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Design of nuclear power plants against seismic events —

Part 6: Post-seismic measures

Conception parasismique des installations nucléaires —
Partie 6: Dispositions et actions post-sismiques

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Foreword

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A list of all parts in the ISO 4917 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The requirements in this document are based on the verification concept ‘Inspection earthquake level' given in ISO 4917-1.

Up to the point where the value of the inspection level is not decisively exceeded, no earthquake-related deviations that could put specified normal operation conditions into question need to be expected in any areas designed against seismic events. Nevertheless, certain measures are performed to verify specified normal operation conditions before the inspection level is decisively exceeded, those measures are specified in this document.

Whenever the value of the inspection level is decisively exceeded, earthquake-related deviations that could put the specified normal operation condition into question cannot anymore be ruled out in the areas designed against seismic events. Therefore, if the inspection level is decisively exceeded the nuclear power plant is shut down and the measures are performed as specified in this document.

Design of nuclear power plants against seismic events —

Part 6:
Post-seismic measures

1 Scope

This document applies to nuclear power plants with water cooled reactors.

This document does not apply to earthquakes stronger than the design basis earthquake.

This document specifies guidance on the actions to be taken in preparation for and following an earthquake at a nuclear power plant. This document is intended to be used as a guideline for decision making regarding continued operation, shutdown and restart of the nuclear power plant after an earthquake. It can also be used to assist operating organizations in the preparation and implementation of an overall pre- and post-earthquake action programme for dealing with situations in accordance with the level of seismic ground motion experienced at the site, and the seismic design level of the plant.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4917-1, *Design of nuclear power plants against seismic events — Part 1: Principles*

ISO 4917-5, *Design of nuclear power plants against seismic events — Part 5: Seismic instrumentation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
specified normal operation
operation for which the nuclear power plant is technically intended, designed and suited

Note 1 to entry: The specified normal operation comprises the operating conditions and operating procedures

a) during functioning condition of the facilities (undisturbed operational state, normal operation, “Normal Operation” according to IAEA Safety Standards Series No. SSR-2/1),

b) during abnormal operation (disturbed operation, malfunction, “Anticipated operational occurrences” according to IAEA Safety Standards Series No. SSR-2/1), and

c) during maintenance procedures (inspection, maintenance, repair).

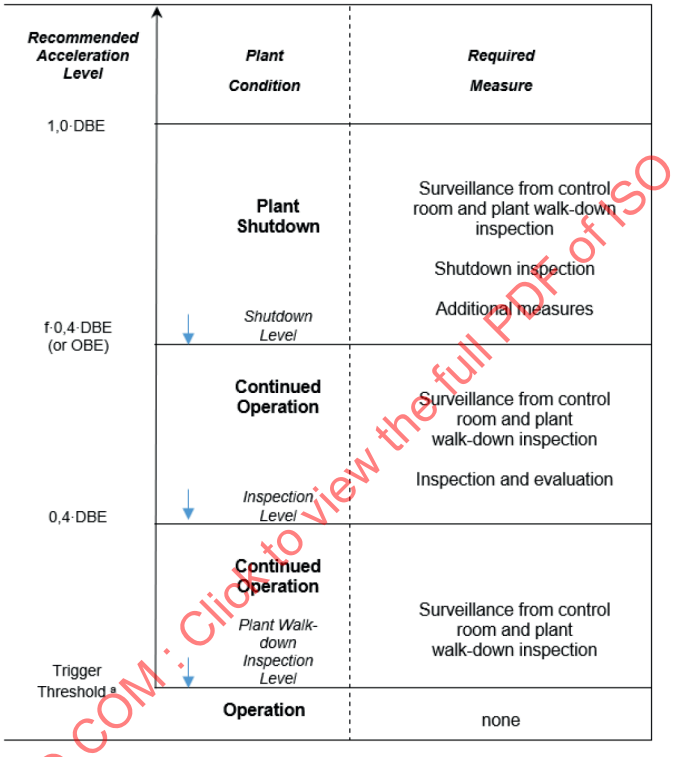
4 Procedure

4.1 General requirements

After occurrence of an earthquake and depending on the level of the recorded acceleration time history a concept of graded measures shall be applied. This concept is shown in Figure 1. The corresponding acceleration levels can be defined as plant-specific. Recommend values are indicated in this figure. Other types of intensity measures (e.g. cumulative absolute velocity (CAV) values) can also be specified additionally.

