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U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.133

LOOSE-PART DETECTION PROGRAM[1] FOR THE PRIMARY SYSTEM OF LIGHT-WATER-COOLED REACTORS

A. INTRODUCTION

Criterion 1, "Quality Standards and Records," of Appendix A, "General Design Critiera for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires that structures, systems, and components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed and that a quality assurance program be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions.

Criterion 13, "Instrumentation and Control," requires, in part, that instrumentation be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions to ensure adequate safety, including those variables and systems that can affect the fission process, the integrity of the core, and the reactor coolant pressure boundary.

Section 50.36, "Technic Specifications," of 10 CFR Part 50 requires an applicant for a facility operating license to provide proposed technical specifications. Paragraph (c)(2), "Limiting Conditions for Operation," identifies a proposed technical specification relating to the lowest functional capability or performance levels of equipment required for safe operation of the facility. Paragraph (c)(3), "Surveillance Requirements," identifies a proposed technical specification relating to test, calibration, or inspection to ensure that the necessary quality of systems and components is maintained, that facility operation will be within the safety limits, and that the limiting conditions of operation will be met. Paragraph (c)(5), "Administrative Controls," requires an applicant for a facility operating license to provide proposed technical specifications relating to reporting necessary to ensure operation of the facility in a safe manner.

Paragraph 20.1(c) of 10 CFR Part 20, "Standards for Protection Against Radiation," states that, in addition to complying with the requirements therein licensees should make every reasonable effort to maintain exposures to radiation as far below the limits specified in Part 20 as is reasonably achievable.

This guide describes a method acceptable to the NRC staff for implementing the above regulatory requirements with respect to detecting a potentially safety-related loose part in light-water-cooled reactors during normal operation. This guide also outlines a program that can help licensees to meet the Part 20 criterion that exposures of station personnel to radiation during routine operation of the station will be "as low as is reasonably achievable" (ALARA).

The Advisory Committee on Reactor Safeguards has* been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

The presence of a loose (i.e., disengaged and drifting) part in the primary coolant system can be indicative of degraded reactor safety resulting from failure or weakening of a safety-related component. A loose part, whether it be from a failed or weakened component or from an item inadvertently left in the primary system during construction, refueling, or maintenance procedures, can contribute to component damage and material wear by frequent impacting with other parts in the system. A loose part can pose a serious threat of partial flow blockage with attendant departure from nucleate boiling (DNB) which in turn could result in failure of fuel cladding. In addition, a loose part increases the potential for control-rod jamming and for accumulation of increased levels of radioactive crud in the primary system.

[1] In this guide, the phrase *loose-part detection program* encompasses recommendations for system hardware and programmatic and reporting procedures. *Loose-part detection system* refers only to system hardware.

* Lines indicate substantive changes from September 1977 issue.

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The primary purpose of the loose-part detection program is the early detection of loose metallic parts in the primary system. Early detection can provide the time required to avoid or mitigate safety-related damage to or malfunctions of primary system components.

The loose-part detection program also serves a second purpose since it can minimize radiation exposure to station personnel by providing for the early detection and general location of abnormal structural conditions. Information from the program can be used by station personnel to focus their efforts when taking remedial action to minimize the formation of wear-generated radioactive crud and to minimize the need for extensive structural repairs. The second purpose is consistent with the guidance contained in Regulatory Guide 8.8, "Information Relevant to Ensuring That Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable," which provides guidance to licensees for maintaining occupational doses to individuals as far below the permissible limits specified in the NRC regulations as is reasonably achievable while, at the same time, providing guidance on methods to ensure that the sum of the doses received by all exposed personnel is also at the lowest practical level.

The Advisory Committee on Reactor Safeguards (ACRS) and the NRC staff have, for the past several years, been encouraging applicants to employ online loose-part detection systems in an attempt to stimulate technological development in that area. This approach has resulted in a substantial increase in industry-wide experience and confidence in these systems and has resulted in the commercial production of loose-part detection systems by several engineering and manufacturing organizations. All applicants for a construction permit or an operating license are required to describe the loose-part detection program for the proposed reactor (Section 4.4.6, "Instrumentation Requirements," of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants").

An improperly developed and poorly implemented loose-part program may require excessive attention by plant operating personnel and more frequent inspections of the primary system that can result in increased radiation exposure. For this reason, this guide emphasizes the need for providing system features that will minimize false alert signals and for developing diagnostic procedures that can be quickly implemented to supplement information from the loose-part detection system to determine the short- and long-term safety significance of a loose part. A well-developed loose-part detection system should enable discrimination of the signal induced by the impact of a loose part from those signals induced by normal hydraulic, mechanical, and electrical background noise and large amplitude electrical transients.

