

ISA-S67.03

1982

STANDARD

**STANDARD FOR LIGHT WATER REACTOR
COOLANT PRESSURE BOUNDARY LEAK DETECTION**



Sponsor

INSTRUMENT SOCIETY of AMERICA
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Coolant Pressure Boundary Leak Detection

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PREFACE

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The ISA Standards and Practices Department is aware of the growing need for attention to the metric system of units in general, and the International System of Units (SI) in particular, in the preparation of instrumentation standards. The Department is further aware of the benefits to USA users of ISA standards of incorporating suitable references to the SI (and the metric system) in their business and professional dealings with other countries. Towards this end this Department will endeavor to introduce SI acceptable metric units in all new and revised standards to the greatest extent possible. The Metric Practice Guide, which has been published by the American Society for Testing and Materials as ANSI designation Z210.1 (ASTM E380-76, IEEE Std. 268-1975), and future revisions, will be the reference guide for definitions, symbols, abbreviation, and conversion factors.

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The American National Standards Institute (ANSI) assigned work on this standard to ISA Committee SP-67 "Nuclear Power Plant Standards" in December, 1973. The assignments, considered a priority project needing urgent and prompt action, was given to Subcommittee SP-67.03 chaired by M. J. Kimbell during the May 20, 1974 Boston ISA Power Conference. The subcommittee performed a literature search of leak test standards and current nuclear power plant practice in relation to reactor coolant leak detection for representative pressurized water and boiling water power reactors. This information was utilized during the preparation of this Standard together with comments received from concerned reviewers.

The information contained in this preface, the footnotes and attached Appendices A and B is included for information only and is not a part of the Standard.

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1 INTRODUCTION

Nuclear power plants vary widely with respect to size, capacity, and design details. Available leak detection methods must be individually examined by the designers to determine their suitability for a particular plant or system. The applicable federal regulation on the requirements for Reactor Coolant Pressure Boundary (RCPB) leak detection is specified in the Code of Federal Regulations, Title 10, Part 50 (10CFR50), Appendix A, Criterion 30.*

Detection of leakage from pressurized pipes and vessels is needed because small leaks may develop into larger leaks or ruptures. During reactor operation, detection of reactor coolant leakage from nonisolatable portions of the RCPB is important to allow early identification of minor flaws before they can develop into a pipe break or component rupture that could result in the accidental loss of coolant. Since the RCPB is housed in a containment structure, physical access is limited during power operation and remote indicating leakage detection systems are necessary.**

This standard defines design criteria that are intended to insure that adequate RCPB leak detection capabilities are provided to the nuclear plant operator and to meet the intent of the Code of Federal Regulations. However, the burden of proof of compliance with federal regulations shall remain the responsibility of the plant owner.

2 SCOPE

This standard covers identification and quantitative measurement of reactor coolant system leakage in light water cooled power reactors. Leak detection for gas and liquid metal cooled reactors and for containment building structures surrounding the reactor coolant pressure boundary is not covered in this standard.

3 PURPOSE

The purpose of this standard is to standardize criteria, methods, and procedures for assuring the design and operational adequacy of reactor coolant pressure boundary leak detection systems used in light water cooled nuclear power plants. A further objective is to encourage design improvements yielding increased utility and reliability of reactor coolant leakage detection systems.

4 DEFINITIONS AND DESCRIPTIONS

As used in this standard, the following definitions apply.

Accessible Area — An area routinely or periodically entered by plant personnel in the performance of routine functions during normal plant operation and in accordance with applicable health physics procedures.

Accuracy — "Degree of conformity of an indicated

*Other related federal regulations not addressed in this standard cover the requirements for RCPB fracture prevention, inservice inspection, coolant makeup capability and quality assurance as specified in the Code of Federal Regulations, Title 10, Part 50 (10CFR50), References (1) and (2).

