U.S. NUCLEAR REGULATORY COMMISSION

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Technical Leads: Sarah Tabatabai
Vladimir Graizer

NUCLEAR POWER PLANT INSTRUMENTATION FOR EARTHQUAKES

A. INTRODUCTION

Purpose

This regulatory guide (RG) describes the seismic instrumentation criteria, including instrumentation type, locations, characteristics, and maintenance, that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for nuclear power plants.

Applicability

This guide applies to applicants and reactor licensees subject to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities" (Ref. 1) and 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 2).

Applicable Regulations

- Appendix S to 10 CFR Part 50, "Earthquake Engineering Criteria for Nuclear Power Plants," provides the engineering criteria for nuclear power plants.
    - Appendix S, Paragraph IV(a)(3), requires shutdown of the nuclear power plant if vibratory ground motion exceeds that of the operating basis earthquake ground motion (OBE).
    - Appendix S, Paragraph IV(a)(4), requires that suitable instrumentation must be provided so that the seismic response of nuclear power plant features important to safety can be evaluated promptly after an earthquake.
- 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," governs the issuance of early site permits, standard design certifications, combined licenses, standard design certifications, combined licenses, standard design approvals, and manufacturing licenses for nuclear power plants.

Written suggestions regarding this guide or development of new guides may be submitted through the NRC's public Web site in the NRC Library at http://www.nrc.gov/reading-rm/doc-collections/, under Document Collections, in Regulatory Guides, at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/contactus.html,

Electronic copies of this RG, previous versions of this guide, and other recently issued guides are also available through the NRC's public Web site in the NRC Library at http://www.nrc.gov/reading-rm/doc-collections/, under Document Collections, in Regulatory Guides. This RG is also available through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html, under ADAMS Accession Number (No.) ML17094A831. The regulatory analysis may be found in ADAMS under Accession No. ML16104A218. The associated draft guide DG-1332 may be found in ADAMS under Accession No. ML16104A220, and the staff responses to the public comments on DG-1332 may be found under ADAMS Accession No. ML17095A314.

Related Guidance

- RG 1.166, “Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions” (Ref. 3), provides guidance for a timely evaluation of the recorded instrumentation data after an earthquake to determine whether plant shutdown is required by 10 CFR Part 50.

- RG 1.167, “Restart of a Nuclear Power Plant Shut Down by a Seismic Event” (Ref. 4), provides guidance for performing inspections and tests of nuclear power plant equipment and structures prior to restart of a plant that has been shut down by a seismic event.

- NUREG-0800, “Standard Review Plan (SRP) for the review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition” (Ref. 5), provides guidance to the NRC staff in their review of Safety Analysis Reports submitted as part of a license application.

    - Section 2.5.1 “Geologic Characterization Information,” provides guidance to the NRC staff on review of the geologic characteristics and tectonic setting of a given site.

    - Section 2.5.2 “Vibratory Ground Motion,” provides guidance to the NRC staff on review of vibratory ground motion likely to affect a given site.

    - Section 3.7.1 “Seismic Design Parameters,” provides guidance to the NRC staff for review of the affect that earthquake design ground motions might have on a given plant’s structures.

- RG 8.8, “Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be as Low as is Reasonably Achievable” (Ref. 6), provides information relevant to attaining goals and objectives for planning, designing, constructing, operating, and decommissioning a light-water reactor (LWR) nuclear power station to meet the criterion that exposures of station personnel to radiation during routine operation of the station will be “as low as reasonably achievable.”

- RG 1.208, “A Performance-Based Approach to Define the Site-Specific Ground Motion Response Spectrum (GMRS)” (Ref. 7), provides guidance on the development of the site-specific ground motion response spectrum.

- RG 1.29, “Seismic Design Classification” (Ref. 8), provides guidance on identifying and classifying those features of LWR nuclear power plants that must be designed to withstand the effects of the SSE.

- American National Standards Institute /American Nuclear Society (ANSI/ANS)-2.2-2016, “Earthquake Instrumentation Criteria for Nuclear Power Plants” (Ref. 9), specifies the required earthquake instrumentation for the site and structures of light-water-cooled, land-based nuclear power plants.

- American National Standards Institute /American Nuclear Society (ANSI/ANS)-2.23-2016, “Nuclear Power Plant Response to an Earthquake” (Ref. 10), specifies the actions a utility should take preceding and immediately following an earthquake felt at a nuclear power plant site to determine the need to shutdown and also the actions necessary to determine the power plant’s readiness to restart if shutdown is required.

Purpose of Regulatory Guides

The NRC issues RGs to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated events, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required. Methods and solutions that differ from those set forth in RGs will be deemed acceptable if they provide a basis for the findings required for the issuance or continuance of a permit or license by the Commission.

Paperwork Reduction Act

This RG provides guidance for implementing the mandatory information collections in 10 CFR Parts 50 and 52 that are subject to the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et. seq.). These information collections were approved by the Office of Management and Budget (OMB), under control numbers 3150-0011 and 3150-0151. Send comments regarding this information collection to the Information Services Branch, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by e-mail to Infocollects.Resource@nrc.gov, and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-10202 (3150-0011, 3150-0151), Office of Management and Budget, Washington, DC 20503.

Public Protection Notification

The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless the document requesting or requiring the collection displays a currently valid OMB control number.