The loose-part detection program outlined in this regulatory guide includes both automatic and manual modes of data acquisition. These data acquisition modes provide for automatic and manual detection of loose parts. The automatic data acquisition mode provides for continuous monitoring of signals, but data are recorded only when the detection system senses that a predesignated alert level has been reached or exceeded. An alarm alerts control room personnel when the alert level is reached or exceeded. In developing an automatic procedure for the continuous, online detection of loose parts, some sensitivity will be sacrificed to minimize the potential for false alert signals. The manual data acquisition mode provides periodic monitoring to detect loose parts, determine system operability (including calibration), establish the alert level, and alert the licensee to data that require evaluation but are of insufficient magnitude or incorrect character to otherwise initiate automatic alert procedures. Manual monitoring of the audio portion of the sensor signals provides very high sensitivity to loose-part impacts with good capability for recognizing spurious audio signals. Manual monitoring does, however, have the potential for increasing the burden on station personnel and should be used only on a periodic basis.

The loose-part detection program outlined herein is not intended to be a research program. Instrumentation and procedures that will result in the need for disproportionate amount of attention by control room personnel are not encouraged. Instrumentation that can be used to determine the approximate size and location of a loose part but that does not interfere with the normal alert and false signal rejection function of the detection program would be useful in complementing other instrumentation to determine the safety significance of a detected loose part. Loose parts traveling through the primary system will generally accumulate, at least for a time, in such natural collection areas as the plenums in reactor vessels and steam generators. Therefore, the NRC staff recommends that sensors be located at these and other natural collection areas. No benefit is seen in instrumenting straight lines of pipe or other areas through which a loose part will quickly pass. Close scrutiny of a relatively small amount of clearly relevant data is considered a better detection program than cursory review of a large volume of less significant data.

A prime consideration in developing the loose-part detection program is the avoidance of procedures requiring excessive attention by control room personnel and excessive reporting by the licensee. The recommended program would require operator action or engineering review when the detection methods indicate the presence or possibility of a loose part or when performing periodic audio monitoring or when confirming the operability of the instrumentation system. Licensee reports to the Commission during operation are necessary when defining the alert level, when a loose part is confirmed to be present, or when the associated technical specification is violated.

Although current loose-part detection systems can, in a large number of cases, detect and indicate the approximate location and weight of a loose part, other information (e.g., that obtained from plant process signals, from an inspection of the facility, or from prior operating history) will be necessary in most instances to determine the safety significance of the loose part. Therefore, no action with respect to reactor operation is recommended based on the information obtained from the loose-part detection system alone.

An alert resulting from the loose-part detection system is considered a warning, and it is important that followup steps (e.g., acquisition of additional diagnostic information) be taken to determine the significance of the alert signal. If a loose part is shown to be present, its short- and long-term safety implications need to be determined.

The potential for damage initiated by a loose part is not necessarily proportional to the impact energy of the loose part. For example, a small piece of flat metal plate may impart little impact energy but could restrict local flow to the reactor core. However, there are technical difficulties in trying to distinguish very-low-energy impact signals from the normal reactor acoustic background noise. Experience with loose-part detection systems for operating pressurized and boiling water reactors provides the basis for establishing an impact energy of 0.5 ft-lb (0.68 joules), e.g., the kinetic energy of a 0.5-lb (0.23 kg) part traveling at 8 ft/sec (2.4 m/sec), as the recommended system sensitivity in Regulatory Position 1.b. Experience shows that signals resulting from metallic-object impacts of that magnitude are distinguishable from the normal background noise, and that, in some instances, even smaller impact energies are discernible at signal levels within background noise levels when the manual audio monitoring mode is being used.

In order to ensure that, as a minimum, each loose-part detection system has the ability to detect what the staff considers to be the most significant range of loose-part weights, the staff recommends (Regulatory Position 1.b) that each loose-part detection system be capable of automatically detecting loose parts that weigh between 0.25 lb (0.11 kg) and 30 lb (13.6 kg) and impact with an energy of 0.5 ft-lb (0.68 joules) or more. The specified weight range is considered to be representative of the most common and significant class of loose parts. In addition, the staff recommends periodic audio monitoring by station personnel to complement the automatic detection system.

The high radiation and thermal cycling environment to which most of the primary system is subjected could in time alter operating characteristics of the loose-part detection system so that surveillance becomes ineffectual either by causing excessive alert signals or by decreasing sensitivity to loose parts. Therefore, in Regulatory Position 1.f the staff recommends that provisions be incorporated into the system to permit channel operability (including calibration) tests. Regulatory Position 5 addresses operability tests as part of a surveillance requirement for a proposed technical specification.