The individual required measures can be found in 4.4, 4.5 and 4.6. These measures should also be addressed in the operator's manual.

NOTE Individual cases can require long-term measures. These can be performed even after the restart of the plant, however, they are not the subjects of this document.



Key

DBE design basis earthquake

OBE operating basis earthquake

[a] Trigger threshold for data registration in accordance with ISO 4917-5.

Figure 1 — Concept of graded measures

In case an earthquake leads to an operational malfunction or design-basis accident, then the required measures to mitigate these events shall be performed with the highest priority.

4.2 Verification of the earthquake

Whenever the seismic recorder is activated (Figure 2, chart item 1) it shall be determined whether an earthquake has occurred. This requirement may be met, e.g., by contacting institutions outside of the nuclear power plant and evaluating the recorded time histories with respect to faulty signals.

If the trigger thresholds for data recording of at least two installation locations of seismic instrumentations were exceeded (plant walk-down inspection level), it shall precautionarily be assumed that an earthquake has occurred.

In case of a faulty signal, its cause shall be determined. All faulty signals shall be documented. The documentation should be maintained as a quality record.

4.3 Classification of the earthquake

When an earthquake has occurred, the response spectra generated from the recorded time histories shall be evaluated based on the following criteria.

The earthquake shall be classified as specified in Figure 2, chart item 2. The corresponding acceleration levels can be defined plant-specific. Recommended values are indicated in Figure 1. Other types of intensity measures (e.g. CAV values) can also be specified additionally.

The factor f (see Annex A) may be assumed as being equal to 1,5. Using a factor f larger than 1,5 requires an individual plant-specific verification.

If the measured response spectrum exceeds the shutdown level (e.g. design basis response spectrum times f·0,4, or if available, the operating basis earthquake, OBE, response spectrum) at any frequency, it should be assumed that the inspection level has been decisively exceeded.

A different reference level (deviating from "design basis spectrum times f·0,4" or "operating basis earthquake OBE response spectrum") is permissible in accordance with ISO 4917-1, provided that, it was verified that specified normal operation of the plant is possible even after the occurrence of an earthquake of that size.

If the inspection level is decisively exceeded only for frequencies above a predetermined plant specific upper bound frequency (e.g. 16 Hz), the status of the plant shall be evaluated by engineering-based considerations. For the length of these activities, a continued operation of the plant is permissible.

NOTE 1 The engineering-based evaluation may be based on, e.g., ground motion, spectral values, magnitudes or cumulative absolute velocity (CAV) values.

NOTE 2 In the case of safety-related buildings and components, the essential frequencies for the evaluation are typically the ones up to 16 Hz.

4.4 Initial measures

To obtain a quick overview of the effects that the earthquake had on the plant, the plant condition shall be determined by performing quickly executable measures.

Independent of the earthquake classification, the plant condition shall be determined by a plant inspection. This requires performing plant check-ups from the control room and plant walk-down inspections.

If the classification of the earthquake indicates that the inspection level was decisively exceeded, then a plant shutdown inspection shall be performed and the plant should be shut down.

4.4.1 Plant check-up from the control room and plant walk-down inspection (Figure 2, chart item 3)

The condition of the plant shall be checked from the control room (e.g. computer printouts, displays, failure alarms, hazard alarms, indications of leakages).