B. DISCUSSION

Reason for Revision

Revisions were made to address new reactor plant configurations and the state of practice of seismic instrumentation. The revisions related to the specified number and locations of seismic instrumentation, address various new reactor plant configurations, and significant technological advances in seismic instrumentation that have been made since the last revision. New reactor plant configurations have Seismic Category I structures located on (1) individual foundations, (2) a single foundation (a nuclear island), or (3) a combination or (1) and (2). To address these changes, more than one foundation or basemat instrument may be needed to characterize rocking or torsional behavior for current new designs with a nuclear island that supports the containment and other Seismic Category I structures. In addition, a free-field downhole sensor is needed if the foundation level depth exceeds 40 feet. Other revisions reflect the state of practice since issuance of Revision 2 in 1997. For example, the upper limit of the free-field acceleration frequency range was increased from 50 Hz to a minimum of 100 Hz, consistent with the upper frequency limit of 100 Hz specified in Regulatory Guide 1.208 in the development of the ground motion response spectra (GMRS).

In addition, this revision of the guide incorporates lessons learned from the earthquakes that occurred in Japan and the United States during 2007 – 2011. Notably, during the Niigataken Chuetsu-Oki Earthquake, limitations on data storage capacity of the seismic instrumentation system at the Kashiwazaki-Kariwa Nuclear Power Plant in Japan resulted in the over-writing of main shock data by aftershock data. As a result, the specified recording duration and battery capacity in Sections C.4.5 and 4.6 are increased from 25 minutes to a minimum of 120 minutes of sensed motion. Section C.4.12.4 also states that the data recording protocol should prevent overwriting of recorded earthquake files.

Background

When an earthquake occurs, it is important to take prompt action to assess the effects of the earthquake at the nuclear power plant. This assessment includes both an evaluation of the seismic instrumentation data and a plant walkdown. Acceleration sensors and solid-state digital time-history recorders installed at appropriate locations will provide time-history acceleration data on the seismic response in the free-field, containment structure, and other Seismic Category I structures. The acceleration sensors need to be located so that the response may be compared and evaluated with the design basis, which are typically ground motion or in-structure response spectra. The sensors are intended to be installed such that occupational radiation exposures associated with their location, installation, and maintenance are maintained as low as is reasonably achievable (ALARA) per 10 CFR Part 20, "Standards for Protection Against Radiation" (Ref. 11). Thorough documentation of instrument, components, and as-installed supporting systems is needed to enable operation, maintenance, and testing. These functions enable confident use of the data.

Instrumentation is provided in the free-field, at the foundation level, and at elevations in Seismic Category I structures. Free-field instrumentation data is used (1) to compare the measured ground motion response to an earthquake to the engineering evaluations used to determine the design input motion to the structures, and (2) to determine whether the OBE has been exceeded. RG 1.166 provides useful information for determination of OBE exceedance. In addition, downhole instrumentation data is used to obtain quality recordings of in situ strong motion at depth, and to validate the site response calculations to develop the GMRS and foundation input response spectra (FIRS). The instruments located at the foundation level, and at elevations in the structures, measure responses that are the input to the equipment or piping and are used in long-term evaluations. Additional guidance is found in RG 1.167, which provides useful information on plant restart following an earthquake. Foundation-level instrumentation provides data on the actual seismic input to the containment and other Seismic Category I structures and is used to quantify differences between the vibratory ground motion at the free-field and at the foundation level. Instrumentation is not located on equipment, piping, or supports since experience has shown that data obtained at these locations are obscured by the vibratory motion associated with normal plant operation.

The guidance in RG 1.166 is based on the assumption that the nuclear power plant has functional seismic instrumentation, including the equipment and software needed to process the data within 4 hours after an earthquake. This is necessary to determine whether plant shutdown is required. This determination is made by comparing the recorded data against OBE exceedance criteria and by evaluating the results of the plant walkdown inspections that take place within 8 hours of the event.

An NRC staff evaluation of seismic instrumentation noted that instruments have been out of service during plant shutdown and sometimes during plant operation for extended durations. The instrumentation system needs to be functional and operated at all times. There are guidelines in Appendix A to Regulatory Guide 1.166 to address non-functional or degraded seismic instrumentation or data processing hardware and software necessary to determine whether the OBE has been exceeded.

The type, location, operating modes, characteristics, installation, activation, remote indication, and maintenance of the seismic instrumentation are described in this guide to help ensure (1) that the data provided are comparable with the data used in the design of the nuclear power plant, (2) that exceedance of the OBE can be determined, and (3) that the equipment will perform as required.

This guide does not address the need for instrumentation that would automatically shutdown a nuclear power plant when an earthquake occurs which exceeds a predetermined size. Also, this guide does not address nuclear power plant designs incorporating base isolation techniques since procedures for the seismic analysis and design are yet to be defined.

It is important that all significant ground motion associated with an earthquake is recorded. This is accomplished by specifying how long before and after the actuation of the seismic trigger the data is recorded. Settings for the instrumentation's pre-event memory are correlated with the maximum distance to any potential epicenter that could affect a specific site. For example, the "P" wave may not be recorded when instrumentation is set for only a 3-second pre-event memory. Also, when an event occurs at some distance and the trigger threshold limit is not exceeded until 15 or 20 seconds into the event, a part of the record, although at low amplitude, is lost. A 60-second value may be more appropriate and is within the capabilities of current digital time-history accelerographs.