**Appendix A provides information on primary coolant leakage detection outside of the containment structure for boiling water reactors (BWR).

value to a recognized accepted standard value, or ideal value". Reference: Instrument Society of America (ISA) Standard S51.1-1979; "Process Instrumentation Terminology."

Boiling Water Reactor (BWR) — A nuclear steam supply system in which process steam is generated in the reactor vessel.

Calibration — "The adjustment of device or series of devices, in order to bring the output to a desired value, within a specified tolerance, for a particular value of input." Reference: ISA S51.1-1979.

Coolant — The fluid contained within the reactor coolant pressure boundary.

Leak — An opening, however minute, that allows undesirable passage of a fluid from its containing boundaries.

Leakage — The fluid that passes through a leak. The fluid referred to in this Standard is the primary coolant water unless otherwise stated.

Abnormal Leakage — That leakage from the Reactor Coolant Pressure Boundary (RCPB) which is considered to be unusual, unexpected or in excess of technical specification allowances.

Allowable Leakage — That leakage value defined in plant operational technical specifications above which plant operation must be altered or interrupted as necessary to perform corrective actions to reduce the leakage to allowable values.

Identified Leakage — See Section 5.1.1.

Leakage Rate — Leakage expressed in volumetric units per unit of time at 20°C and one atmosphere pressure.

Unidentified Leakage — See Section 5.1.1 and 5.1.2.

Monitoring Instrument System — A system that provides information about RCPB leakage conditions so that the operator can take action.

Nuclear Safety Related (NSR) — Instrumentation "which is essential to: 1) Emergency Reactor Shutdown; 2) Containment Isolation; 3) Reactor Core Cooling; 4) Containment or Reactor Heat Removal; 5) prevention or mitigation of a significant release of radioactive material to the environment or, is otherwise essential to provide reasonable assurance that a nuclear power plant can be operated without undue risk to the health and safety of the public." Reference: ISA S67.01-1979.

Non-Nuclear Safety (NNS) — Instrumentation not included in NSR.

Operating Basis Earthquake (OBE) — That earthquake which "... could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces 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 are designed to remain functional." Reference 10CFR100, Appendix A, III(d).

Pressurized Water Reactor (PWR) — A nuclear steam supply system in which the pressurized primary coolant fluid is heated by the reactor core, and the process steam is generated in a steam generator by heat transfer from the primary coolant.

Primary Containment — The structure that encloses the reactor coolant pressure boundary.

Reactor Coolant Pressure Boundary (RCPB) — "... all those pressure-containing components of boiling and pressurized water-cooled nuclear power reactors, such as pressure vessels, piping, pumps, and valves, which are:

- (1) Part of the reactor coolant system, or
- (2) Connected to the reactor coolant system, up to and including any and all of the following:
 - (i) The outermost containment isolation valve in system piping which penetrates primary reactor containment.
 - (ii) The second of two valves normally closed during normal reactor operation in system piping which does not penetrate primary reactor containment.
 - (iii) The reactor coolant system safety and relief valves.

For nuclear power reactors of the direct cycle boiling water type, the reactor coolant system extends to and includes the outermost containment isolation valve in the main steam and feedwater piping." Reference: 10CFR50, Section 50.2(v).

Sensitivity — "... ratio of the change in output magnitude to the change of the input which causes it after the steady-state has been reached." Reference: ISA S51.1-1979.

Time Constant — "The time required for the output of a first-order system forced by a step change to complete 63.2 percent of the total rise or decay." Reference: ISA S51.1-1979.

Time Response of Instrumentation — "... an output expressed as a function of time, resulting from the application of a specified input under specified operating conditions." Reference: ISA S51.1-1979.

5 LEAKAGE CLASSIFICATIONS AND SOURCES

The significance of leakage from the RCPB will depend upon the leak location, the leakage rate, duration, and the nature of the flow path permitting the leakage. Through-wall cracks or flaws are the most difficult to detect and monitor because they can occur at any RCPB location. This type of leak is also of most concern because the leak may develop from some unpredicted combination of internal defects and external stresses in a nonisolatable portion of the RCPB.