Within the framework of an immediately initiated plant walk-down inspection (see Annex B), a visual inspection shall be performed to identify possible deviations caused by the earthquake. In this context, areas designed against, as well as areas not designed against seismic events shall be inspected. The type and extent of the plant walk-down inspection depend on the specific features of the plant and shall be specified in the operating regulations.

The plant walk-down inspection shall be performed at least with the extent and quality of a regular inspection round.

The results of the plant check-up and plant walk-down inspection shall be documented. The documentation shall be maintained as a quality record to be made available for third party audits.

4.4.2 Deviations caused by the earthquake (Figure 2, chart item 4)

During the plant walk-down inspection, particular attention shall be paid to obviously recognizable, earthquake-related deviations.

Provided, the earthquake classification shows that the inspection level was not reached and no earthquake-related deviations were discovered, then no in-depth measures are required and continued operation of the plant is permissible. If, however, earthquake-related deviations were discovered, it shall be checked whether the specified normal operation condition is being maintained.

If the earthquake classification shows that the inspection level was reached but not decisively exceeded and that no earthquake-related deviations were discovered, then in-depth measures shall be initiated. However, if earthquake-related deviations were discovered it shall first be checked to determine whether the specified normal operation condition is upheld before the in-depth measures are initiated.

4.4.3 Specified normal operation condition in accordance with the operating manual (Figure 2, chart item 5)

The specified normal operation condition may be considered as being maintained if the respective prerequisites and conditions specified in the operating manual are met and no earthquake-related deviations were detected that would lead to restricting specified normal operation.

If earthquake-related deviations are detected, the specified normal operation condition shall be checked and confirmed.

Provided, the specified normal operation condition is maintained, a continuation of plant operation should be permissible for the time being and the inspections and analyses described in 4.5.2 shall be performed.

If, however, the specified normal operation condition has not been maintained, a shutdown inspection as specified in 4.5.4 shall be performed and the plant shall be shut down as specified in 4.6.2.

4.5 In-depth measures

4.5.1 General

In-depth measures shall be performed depending on the classification of the earthquake and on the results of the initial measures. In-depth measures shall normally either ascertain the specified normal operation condition of the plant or facilitate its safe shutdown. The measures should be included in the operator's manual.

Provided the earthquake classification indicates that the inspection level was not reached, then in-depth measures are only required to be performed if earthquake-related deviations were detected.

If the classification of the earthquake indicates that the inspection level is exceeded, then in-depth measures shall be performed.

4.5.2 Special/seismic inspections and analyses (Figure 2, chart item 6)

The special/seismic inspection shall be performed by a special plant inspection team as a walk-down inspection of the entire plant.

NOTE Examples for possible indications of earthquake-related deviations are presented in Annex C.

The limited accessibility of exclusion areas shall be taken into account depending on the actual plant conditions.

The plant walk-down inspection team shall normally be made up of qualified persons and of personnel who are familiar with the condition of the plant before the earthquake. The composition of the plant walk-down inspection team and the extent of the ad hoc inspections shall be individually specified for the respective plant.

An analysis of the action effects shall be performed for those seismic category 1 components and civil structures for which an earthquake-related deviation was detected.

For those seismic category 1 components and civil structures for which an earthquake-related deviation was detected, additional exemplary seismic category 1 components shall be chosen for which the earthquake is the governing load case and that are highly stressed:

a) two pipelines,

b) two pipeline supports,

c) two vessel support structures,

d) two pump supports, and

e) two valves with high super structures.

These components shall either be subjected to an analysis of the action effects due to the earthquake or their previously identified locations of highest load shall be subjected to non-destructive examinations. It is permissible to base the analysis of the action effects on the plant and system conditions that had existed during the earthquake.

The number of load cycles that occurred during the earthquake shall be determined at the measuring points and shall be evaluated.

Earthquake-related deviations of seismic category 2 components and civil structures shall be evaluated with respect to possible effects they might have on seismic category 1 components and civil structures.