Harmonization with International Standards

The International Atomic Energy Agency (IAEA) has established a series of safety guides and standards constituting a high level of safety for protecting people and the environment. IAEA safety guides present international good practices and increasingly reflects best practices to help users striving to achieve high levels of safety. Pertinent to this regulatory guide, Section 7 of IAEA Safety Guide NS-G-1.6, "Seismic Design and Qualification for Nuclear Power Plants" (Ref. 12), addresses the seismic instrumentation to be installed at a nuclear power plant site. This regulatory guide is consistent with the basic safety principles provided by IAEA Safety Guide NS-G-1.6.

Documents Discussed in Staff Regulatory Guidance

This regulatory guide endorses, in part, the use of one or more codes or standards developed by external organizations, and other third party guidance documents. These codes, standards and third party guidance documents may contain references to other codes, standards or third party guidance documents ("secondary references"). If a secondary reference has itself been incorporated by reference into NRC regulations as a requirement, then licensees and applicants must comply with that standard as set forth in the regulation. If the secondary reference has been endorsed in a regulatory guide as an acceptable approach for meeting an NRC requirement, then the standard constitutes a method acceptable to the NRC staff for meeting that regulatory requirement as described in the specific regulatory guide. If the secondary reference has neither been incorporated by reference into NRC regulations nor endorsed in a regulatory guide, then the secondary reference is neither a legally-binding requirement nor a "generic" NRC approved acceptable approach for meeting an NRC requirement. However, licensees and applicants may consider and use the information in the secondary reference, if appropriately justified, consistent with current regulatory practice, and consistent with applicable NRC requirements.

C. STAFF REGULATORY GUIDANCE

This section provides detailed descriptions of the methods, approaches, or data that the staff considers acceptable for meeting the requirements of Appendix S to 10 CFR Part 50 for the type, locations, functionality, characteristics, installation, actuation, remote indication, accompanying materials, and maintenance of seismic instrumentation.

1. Seismic Instrumentation Type and Location

1.1 Scope

Solid-state digital instrumentation that enable the processing of data at the plant site within 4 hours of the seismic event should be used.

1.2 Instrument Type and Location

Table 1 and Figures 1 through 4 in ANSI/ANS-2.2-2016 provide an acceptable method for placement of seismic sensors for various nuclear power plant design configurations. Triaxial acceleration sensors should be installed at the locations described below.

(1) Free-field.

(a) At the free ground surface, the location should be consistent with the site conditions and properties used to determine the site-specific GMRS. If the site condition at the free-field instrument location is different from the site condition at the plant site, transfer functions should be developed in advance to transfer the free-field motion at the instrument location to the plant site and should be included in the assessment of the free-field recorded motion at the plant site.

(b) Downhole instrumentation at a depth corresponding to the foundation level if this depth exceeds 40 ft. below plant grade.

(c) Placed at an appropriate distance away from structures, such that the free-field ground motion is recorded (see Section C.1.3.1 of this guidance).

(d) Located so that (a) and (b) are as close to being directly over each other as practical.

(2) Containment foundation.

(a) One instrument when the foundation supports only containment and internal structures; or

(b) Three instruments when the foundation supports the containment/internal structure, and other Seismic Category I structures and forms a "nuclear island." The instruments should be appropriately placed to record the rocking or torsional responses predicted by the analyses; or

(c) One instrument when the foundation supports the containment/internal structure, and other Seismic Category I structures, denoted a "nuclear island;" and justification is provided that the rocking or torsional responses predicted by the response analyses are insignificant.

(3) Two higher elevations (excluding the foundation) on a structure inside the containment (i.e., a structure internal to the primary or secondary containment and supported by the containment foundation).

(4) A Seismic Category I structure foundation included in a certified standard design or facility where the expected response is different from that of the containment structure.

(5) An elevation (excluding the foundation) on a Seismic Category I structure selected in 4 above.

(6) An elevation in a non-containment Seismic Category I structure supported by the containment foundation.

(7) A Seismic Category I structure foundation not included in a certified standard design or facility.

(8) A higher elevation in the instrumented Seismic Category I structure selected in (7).

(9) Alternatives to sensor locations C.1.2(2) through C.1.2(8) may be necessary in order to support other instrumentation criteria in this regulatory guide. Alternative locations should be selected and justified by the nuclear plant designer or applicant/licensee to ensure that comparisons can be made with the calculated vibratory responses used in the certified standard design or facility.

1.3 Instrument Location Considerations

The specific locations for instrumentation should be determined by the nuclear plant designer or applicant/licensee to obtain the most pertinent information consistent with maintaining occupational radiation exposures ALARA for the location, installation, and maintenance of seismic instrumentation. In general the following should be done:

1.3.1 *Free-Field Sensors*

The free-field sensors should be located and installed so that they record the motion of the ground surface and so that the effects associated with surface features, buildings, and components on the recorded ground motion will be insignificant. A distance of at least one major structural dimension (height or length, whichever is greater) away from all large structures in the vicinity should be maintained where possible as recommended by the "Guidelines for Installation of Advanced National Seismic System Strong-Motion Reference Stations," published by Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) (Ref. 13). The NRC staff has reviewed these guidelines and concluded they are an acceptable approach for installation of free-field sensors.

1.3.2 *In-structure Instrumentation*

The in-structure instrumentation should be placed at optimum locations that have been included in the building dynamic analysis so that the measured motion can be directly compared with the design in-structure response spectra. Instrumentation should also be placed at locations using other considerations such as risk-informed locations[1]. The instrumentation should not be located on a secondary structural frame member that is not modeled as a mass point in the building dynamic model. Locations should be selected to record highly amplified response rather than slightly amplified response. Thus, it would be inappropriate to locate instruments where amplification would not be expected.