Since an earthquake could induce a loose part in the primary system, it is desirable that the loose-part detection system be designed to function following all seismic events that do not require plant shutdown. Recording equipment, however, need not be designed to function without maintenance following such seismic events provided the system retains audio or visual alarm capability.

C. REGULATORY POSITION

An in-service loose-part detection program should be implemented for the primary system of light-water-cooled reactors during preoperational testing and the startup and power operation modes in accordance with the following guidelines:

1. System Characteristics

The following features should be incorporated into each loose-part detection system.

a. *Sensor Location*. Sensors capable of detecting acoustic disturbances should be strategically located on the exterior surface of the reactor coolant pressure boundary. A minimum of two sensors, suitably located to provide broad coverage, should be located at each natural collection region (e.g., reactor vessel upper and lower plenums and each pressurized-water-reactor steam generator reactor coolant inlet plenum).

b. *System Sensitivity*. The online sensitivity of the automatic detection system should be such that, as a minimum, the system can detect a metallic loose part that weighs from 0.25 lb (0.11 kg) to 30 lb (13.6 kg) and impacts with a kinetic energy of 0.5 ft-lb (0.68 joules) on the inside surface of the reactor coolant pressure boundary within 3 feet (0.91 meter) of a sensor. If the recommended sensitivity cannot be achieved by automatic alert because of specific in-plant conditions, these conditions and the actual online sensitivity should be specified at the time the alert level is provided (see Regulatory Position 3.a(2)(a)). As an example, one acceptable method for verifying this online sensitivity is to demonstrate (1) the basic system sensitivity during plant shutdown and (2) that the background noise measured during normal plant operation is sufficiently small that the signal associated with the specified detectable loose-part impact would be clearly discernible in the presence of this background noise.

c. *Channel Separation*. The instrumentation channels (e.g., cabling, amplifiers) associated with the two sensors recommended at each natural collection region should be physically separated from each other starting at the sensor locations to a point in the plant that is always accessible for maintenance during full-power operation.

d. *Data Acquisition System*. The system should include both automatic and manual startup of data acquisition equipment (see Regulatory Position 3). In the event the alert level is reached or exceeded, the data acquisition system should automatically activate, and an audible or visual alarm should alert the control room personnel of that condition. The data acquisition system should provide for the recording of all sensor signal waveforms in either analog or digital form with the acceptability for selecting, as a minimum, any four sensors for simultaneous recording. The system should be capable of immediate visual and audio monitoring of all signals.

e. *Alert Level*. Provision should be made for incorporating into the system an alert level that is indicative of the presence of a loose part consistent with Regulatory Position 1.b. Depending on the alert logic (i.e., internal processing of system signals), raw or processed signals should be automatically and continuously compared to the alert level.

Points to be considered in establishing the alert level are noted in Regulatory Position 2.

f. *Capability for Sensor Channel Operability Tests*. Provision should be made for periodic online channel check and channel functional tests and for offline channel calibration[2] during periods of cold shutdown or refueling (see Regulatory Position 3.a(3)).

g. *Operability for Seismic and Environmental Conditions*. Components of the loose-part detection system within containment should be designed and installed to perform their function following all seismic events that do not require plant shutdown, i.e., up to and including the Operating Basis Earthquake (OBE). Recording equipment need not function without maintenance following the specified seismic event provided the audio or visual alarm capability remains functional. The system should also be shown to be adequate by analysis, test, or combined analysis and test for the normal operating radiation, vibration, temperature, and humidity environment.

h. *Quality of System Components*. Components should be of a quality that is consistent with minimum maintenance requirements and low-failure rates. Components within the containment should be compatible with the 40-year design life of the reactor system. In those instances where a 40-year design life is not practicable, a replacement program should be established for these parts that are anticipated to have limited service life.

i. *System Repair*. The system should be designed to facilitate the recognition, location, replacement, repair, and adjustment of malfunctioning components. Equipment, procedures, and layout should facilitate maintenance to minimize personnel time in high radiation areas and minimize occupational radiation exposure.

2. Establishing the Alert Level

In all cases, the alert level should be consistent with Regulatory Positions 1.b and 1.e and should include the effects of background noise.