5.1 Leakage Classifications

A principal concern in leakage monitoring is the capability to discriminate between unidentified leakage from the RCPB and leakage from identifiable sources into the containment. Being able to discriminate allows more

rapid and reliable assessment of plant operating conditions. The following leakage classifications, as used in this standard, facilitate identification of leakage sources and interpretation of leakage data:

5.1.1 Identified Leakage

- (A) Leakage into collection systems, e.g., pump seal or valve packing leakage that is collected and measured, or
- (B) Leakage into the containment which meets all of the following conditions:
 - (1) The leaks have been specifically located and the rate quantified.
 - (2) The leaks are not cracks or flaws in the RCPB.

An example of (B) above is a quantified leakage of component cooling water into the containment.

5.1.2 Unidentified Leakage

Leakage into the containment which is not classified as identified leakage.

5.1.3 Intersystem Leakage

Coolant leakage across RCPB passive barriers such as heat exchanger tubes or tube sheets into other closed systems. Such leakage is not normally released to the containment atmosphere and is a separate classification.

5.1.4 Other Leakage

Any leakage not from the RCPB and outside of the reactor containment structure, if not covered by the above classifications. An example of such leakage could be leakage from steam or feedwater lines outside the containment structure of a BWR plant. A summary of such leakage sources and typical detection methods frequently used is given in Appendix A of this standard.

5.2 Potential Identified Leakage Sources

Variations in plant designs do not allow a single definitive check list of all potential leakage sources. However, probable leakage sources can be identified during plant design and appropriate leakage detection, measurement and collection (leakoff) systems provided. Collection and isolation, to the extent practical, of leakage from identified sources enhance the monitoring capability for unidentified leakage. The following are some of the more common types of leakage sources that can be easily identified:

- (A) *Dynamic seals* such as valve stem packing, pump drive shaft seals and control rod drive gland seals.
- (B) *Static seals* such as the reactor head pressure seals, equipment gaskets and valve seat seals in lines connected to the RCPB.
- (C) *Pressure relief systems* such as pressure relief valves, rupture disks and safety relief valves.
- (D) *Passive interface boundaries with the RCPB* such as instrument bellows, diaphragms and Bourdon tubes, thermometer wells and heat exchanger tubes.

6 GENERAL DESIGN REQUIREMENTS

This standard is not intended to replace applicable handbooks and texts, such as References (11) and (12), which provide detailed design and analytical techniques. Suggested methods and procedures for developing required design information are given in the references and appendices to this standard.

6.1 Principal Monitoring Systems for Unidentified Leakage

At least three dissimilar, diverse, and independent principal methods of monitoring coolant leakage from the RCPB to the containment shall be provided. One of these methods shall be sump level and/or sump flow monitoring. Other acceptable methods are identified in Section 7 and Table 1.

6.2 Coolant Leakage Detection System Performance

The sensitivity and response characteristics for each of three principal leak detection monitoring systems shall be shown by design calculations or performance tests to be capable of indicating and alarming a 1 gpm (3.8 liters/min) leakage increase within one hour. It is recognized that some systems other than sump monitoring may not be capable of meeting this requirement during certain normal plant operating conditions. In these cases, these systems shall be designed for leakage sensitivity that is as high as reasonably achievable. When identified leakages are superimposed on unidentified leakages the above sensitivity requirements shall apply also.

6.3 Safety Classification

The RCPB leak detection systems covered in this standard are non-nuclear safety systems or monitoring instrument systems.

6.4 Collecting and Measuring Identified Leakages

Seals, relief systems, and other probable sources of leakage shall be identified. Leakage collection and measurement systems shall be provided for sufficient identified sources to limit the expected leakage to the containment atmosphere to the extent practical. The residual uncollected liquid leakage shall not prevent unidentified liquid leakage monitoring systems from meeting Section 6.2 requirements.