1.3.3 *ALARA Design Review*

A design review of the location, installation, and maintenance of proposed instrumentation for maintaining exposures ALARA should be performed by the facility in the instrumentation planning stage in accordance with RG 8.8. Instrumentation should be placed in a location with as low a dose rate as is practical, consistent with other requirements.

1.3.4 *Maintenance Considerations*

Instruments should be selected to require minimal maintenance and in-service inspection, as well as minimal time and numbers of personnel to conduct installation and maintenance.

2. Instrumentation at Multi-Unit Sites

All units at the site should have the same instrumentation unless it can be demonstrated that the site conditions across the site are essentially the same and the expected structural response of each unit are identical. In this case, a reduced set of instrumentation may be used. Adequate free-field instruments should be provided to capture differences in site response, unless it can be demonstrated that one free-field instrument is adequate. In the case of separate control rooms for the same or different certified designs, annunciation should be provided to all control rooms as specified in Section C.7 of this guidance.

3. Seismic Instrumentation Operating Modes

The seismic instrumentation should be functional during all modes of plant operation, including periods of plant shutdown. Maintenance and repair procedures should provide for keeping the maximum number of instruments in service during plant operation and shutdown. Procedures should be established to identify whether an instrument was operating appropriately during an earthquake following the functional check(s) recommended by the instrument manufacturer. Appendix A to RG 1.166 provides guidance on actions to take if the instrumentation is discovered to have been out of service during an earthquake.

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1 Risk informed locations are locations having systems and components identified as important to safety, based on risk importance concepts such as those contained in Regulatory Guide 1.201 (Ref. 14), or a seismic probabilistic risk assessment or a seismic margin assessment.

4. Instrumentation Characteristics

4.1 In-service Testing

The design should include provisions for in-service testing. The instruments should be capable of periodic channel checks during normal plant operation.

Instruments capable of "remote" in-service channel checks should be utilized. Some instruments may be placed in non-accessible locations; their design should allow for remote in-service testing.

4.2 In-place Functional Testing

The instruments should have the capability for in-place functional testing.

4.3 Inaccessible Sensor Locations

Instrumentation stations should be accessible for maintenance during full-power operation. Instrumentation that has sensors located in inaccessible areas should contain provisions for data recording in an accessible location, and the instrumentation should provide an external remote alarm to indicate actuation. The free-field instrumentation should be accessible immediately following an earthquake.

4.4 Pre- and Post-Event Recording Limits

The instrumentation should record, at a minimum, 60 seconds of low-amplitude motion prior to seismic trigger actuation, continue to record the motion during the period in which the earthquake motion exceeds the seismic trigger threshold, and continue to record low-amplitude motion for a minimum of 60 seconds beyond the last exceedance of the seismic trigger threshold.

4.5 Recording Duration

The instrumentation should be capable of recording a minimum of 120 minutes of sensed motion.

4.6 Battery Capacity

The battery should be of sufficient capacity to power the instrumentation to sense and record a minimum of 2 hours (120 minutes) of triggered event data. This can be accomplished by providing enough battery capacity for a minimum of 24 hours of operation without access to main power, in combination with a battery charger whose line power is connected to an uninterruptable power supply. Other combinations of larger battery capacity and alarm intervals may be used.

4.7 Reliability

Instruments should be operating during all modes of operation; including periods of plant shutdown (see Section C.3 of this guidance).

Instrument operational reliability should be demonstrated prior to installation through prototype, environmental, vibratory, or historical test results, or a combination thereof. The instrumentation should be designed to perform its function satisfactorily over an appropriate range of environmental conditions anticipated at its location, including:

- vibration (maximum free-field and in-structure earthquake-induced motion as predicted by the plant designer);
- temperature (both high and low);
- moisture (humidity, rain, snow, temporary submersion due to flooding, salt drift near coastlines, etc.);
- pressure (as it affects sensor noise);
- wind (as it may affect physical integrity of the system components as well as seismic noise);
- sun (as it affects short-term thermal changes and long-term material degradation);
- radio frequency interference (both from external and internal sources);
- magnetic interference from external sources; and
- radiation throughout the plant's design range for instrument locations.

4.8 Frequency Range

The instrumentation and recorder frequency ranges given in Sections C.4.11 through C.4.13 are typical. For some applications higher or lower ranges might be more appropriate. The ranges selected should be consistent with the vibration characteristics of the supporting structure and equipment and the function of the instrument.

4.9 Calibration

Time-history recorders should have the capability for in-place functional testing that can be recorded as a permanent part of the acquired information. Section C.9.2.2 describes the necessary maintenance tasks and schedule related to performing channel functional tests and calibration.

4.10 Time-History Recorder

The components of the time history recorder (acceleration sensor, recorder, seismic trigger) may be assembled in a self-contained unit or may be separately located. Characteristics of an acceleration sensor, recorder and seismic trigger are defined below in Sections C.4.11-4.13.

4.11 Acceleration Sensors

4.11.1 *Dynamic Range*

The acceleration sensors shall have a minimum dynamic range of 110 dB or 300,000:1 (not less than 18-bit) and the sensor should be able to record 4.0g zero to peak.