The functioning of the terminating elements of the reactor protection system, of the components of the emergency power supply and of the emergency system shall be inspected, as far as this is possible under the actual operating condition.

The results of the inspections and analyses shall be documented. The documentation should be maintained as a quality record.

4.5.3 Specified normal operation condition and permissible loads (Figure 2, chart item 7)

Provided, the inspections and analyses have not uncovered any earthquake-related deviations, then the specified normal operation condition shall be considered as ascertained and continued operation of the plant is permissible (Figure 2, chart item 7).

If, however, the inspections and analyses have uncovered earthquake-related deviations, a continuation of the plant operation is not permissible for the time being and the shutdown inspection specified in 4.5.4 shall be performed.

4.5.4 Shutdown inspection (Figure 2, chart item 9)

The availability of the systems necessary for a safe shutdown (e.g., emergency power supply, residual heat removal and required auxiliary systems) shall be checked and, if required, made available.

NOTE Required systems and actions to be taken for a safe shutdown can be found in the operation manual of the plant.

4.6 Resulting measures

4.6.1 Continued operation (Figure 2, chart item 8)

Provided, the inspections under 4.4.2 or 4.5.3 show that the specified normal operation condition is upheld, a continuation of the plant operation is permissible.

4.6.2 Shutting down the plant (Figure 2, chart item 10)

If, however, the inspections in 4.4.3 or 4.5.3 show that the specified normal operation condition is not upheld or that the inspection level is decisively exceeded, then the plant shall be shut down under consideration of the findings in 4.5.4.

4.6.3 Additional procedures (Figure 2, chart item 11)

Additional measures required in individual cases shall be specified in close consultation with the regulatory authority.