The following points should be considered when establishing the alert levels:

a. The alert logic should incorporate suitable internal criteria to distinguish the transient signal caused by the impact of a loose part from the signals associated with normal hydraulic, mechanical, and electric noise and large-amplitude electrical transients. For example, it may be desirable to include logic that requires the comparison of two or more sensor signals with the alert level.

b. False alert signals resulting from plant maneuvers (e.g., control-rod stepping, reactor trip, pump starts, and other known sources that cannot be avoided by the procedures associated with Regulatory Position 2.a) may be avoided by automatic procedures that momentarily override the alert-level alarm. Alternatively, administrative procedures may be used by control room personnel in lieu of automatic procedures to identify and make allowance for alert signals caused by plant maneuvers.

c. The alert logic may provide for the alert level to be a function of the normal steady-state operating condition.

d. As appropriate, it may be desirable for the alert logic to provide for the alert level to vary from sensor to sensor to compensate for the inherent level of background noise at a specific transducer location.

3. Using the Data Acquisition Modes

The loose-part detection program should include data acquisition in automatic and manual modes. The automatic mode is for continuous, online detection of loose parts. The manual mode is to be used periodically for detecting loose parts, determining system operability (including calibration), establishing the alert level, and detecting significant safety-related trends in the sensor signals and for diagnostic purposes.

a. *Manual mode*. This mode of data acquisition should be used at the following times for the indicated purpose.

(1) Preoperational testing: Establish alert level for this test phase.

(2) Startup and power operation.

(a) Establish alert levels for startup and power operation. The alert level for power operation should be submitted to the Commission (in the startup report when one is provided) within 90 days following completion of the startup test program if the alert level is for power operation following initial startup or there is a change to the preexisting alert level for power operation. Temporary changes to the alert level need not be reported.

(b) At least once per 24 hours: Perform channel check.

(c) At least once per 7 days: Listen to audio portion of signals from all recommended sensors for the

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[2]The standard technical specifications define *channel check*, *channel functional test*, and *channel calibration* as follows:

A *channel check* is the qualitative assessment of channel behavior during operation by observation, including, where possible, comparison of the channel indication or status with other indications or status derived from independent instrument channels measuring the same parameter.

A *channel functional* test for analog channels is the injection of a simulated signal into the channel as close to the primary sensor as practicable to verify operability, including alarm and trip functions; for bistable channels it is the injection of a simulated signal into the channel sensor to verify operability, including alarm and trip functions.

A *channel calibration* is the adjustment, as necessary, of the channel output so that it responds with the necessary range and accuracy to known values of the parameter that the channel monitors. The channel calibration encompasses the entire channel, including the sensor and alarm and trip functions, and includes the channel functional test. The channel calibration may be performed by any series of sequential, overlapping, or total channel steps so that the entire channel is calibrated.

purpose of detecting the presence of loose parts. If signals indicate the presence or possibility of a loose part, station personnel should actuate the data acquisition system to obtain data for further evaluation.

(d) At least once per 31 days: Perform channel functional tests.

(e) At least once per 92 days: Verify that the background noise measured during normal plant operation is sufficiently small that the signal associated with the specified detectable loose-part impact would be clearly discernible in the presence of this background noise. Verify that the signal from each recommended sensor does not falsely indicate the presence of a loose part. This should include comparison with data, including audio data, obtained at the time of the last two quarterly measurements to verify that there does not exist a significant trend or anomaly that may falsely indicate the presence of a loose part. The alert level and alert logic may be revised to provide for the background noise of these later measurements. If the revision is not temporary, its details should be submitted within 60 days to the Commission as an amendment to the program description.

(3) Cold shutdown or refueling: At least once per 18 months, verify channel calibration using a controlled mechanical input (e.g., weight falling through a known distance that impacts the external surface of the reactor coolant pressure boundary). Channels should, as necessary, be recalibrated at this time. If recalibration is necessary, consideration should be given to replacement of unstable components.

b. *Automatic mode*. The automatic mode should be activated automatically when the predesignated alert level is exceeded. Activation should comprise an audible or visual alarm to the control room operator and simultaneous initiation of data recording equipment. Data should be acquired for a sufficient period of time to properly characterize the signals from sensors suitably selected to provide maximum diagnostic information (e.g., the alarming sensor and several adjacent sensors may be selected). Each alert should be documented with regard to time and plant condition.

If the alert level is exceeded or if the weekly audio monitoring or quarterly measurements indicate the presence or possibility of a loose part, diagnostic steps should be taken within 72 hours to determine whether a loose part is present and to determine its safety significance.

4. Content of Safety Analysis Reports

A description of the loose-part detection program should be submitted to the Commission in response to the NRC staff request for information on loose-part detection systems in Section 4.4.6, "Instrumentation Requirements," of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."