4.11.2 *Frequency Range*

The frequency range should be from zero Hz to a minimum of 100 Hz or an equivalent frequency demonstrated to be adequate by computational techniques applied to the resultant accelerogram, except the one located in the free-field.

The free-field acceleration sensor frequency range should be zero Hz to a minimum of 100 Hz.

4.11.3 *Spurious Resonances*

No spurious resonances within the frequency range of zero Hz to 100 Hz.

4.11.4 *Cross Axis Sensitivity*

Sensitivity to acceleration components orthogonal to the sensing axis should not exceed 0.01 g/g.

4.12 <u>Recorder</u>

4.12.1 *Sample Rate (Recording Speed)*

The sample rate should be at least 250 samples per second (0.004 sec) in each of the three directions.

4.12.2 *Bandwidth*

The bandwidth should be from zero Hz to a minimum of 100 Hz.

4.12.3 *Dynamic Range*

The dynamic range should be 300,000:1 or greater (not less than 110 dB or 18-bit), and the instrumentation should be able to record 4.0g zero to peak.

4.12.4 *Media*

The recorder should have archival capability. The data recording protocol should prevent overwriting of recorded earthquake files in the event memory is full. All earthquake records should be retained for the life of the plant. Information should be stored digitally on archival quality storage media. If the record is stored on computer memory, provisions should be made to transfer the record to a permanent medium during the processing phase to prevent accidental loss. Furthermore, redundant storage should be in place, i.e. data may be transmitted to an offsite location but a redundant set of data should always reside at the plant or another independent location. The documentation and retention of all earthquake records should be commensurate with the recordkeeping for other plant equipment.

4.12.5 *Timing*

Data on the time of the earthquake occurrence should be adequate to differentiate the main shock from any foreshock and aftershock with absolute timing accuracy of not less than 5 millisecond (msec) of absolute Universal Time Coordinated (UTC) time. A

GPS, network timing protocols, or another equivalent timing protocol shall be applied to both the timing and sampling of all data channels to provide this minimum accuracy.

4.13 Seismic Trigger

4.13.1 *Actuating Level*

The seismic trigger should be set to actuate at a maximum of 0.01 g.

4.13.2 *Frequency Range*

The frequency range of the seismic trigger should include the range of 1 Hz to 10 Hz.

4.13.3 *Output*

The seismic trigger output should be compatible with the device to be actuated.

4.13.4 *Proximity*

The seismic trigger may be integral to or separate from the time history recorder.

5. Instrumentation Installation

5.1 Mounting

The instrumentation should be designed and installed so that the mounting is rigid and remains so over time. In addition, all instrument components should remain tight over time. Installation at open ground locations requires constructing a reinforced concrete mounting pad with a lightweight enclosure. An acceptable enclosure is a commercial power plant type fiberglass or aluminum lightweight enclosure (instrument shelter or T-hut) not exceeding 50 in. x 50 in. x 50 in. and weighting less than 200 lbs. If a special, light instrument hut is used, the pad should be approximately 4 ft. square, with 6 in. x 18 in. piers to ensure effective coupling. A small concrete slab/pad and a lightweight enclosure will help meet the goal that the transmissibility of the installed strong-motion station be 1.0 over the frequency range 0-50 Hz; see the COSMOS "Guidelines for Installation of Advanced National Seismic System Strong-Motion Reference Stations," (Ref. 13) for supporting information.

The downhole instrument package should be securely attached to the bottom of the downhole to move with the medium it is embedded in. In addition, the sensor package should not add noise to the signal due to loose component rattling during strong shaking.

5.2 Orientation

The instrumentation should be oriented so that the horizontal components are parallel to the orthogonal horizontal axes assumed in the seismic analysis of the structure. Triaxial acceleration sensors should be mounted orthogonally with no more than 2 degrees out of orthogonality.

The downhole sensor orientation should be controllable, and known without the use of data recordings. Downhole electronic compasses have become available to measure orientation, which makes orientation easier to achieve. Also, if the downhole sensor locking device includes a pin to control orientation relative to the casing, orientation repeatability is obtained.

5.3 Protection

Protection should be provided against accidental impacts due to earthquake-induced failures of structures, nonstructural elements, equipment, or other features.

Strong motion instrumentation installed in areas prone to flooding should be adequately protected from water damage. Recorders and associated components that can be damaged by water should be installed above the highest water level predicted to occur, increased by a factor of 1.3. Sensors, cabling connectors and any other components installed at lower levels should be sealed against water intrusion, and be able to withstand immersion to a depth of three meters for an extended time. The central recorder should be able to withstand flooding of its remote sensors without compromising its operation or the integrity of any stored data.

5.4 Accessibility

Instrumentation stations should be accessible for maintenance during full-power operation. Seismic instrumentation with sensors located in inaccessible areas should contain provisions for data recording and certain maintenance operations at an accessible location, and the instrumentation should provide for an external remote alarm to indicate actuation. The free-field station should be accessible immediately following an earthquake.

5.5 Accuracy

Installed instrumentation should maintain timing and recording accuracy throughout the design range of environmental conditions, such as temperature, humidity, pressure, vibration, and radiation.

5.6 Instrumentation Station Environment

Instruments and their interconnections should be installed in accordance with the manufacturer's recommendations consistent with the COSMOS, "Guidelines for Installation of Advanced National Seismic System Strong-Motion Reference Stations."

5.7 Interconnection of Instruments

All time history recorders at the plant should be interconnected to be activated at the same time. All instruments on the site should maintain a common time scale with relative timing accuracy not less than 1 millisecond and absolute timing accuracy better than 5 milliseconds of absolute UTC time.

