response spectrum corresponds to the at least 0.4 times the scaled value of the design response spectrum. A higher value for inspection level is admissible if normal operation of the plant is verified after occurrence of an earthquake of this strength. Note here is that the operation basis earthquake (OBE) in accordance with KTA 2201.1 (1975) corresponds not to the DBE according to KTA 2201.1 (2011), but rather to the inspection level. Furthermore, an initial evaluation for the entire frequency range is carried out. If exceeding only occurs in the frequency range above 16 Hz, the plant can be initially continue operation depending of the outcome of engineering judgments and if in reviewing no changes are detected by seismic actions.

(3) Checks of control room records and fault indication system (e. g. on line computer records) and plant-walk downs
The objective is to detect obvious changes caused by the earthquake that provide the intended system status (normal operation) into question. If such an apparent change in a region below the inspection level is indicated, this is an indication of a non normal operation status. A review from the control room to changes in process parameters or fault indication should be performed. Furthermore, system, structures and components shall be checked with particular attention to changes that are due to seismic actions. The classification and extent of the plant-walk down is set in the operating regulations. The inspections shall be documented.

(4) Plant inspection and review of plant status
Here, the objective is to detect by non-obvious deviations due to seismic event, which may impair the proper plant status. An inspection team should consist of personnel who know the system state before the earthquake event. The findings from inspections for conducting seismic PSA should also be considered, c.f. Thuma and FAK PSA 2005. Here are selected system, structures and components (SSC) should analyzed exemplarily, where earthquake is the leading load case. A more detailed analysis of other SSC is not considered necessary because the stress limits for the specified operation state can be achieved only at a significant excess of the inspection level.

(5) Specified operation state
The specified operation state is met if the following statements are true:

- The conditions of the operation manual are fulfilled. These include in particular the availability requirements for safety-systems.

- The plant walk no obvious changes are observed that provide the specified operation state in question.
- At installation inspection no obvious changes are found to provide the specified operation state in question.
- No changes have occurred that may affect the specified operation state by subsequent exposure. The supplementary analysis of the exemplary system, structures and components confirm the conservatism of the calculation model.
- The performed reevaluations and inspections of earthquake related deviations confirms the specified operation state.

(6) **Continue normal operation**
If the specified operation state acc. to point (5) is confirmed and if the inspection level is not exceeded significantly, normal operation could be continued.

(7) **Shut-down inspection**
Before starting shut-down operation mode the plant status has to be checked from the control room and conducting a plant-walk down. The operability of the emergency power supply, the residual heat removal and the necessary auxiliary systems should be checked. An essential starting point for the shut-down of the plant is the finding of deviations of the specified normal operation state

(8) **Shut-down according to operation manual**
If inspection for shut-down according to point (7) confirms the specified normal operation state of the plant, the plant must be shut-down in accordance to operation guidelines. Otherwise further defense-in-depth measures shall defined.

(9) **Further measures** are determined in each case in consultation with the Supervisory Authority.

SUMMARY

Finally, Table 3 shows the classification of the KTA 2201 in the requirements of the IAEA SR No. 66. In this context, it should again be noted that the KTA panel considers an extension of the KTA in accordance with IAEA SR No. 66 is not required for the expected earthquake in Germany.

Currently in Germany the safety standard series KTA 2201 “Design of Nuclear Power Plants against Seismic Events” with their parts 1 to 6 is being revised. Part 1 “Principles2 was published in November 2011, followed by updated releases of KTA 2201.2 (“Subsoil”) and 2201.4 (“Components”) in 2012. Final approval of KTA 2201.3 (“Structural components”) is expected by end of 2013. The final drafts of Parts 5 (“Seismic instrumentation”) and Part 6 (“Post-seismic measures”) are expected in 2013.

Proposals as draft standards are submitted to KTA steering committee.

Table 3: Post earthquake action-levels according to IAEA (2011-05)

		Earthquake level EL		
Damage level DL		EL 1	EL 2	EL 3
DL 1	No significant damage to important to safety SSCs No significant damage to not important to safety SSCs	Covered by KTA 2201	Action level 1	Action level 5
DL 2	No significant damage to important to safety SSCs Significant damage to not important to safety SSCs, not required for power		Action level 2	Action level 6

	generation			
DL 3	No significant damage to important to safety SSCs Significant damage to not important to safety SSCs, required for power	Action level 3		Action level 7
DL 4	Significant damage to important to safety SSCs	Action level 4		Action level 8

REFERENCES

KTA 2201.1 (2011-11). Safety Standards of the Nuclear Safety Standards Commission (KTA). "Design of Nuclear Power Plants against Seismic Events; Part 1: Principles".

KTA 2201.5 (Draft, 2012-07-24). Safety Standards of the Nuclear Safety Standards Commission (KTA). "Design of Nuclear Power Plants against Seismic Events; Part 5: Seismic Instrumentation."

KTA 2201.6 (Draft, 2012-08-08). Safety Standards of the Nuclear Safety Standards Commission (KTA). "Design of Nuclear Power Plants against Seismic Events; Part 6: Post-seismic actions."

BMU (2011-10). Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (BMU). "EU Stresstest National Report of Germany. Implementation of the EU Stress Tests in Germany", 31.10.2011.

BMU (2012). Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (BMU), "Sicherheitsanforderungen an Kernkraftwerke", Bekanntmachung vom 20.11.2012. http://www.bmu.de/.../pdf/sicherheitsanforderungen_an_kkw_2012_bf.pdf.

CNS (2011). Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (BMU). Convention on Nuclear Safety: "Report by the Government of the Federal Republic of Germany for the Fifth Review Meeting in April 2011".

IAEA (2011-05). Safety Report Series No. 66 Earthquake Prepardness and Response for Nuclear Power Plants

EPRI (1989-12). Guidelines for Nuclear Plant Response to an Earthquake EPRI NP 6695

NUREG (1997-1166). Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions NRC-Regulatory Guide 1.166, March 1997

NUREG (1997-1167). Restart of a Nuclear Power Plant Shut Down by a Seismic Event. NRC-Regulatory Guide 1.167, March 1997

FAK PSA (2005). Facharbeitskreis Probabilistische Sicherheitsanalysen (FAK PSA): "Methoden- u. Daten zur probabilistischen Sicherheitsanalyse für Kernkraftwerke", 2005, Bundesamt für Strahlenschutz (BfS), urn:nbn:de:0221-201011243824 und urn:nbn:de:0221-201011243838.

Thuma, G.; Türschmann, M.; Krauß, M.: Development of advanced methods for seismic probabilistic safety assessments. In: Furuta, Frangopol & Shinozuka (Eds): Proceedings of the International Conference on Safety, Reliability and Risk of Structures, Infrastructures and Engineering Systems, London, Taylor & Francis Group, (2010), p. 1641–1645.

BMU (2005). Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit - BMU), Leitfaden zur Durchführung der Sicherheitsüberprüfung gemäß §19a des Atomgesetzes – Leitfaden probabilistische Sicherheitsanalyse – für Kernkraftwerke in der Bundesrepublik Deutschland, Bundesanzeiger Nr. 207a vom 03.11.2005 (in German) http://www.bfs.de/de/bfs/recht/rsh/volltext/3_BMU/3_74_3.pdf.