The program description should include those items covered in Regulatory Positions 1, 2, and 3. Special attention should be given to the following items:

a. Sensor types, mounting locations, and mounting procedures, including criteria for choice of sensor and mounting locations.

b. Data acquisition, recording, and calibration equipment.

c. Anticipated major sources of external and internal extraneous noise.

d. Precautions taken to ensure acquisition of quality data.

e. Description of the manner in which the alert level will be determined and also the alert logic (if any) employed by the system hardware and software in generating an alert signal. This should include a description of the program capability for distinguishing between a loose part and normal background noise.

f. Reference to the technical specification (see Regulatory Position 5).

g. Summary of supplemental data and diagnostic procedures that are available and that can be used as part of a diagnostic program to confirm the presence of a loose part. The summary should address the use of information from plant process signals, radiation leakage monitors, operating history, exercising of control rods, cycling of primary coolant pumps, and inspection of the primary coolant system.

h. Procedures for performing channel check, channel functional test, and background noise measurements.

i. Procedures for minimizing radiation exposure to station personnel during maintenance, calibration, and diagnostic procedures. (Reference in Chapter 12, "Radiation Protection," of the Safety Analysis Report.)

j. Training program for plant personnel that addresses operation of the system hardware and the purpose and implementation of the loose-part detection program. (Reference in Chapter 13, "Conduct of Operations," of the Safety Analysis Report.)

k. The applicant should verify that the system within containment will be designed and installed to function following all seismic events up to and including the OBE.

5. Technical Specification for the Loose-Part Detection System

A technical specification for the loose-part detection system should be provided. The technical specification should include:

a. The location of the required sensors.

b. A limiting condition for operation requiring the loose-part detection system to be operable during startup and power operation. If all channels of one or more collection regions are inoperable for more than 30 days, the reactor need not be shutdown, but a special report should

be prepared and submitted to the Commission within the next 10 days outlining the cause of the malfunction and the plans for restoring the channel(s) to an operable status.

c. A surveillance requirement that each channel of the loose-part detection system be demonstrated operable by a channel check performed at least once per 24 hours, a channel functional test performed at least once per 31 days, and a calibration test performed at least once per 18 months.

6. Notification of a Loose Part

If the presence of a loose part is confirmed, the Commission should be notified according to the guidelines for reportable occurrences that call for "prompt notification with written followup" as summarized in Regulatory Guide 1.16, "Reporting of Operating Information–Appendix A Technical Specifications."

The followup report to be submitted to the Commission within 2 weeks of the initial notification of the presence of a loose part should include (1) a summary of data obtained in the manual and automatic data acquisition modes; (2) a summary of the analysis, inspections, and correlations with operating data that were performed to evaluate data from the loose-part detection program; and (3) a summary of conclusions and a description of modifications or other actions planned or already performed to evaluate the safety implication of the loose part or to ensure that system and component safety functions are not impaired.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants regarding the NRC staff's plans for using this regulatory guide.

This guide reflects current NRC staff practice as outlined in Section 4.4 of the Standard Review Plan. The method presented in this guide has been recognized as acceptable for complying with the Commission's regulations since January 1, 1978.

Therefore, except in those cases in which the applicant proposes an acceptable alternative method for complying with the specified portions of the Commission's regulations, the method described herein will be used by the NRC staff in the evaluation of all construction permit applications and all operating license applications under review by the staff after January 1, 1978.

For reactors licensed to operate prior to January 1, 1978, loose-part detection systems that conform to commitments of the license application should be installed and operable. The installation should be reviewed by the licensee to ensure that the quality of the installation and the calibration and use of the equipment are consistent with the recommendations of this guide to the extent feasible for the loose-part detection system to which the licensee committed. The review should include an evaluation of the conformance to the appropriate programmatic aspects of the guide, specifically Sections C.2 and C.3, and whether specific hardware or installation modifications are needed to make the systems effective for the detection of loose parts.

In cases where licensees of operating reactors (licensed prior to January 1, 1978) have not previously committed to install a loose-part detection system or where the design of an existing system precludes upgrading to an effective functional capability, the licensee should install a system in conformance with the programmatic aspects of the guide, specifically Sections C.2 and C.3, or propose an acceptable alternative. In cases where a loose part is known to be present or there exists a high probability that a part may become loose based on experience with other reactors of similar design, a loose-part detection system conforming to this guide should be installed.

A letter will be sent to the licensee for each operating plant requesting that each licensee complete a review of his loose-part detection program and make any appropriate provisions for equipment and program revisions. Documentation describing the results of this review and the resultant loose-parts detection program should be prepared and available for inspection. It is the intent of the NRC to require that this effort, including the documentation, be completed within 6 months after the effective issuance date of this guide unless additional time is justified by the licensee in response to the NRC request to review the loose-part detection program.

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