6. Instrumentation Actuation

6.1 Ground Motion Actuation

The time history recorders should be activated by either horizontal or vertical input vibratory ground motion. Since the time history recorders are interconnected, they should be activated by the same trigger. In this case, the trigger should be located with the time history recorder nearest to the free-field ground station.

6.2 Spurious Triggering

Spurious triggering should be avoided.

6.3 Threshold Ground Motion Acceleration

The seismic trigger mechanisms of the time history recorder should be set for a threshold ground acceleration of not more than 0.01g.

7. Remote Indication

Triggering of the free-field, downhole, or any foundation-level time-history recorder should be annunciated in the control room. If there is more than one control room at the site, annunciation should be provided to each control room.

8. Accompanying Materials

The calibration standards, computer software, record analyzers, etc., required to process the records from the seismic instruments should be on hand at the site and at other locations, if any, where records will be processed to ensure that the records can be processed within 4 hours after an earthquake.

9. Maintenance

9.1 General

The purpose of the maintenance program is to ensure that the seismic equipment will perform as required. Maintenance should be preplanned and performed in accordance with documented instructions or drawings appropriate to the instrument. The technical, testing, and administrative portions of the maintenance procedures should be defined and documented before plant startup. As stated in Section C.3 of this guidance, the maintenance and repair procedures should provide for keeping the maximum number of instruments in service during plant operation and shutdown.

The maintenance program should address technical, testing, and administrative procedures

After initial installation and each servicing of the free-field time history recorder, a response spectrum and a standardized cumulative absolute velocity (CAV) should be calculated using the analysis software for a standard input signal or suitable test earthquake time history to test and verify the analysis software. The CAV represents the time integral of absolute acceleration over the duration of the strong shaking. For seismic instrumentation Electric Power Research Institute (EPRI) TR-100082, "Standardization of the Cumulative Absolute Velocity" (Ref. 15), provides an acceptable algorithm for calculating a standardized CAV. The EPRI algorithm ignores small-amplitude shaking and has been shown to be a good indicator of the damage potential of earthquake ground motion.

Downhole instrumentation needs to be retrieved only for repair. After a sensor package has been retrieved, the redeployment should, if at all possible leave the instrument at the same depth in the hole, and oriented the same as during the previous period to maintain consistency with other instruments on the site and previously recorded earthquake motions.

9.2 Schedule

9.2.1 *General*

Maintenance schedules should specify timing of inspections, and replacement of such items that have a specified lifetime. Adequate consideration should be given to the characteristics and operational life of each type of equipment.

9.2.2 *Specific Maintenance Tasks*

Systems should be given channel checks every 2 weeks for the first 3 months of service after startup. Failures of devices normally occur during initial operation. After the initial 3-month period and 3 consecutive successful checks, monthly channel checks are sufficient. The channel functional test should be performed every 6 months. Channel calibration should be performed every 24 months or during each refueling outage, whichever comes first. The monthly check should include checking the batteries (i.e. battery voltages, appearance, and age).

Accessible instrumentation should be visually inspected once per month in order to detect signs of physical damage. Instruments that cannot be inspected monthly should be visually inspected when plant operations allow. A justification for extending inspections to a periodicity greater than one month should be justified and supported by related procedures. If an instrument becomes non-functional and needs to be replaced it should be replaced by a comparable accelerograph with specifications same or exceeding the current requirements (specifications) and compatible with existing system.

9.3 Test Data Requirements

The supplier of seismic instrumentation should include in the documentation of each product a specific explanation of how to accomplish a channel check, channel functional test, and channel calibration.

D. IMPLEMENTATION

The purpose of this section is to provide information on how applicants and licensees[2] may use this guide and information regarding the NRC's plans for using this regulatory guide. In addition, it describes how the NRC staff complies with 10 CFR 50.109, "Backfitting" and any applicable finality provisions in 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

Use by Applicants and Licensees

Applicants and licensees may voluntarily[3] use the guidance in this document to demonstrate compliance with the underlying NRC regulations. Methods or solutions that differ from those described in this regulatory guide may be deemed acceptable if they provide sufficient basis and information for the NRC staff to verify that the proposed alternative demonstrates compliance with the appropriate NRC regulations. Current licensees may continue to use guidance the NRC found acceptable for complying with the identified regulations as long as their current licensing basis remains unchanged**.**

Licensees may use the information in this regulatory guide for actions which do not require NRC review and approval such as changes to a facility design under 10 CFR 50.59, "Changes, Tests, and Experiments." Licensees may use the information in this regulatory guide or applicable parts to resolve regulatory or inspection issues.

Use by NRC Staff

The NRC staff does not intend or approve any imposition or backfitting of the guidance in this regulatory guide. The NRC staff does not expect any existing licensee to use or commit to using the guidance in this regulatory guide, unless the licensee makes a change to its licensing basis. The NRC staff does not expect or plan to request licensees to voluntarily adopt this regulatory guide to resolve a generic regulatory issue. The NRC staff does not expect or plan to initiate NRC regulatory action which would require the use of this regulatory guide. Examples of such unplanned NRC regulatory actions include issuance of an order requiring the use of the regulatory guide, requests for information under 10 CFR 50.54(f) as to whether a licensee intends to commit to use of this regulatory guide, generic communication, or promulgation of a rule requiring the use of this regulatory guide without further backfit consideration.