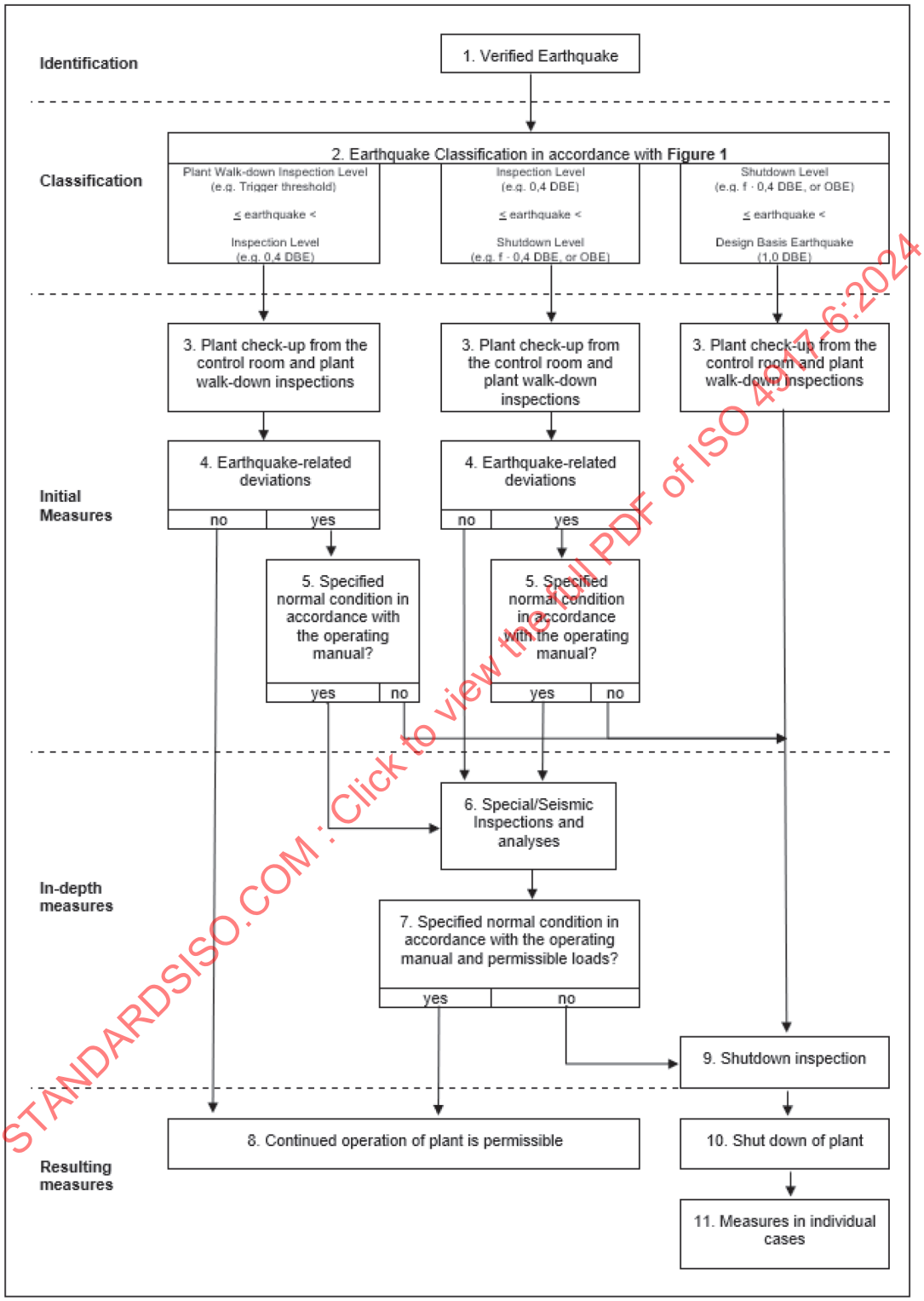


Figure 2 — Post-seismic measures

Annex A
(informative)

Derivation of factor, *f*

The inspection level shall be considered to be decisively exceeded if the level of the actual earthquake (response spectrum) is higher than *f*-times the inspection level (or if available, the operating basis earthquake OBE response spectrum). Then the shutdown level is reached. The recommended level of the inspection level is 0,4 times the design basis earthquake.

The conservativeness of the factor *f* is founded in the understanding that operation may harmlessly be continued, provided, the earthquake-related loads lie within elastic limits or plastic deformations are restricted to regions of geometric discontinuities.

For pressurized or radioactivity-containing components this is the case if service level C is not exceeded.

NOTE The service levels can be found in ISO 4917-4.

Provided, the design basis earthquake is accounted for by a design for service level D, then service level C is reached at $\alpha \cdot$ DBE where α shall be calculated by Formula (A.1).

$$\alpha = \left(\frac{\text{perm } \sigma^{C}}{\text{act } \sigma^{A}} - 1 \right) \Big/ \left(\frac{\text{act } \sigma^{D}}{\text{act } \sigma^{A}} - 1 \right) \tag{A.1}$$

(perm – permissible; act – actual)

The calculation of the factor α as well as the entire calculatory chain for the design against earthquakes is based on the following conservative assumptions:

— Cautious assumptions regarding $\text{act } \sigma^{A}$ and $\text{act } \sigma^{D}$,

— in part more favourable operating conditions during the respective earthquake,

— narrow-banded spectra of the respective earthquake,

— based on experience, a more advantageous component behaviour than verified based on the analyses specified in ISO 4917-1 to ISO 4917-5.

Table A.1 lists the safety-related components grouped according to their corresponding α-values. The engineering-based assessment of these results and of the remaining conservativeness leads to a factor α = 0,6. Depending on the plant related investigations (i.e. calculatory check of the safety-related vessels with austenitic support lugs or beam supports), this value can possibly be increased up to α = 0,7.

This corresponds to a factor f = 1,5, possibly increased up to f = 1,75.