During regulatory discussions on plant specific operational issues, the staff may discuss with licensees various actions consistent with staff positions in this regulatory guide, as one acceptable means of meeting the underlying NRC regulatory requirement. Such discussions would not ordinarily be considered backfitting even if prior versions of this regulatory guide are part of the licensing basis of the facility. However, unless this regulatory guide is part of the licensing basis for a facility, the staff may not represent to the licensee that the licensee's failure to comply with the positions in this regulatory guide constitutes a violation.

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2 In this section, "licensees" refers to licensees of nuclear power plants under 10 CFR Parts 50 and 52; and the term "applicants," refers to applicants for licenses and permits for (or relating to) nuclear power plants under 10 CFR Parts 50 and 52, and applicants for standard design approvals and standard design certifications under 10 CFR Part 52.

3 In this section, "voluntary" and "voluntarily" means that the licensee is seeking the action of its own accord, without the force of a legally binding requirement or an NRC representation of further licensing or enforcement action.

If an existing licensee voluntarily seeks a license amendment or change and (1) the NRC staff's consideration of the request involves a regulatory issue directly relevant to this new or revised regulatory guide and (2) the specific subject matter of this regulatory guide is an essential consideration in the staff's determination of the acceptability of the licensee's request, then the staff may request that the licensee either follow the guidance in this regulatory guide or provide an equivalent alternative process that demonstrates compliance with the underlying NRC regulatory requirements. This is not considered backfitting as defined in 10 CFR 50.109(a)(1) or a violation of any of the issue finality provisions in 10 CFR Part 52.

Additionally, an existing applicant may be required to comply to new rules, orders, or guidance if 10 CFR 50.109(a)(3) applies.

If a licensee believes that the NRC is either using this regulatory guide or requesting or requiring the licensee to implement the methods or processes in this regulatory guide in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfit appeal with the NRC in accordance with the guidance in the NRC Management Directive 8.4, "Management of Facility-Specific Backfitting and Information Collection" (Ref. 16), and NUREG-1409, "Backfitting Guidelines," (Ref. 17).

GLOSSARY

acceleration sensor	An instrument capable of sensing absolute acceleration and producing an analog or digital signal that can be transmitted to a recorder.
accessible instruments	Instruments or sensors whose locations permit ready access during plant operation without violation of applicable safety regulations, such as those of the Occupational Safety and Health Administration (OSHA) or regulations dealing with plant security or radiation protection safety.
certified seismic design response spectra (CSDRS)	Site-independent seismic design response spectra that have been approved by the NRC as the seismic design response spectra for an approved certified standard design nuclear power plant.
certified standard design	See standard design certification.
channel calibration (primary calibration)	The determination and, if required, adjustment of an instrument, sensor, or system such that it responds within a specific range to an acceleration, velocity, or displacement input, as applicable, or responds as intended to the provided known input.
channel check	The qualitative verification of the functional status of the time-history recorder and sensor. This check is an "in-situ" test and may be the same as a channel functional test.
channel functional test (secondary calibration)	The determination, without adjustment, that an instrument, sensor, or system responds to a known input of such character that it will verify that the instrument, sensor, or system is functioning in a manner that can be calibrated.
containment	See primary containment and secondary containment.
containment foundation	The foundation of the containment or reactor building including adjacent foundations if they are constructed integrally with the containment foundation.
cumulative absolute velocity	The time integral of absolute acceleration over the duration of the strong shaking.
foundation input response spectra (FIRS)	When the site-specific ground motion response spectra (GMRS) and the site-independent certified seismic design response spectra (CSDRS) are determined at different elevations, the site-specific GMRS need to be transferred to the base elevations of each Seismic Category I foundation.

free field The free-field is defined as those locations on the ground surface or in the site soil column that are sufficiently distant from the nuclear power plant structures to be essentially unaffected by the vibration of these structures. Therefore, a time-history recorder located at the free-field records essentially the free-field ground motion.

ground motion response spectra (GMRS) Site-specific ground motion response spectra characterized by horizontal and vertical response spectra determined as free-field motions on the ground surface or as free-field outcrop motions on the uppermost in-situ competent material using performance-based procedures in accordance with RG 1.208. The GMRS represents the first part of the development of the Safe Shutdown Earthquake ground motion (SSE) for a site as a characterization of the regional and local seismic hazard. The final SSE must satisfy both 10 CFR 100.23 and Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50.

nonaccessible instruments Instruments or sensors in locations that do not permit ready access during plant operation because of a risk of violating applicable plant operating safety regulations, such as OSHA, or regulations dealing with plant security or radiation protection safety.

operating basis earthquake ground motion (OBE) The vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public will remain functional. The OBE is only associated with plant shutdown and inspection after an earthquake unless specifically selected by the applicant as a design input.

nuclear island The nuclear island is comprised of those concrete and steel structures, and associated foundations, that house/contain safety-related equipment such as the reactor, reactor coolant system components and related piping systems, containment pressure boundary, auxiliary building equipment such as diesel generators, Class1E electrical switchgear, safety injection systems and the control room.

primary containment The principal structure of a unit that acts as the barrier, after the fuel cladding and reactor pressure boundary, to control the release of radioactive material. The primary containment includes (1) the containment structure and its access openings, penetrations, and appurtenances, (2) the valves, pipes, closed systems, and other components used to isolate the containment atmosphere from the environment, and (3) those systems or portions of systems that, by their system functions, extend the containment structure boundary (e.g., the connecting steam and feedwater piping) and provide effective isolation.