Table A.1 — Shutdown level in the case of safety related components

Row	Component group		Maximum stress limit for DBE	Shutdown level $\alpha \cdot$ DBE
1[a]	Pipelines	welded	3 S_m (= R_mT)	0,7
2[b]		flanged	Flange: R_p0,2T	1
3[b]	Supports, mounting brackets - steel structures		R_p0,2T	1
4[c]	Active mechanical components		R_p0,2T or deformation analysis	1
5[e]	Vessels, heat exchangers		min. (3,6 S_m, R_mT)	>0,5 (up to 0,7)
6[d]	Electrotechnical components and controls		Experimental verification	1
7[e]	Seismic category 2 components and pipelines		Same as seismic category 2 components and pipelines	>0,5 (up to 0,7)
8[b]	Containment vessel		0,94 · R_p0,2T	1

[a] On account of design load cases and the required deflection limitation, a value for act σ^A < 0,75 S_m may be assumed. With the otherwise conservative assumptions this leads to α = 0,7.

[b] Since the design for the DBE is such that the yield strength will not be exceeded, the loads up to 100 % DBE will remain in the elastic range. Connecting elements, however, are rated higher anyway and therefore: α = 1,0.

[c] Since the design for the DBE requires either a verification of Service Level B or a deformation verification, no impermissible plastic deformations will occur up to 100 % DBE and therefore: α = 1,0.

[d] Provided, the active functioning is experimentally verified up to 100 % DBE: α = 1,0.

[e] Since the sum of the primary and secondary stresses ($PL + Q \leq 3\ S_m$) is significant for Service Levels A and B, a value of act $\sigma_L{}^A \leq S_m$ can be assumed for the austenitic materials in all situations occurring in the plant. With an otherwise conservative approach, this leads to:

— α = 0,5 for austenitic materials and a corresponding value;

— α = 0,9 up to 1,0 for ferritic materials.

Since α = 0,5 only applies to vessels with brackets or supports, an intensive investigation of these (generally few) vessels opens the possibility to raise the value of α maybe even to the most advantageous value α = 0,7, the value for welded pipelines.

Annex B
(informative)

Directives for plant walk-down inspections

The following list contains examples (based on IAEA Report Series No. 66) for possible earthquake-related deviations that need special attention during plant walk-down investigations. The objective of the visual inspection in the course of a plant walk-down inspection is to identify obviously apparent damages.

— Leakages in pipeline systems, particularly at flanges, threaded nozzles and branching-off pipelines.

— Damage to low-pressure tank vessels, especially flat-bottom tanks.

— Damage to switchyard components.

— Increased vibrations, increased bearing temperatures and unusual sounds of rotating components.

— Displaced, fallen-over or fallen-down objects.

— Damages to, and loosening of anchoring.

— Damages to pipes, electric cables and cable ways.

— Indications of an excessive displacement of cable and component supports.

— Indications that containment penetrations are possibly adversely affected.

— Indications that components have impacted each other.

The findings and results of the walk-down inspections shall be documented. The documentation should be maintained as a quality record.

Annex C
(informative)

Special/Seismic inspections

The following observations can, among others, be indicative of earthquake-related deviations:

a) platforms and mountings:
   - newly flaked off paint;
   - visible cracks in weld seams;
   - concrete dust, visible cracks in the wall near anchors;
   - visible deformations or displacements.

b) civil structures:
   - concrete spallings;
   - in-seepage of water;
   - cracks in the concrete;
   - visible damages to the containment isolation components (preventing a release of radioactivity);
   - damages to doors;
   - damages to suspended ceilings;
   - damages to lighting elements;
   - uplift and lowering of the ground.

c) ventilation ducts:
   - visible deformations;
   - leakages.

d) cable way constructions:
   - visible deformations;
   - visible damages to cables;

e) pipelines:
   - restrained expansion, restrained vibration;
   - damages to wall penetrations;
   - visible deformations;
   - leakages;
   - damage to subsoil-embedded pipelines and other distribution systems (pipe breaks and ground anomalies).