recorder	An instrument capable of recording the data from an acceleration sensor or sensors.
safe shutdown earthquake ground motion (SSE)	The vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems and components are those necessary to ensure: • The integrity of the reactor coolant pressure boundary, • The capability to shut down the reactor and maintain it in a safe shutdown condition, or • The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures of nuclear radiation exceeding allowable amounts.
secondary containment	The structure surrounding the primary containment that acts as a further barrier to control the release of radioactive material.
secondary Category I structure, system, or component	Structures, systems, and components (SSCs) important to safety that are required to be designed/qualified to withstand the effects of the safe shutdown earthquake ground motion (SSE) and remain functional. Guidance for determining the category of an SSC is given in RG 1.29, "Seismic Design Classification."
seismic trigger	A device that starts the time-history recorder after a preset acceleration has been exceeded.
standard design	A design which is sufficiently detailed and complete to support certification or approval in accordance with 10 CFR Part 52 , and which is usable for a multiple number of units or at a multiple number of sites without reopening or repeating the review.
standard design certification or design certification	A Commission approved final standard design for a nuclear power facility. This design may be referred to as a certified standard design.
time history recorder	An instrument capable of sensing and recording acceleration versus time. The resulting recorded time histories may be stored locally and/or transmitted to other storage devices for processing and permanent storage. The components of the time-history recorder (acceleration sensor, recorder, seismic trigger) may be assembled in a self-contained unit or may be separately located.
triaxial	Able to measure a variable in three mutually orthogonal components (directions), one of which is usually vertical; applies to description of the function of an instrument or group of instruments.

REFERENCES[4]

1. *U.S. Code of Federal Regulations* (CFR), "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter I, Title 10, "Energy."

2. CFR, "Licenses, Certifications, and Approvals for Nuclear Power Plants," Part 52, Chapter I, Title 10, "Energy."

3. U.S. Nuclear Regulatory Commission (NRC), RG 1.166, "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions," Washington, DC.

4. RG 1.167, "Restart of a Nuclear Power Plant Shutdown by a Seismic Event," Washington DC.

5. NRC, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Washington, DC.

6. NRC, RG 8.8, "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable," Washington, DC.

7. NRC, RG 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion," Washington DC.

8. NRC, RG 1.29, "Seismic Design Classification for Nuclear Power Plants," Washington DC.

9. American National Standards Institute/American Nuclear Society (ANSI/ANS)-2.2-2016, "Earthquake Instrumentation Criteria for Nuclear Power Plants," American Nuclear Society, La Grange Park, Illinois (2016).

10. ANSI/ANS-2.23-2016, "Nuclear Power Plant Response to an Earthquake," American Nuclear Society, La Grange Park, Illinois (2016).[5]

11. CFR, "Standards for Protection Against Radiation," Part 20, Chapter I, Title 10, "Energy."

12. International Atomic Energy Agency (IAEA) Safety Standard NS-G-1.6, "Seismic Design and Qualification for Nuclear Power Plants," Vienna, Austria, 2003.[6]

[4] All publicly available NRC documents are available electronically through the NRC Library on the NRC's public Web site at: http://www.nrc.gov/reading-rm/doc-collections. The documents also can be viewed online or printed for a fee in the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone 301-415-4737 or 800-397-4209; fax 301-415-3548; and e-mail pdr.resource@nrc.gov.

[5] Copies of American Nuclear Society (ANS) standards may be purchased from the ANS Web site (http://www.new.ans.org/store/); or by writing to: American Nuclear Society, 555 North Kensington Avenue, La Grange Park, Illinois 60526, U.S.A., Telephone 800-323-3044.

[6] Copies of International Atomic Energy Agency (IAEA) documents may be obtained through their Web site: WWW.IAEA.Org/ or by writing the International Atomic Energy Agency P.O. Box 100 Wagramer Strasse 5, A-1400 Vienna, Austria. Telephone (+431) 2600-0, Fax (+431) 2600-7, or E-Mail at Official.Mail@IAEA.Org

13. Consortium of Organizations for Strong-Motion Observation Systems (COSMOS), "Guidelines for Installation of Advanced National Seismic System Strong-Motion Reference Stations," Richmond, California, July 2001.[7]

14. NRC, RG 1.201, "Guidelines for Categorizing Structures, Systems, and Components in Nuclear Power Plants According to their Safety Significance," Washington, DC.

15. Electric Power Research Institute (EPRI) TR-100082, "Standardization of the Cumulative Absolute Velocity," Electric Power Research Institute, Palo Alto, California, December 1991.[8]

16. NRC, Management Directive 8.4, "Management of Facility-Specific Backfitting and Information Collection," Washington, DC.

17. NRC, NUREG-1409, "Backfitting Guidelines," Washington, DC.

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[7] Copies of this document may be obtained from COSMOS, Pacific Eqrthquake Engineering Center, University of California Berkeley, 1301 South 46th ST., Richmond, CA 94804 or on line at: http://www.cosmos-eq.org/publications/reports/Guidelines_ANSS.pdf

[8] Copies of Electric Power Research Institute (EPRI) documents may be obtained by contacting the Electric Power Research Institute, 3420 Hillview Avenue, Palo Alto, CA 94304, Telephone: 650-855-2000 or on-line at http://my.epri.com/portal/server.pt.