Leakage to the primary reactor containment from identified sources shall be collected or otherwise isolated so that:

- (A) The flow rates from identified leaks are monitored separately from unidentified leaks.
- (B) The total flow rate from identified leaks can be established and monitored with a sensitivity capable of detecting a 1 gpm (3.8 liters/min) leakage increase within 1 hr for PWR plants and 2 gpm (7.6 liters/min) leakage increase within 1 hr for BWR plants.

6.5 Monitoring Intersystem Leakage

Provisions shall be made to monitor systems connected to the RCPB through passive barriers for indications of

intersystem leakage. Acceptable methods include radioactivity monitoring and water inventory monitoring. See Appendix A for additional information.

6.6 System Availability

The RCPB leakage detection systems shall be designed to operate whenever the plant is not in cold shutdown condition.

6.6.1 Ambient Conditions

Monitoring system shall be designed to maintain specified accuracy and performance features for the range of ambient temperature, humidity, and radiation levels that are expected at the component locations during normal plant operations.

6.6.2 Seismic Events

The sump monitoring system and at least one of the other diverse monitoring channels provided shall be demonstrated to be acceptable for the design requirements after any seismic event for which plant shutdown is not required, i.e., less than an operating basis earthquake. The guidelines of IEEE Standard 344, Reference (6), may be used for seismic qualification.

Recorders need not function during or after seismic events provided alarm and indication capability remain available.

6.7 Human Engineering and Operability Features

6.7.1 Displays and alarms for all leakage detection systems shall be located in the main control room. In cases where additional process displays related to leakage are identified, these indications should be provided at one general display location. Leakage monitoring displays may also include computer functions and CRT displays. Quantitative measurements with procedures for locating leakage sources should be monitored and controlled from one general display location.

6.7.2 Capability for online calibration of leakage detection channels by simulated detector outputs or other means shall be provided. Readouts, alarm set points, and calibration factors shall be capable of periodic adjustment to compensate for changes in actual environmental or background conditions.

6.7.3 Leakage measuring system displays shall be expressed in volumetric units or if expressed in other units, conversion capability shall be provided. Capability for trend monitoring of measured leakage shall be provided.

6.7.4 Capability for entire channel calibration and maintenance during refueling outages shall be provided. The leakage detection systems shall be designed and located for ease of periodic testing, servicing, removal, and replacement.

6.8 Power Sources

Two of the three principal leakage detection systems shall be energized from separate power sources. Seismically qualified systems shall be powered from seismically qualified power sources.

6.9 Design Basis Documentation

Compliance with this standard shall be supported by design basis documentation to include the following:

- (A) The data and design basis used for the design of each RCPB leak detection system, e.g., primary coolant temperature, pressure, radioactivity.
- (B) A description of the analytical derivations and methods used to determine each system's sensitivity, response time, and alarm set point.
- (C) The limitation and approximate accuracy of each leak detection method and its leakage measurement range in coolant volume per unit of time.
- (D) Seismic qualification as appropriate.
- (E) The procedures which describe the calibration and operation of the RCPB leakage detection systems.
- (F) Identification and seismic classification of the power source for each monitoring system.

7 SPECIFIC LEAKAGE DETECTION METHODS AND THEIR REQUIREMENTS

The objective of leakage detection is to identify and quantify the leakage to such an extent that the seriousness of the leak can be determined. The following subsections present requirements and brief descriptions of methods that have been successfully applied to the detection, measurement, or location of leakage from the RCPB⁽³⁾. Methods considered to be developmental, such as acoustic^(4,17) and ultrasonic, or not in general use are not discussed in this standard. However, this should not discourage the utilization of such methods if they meet the requirements of this standard. The calculational methods and procedures discussed hereafter and in the Appendix B represent idealized cases. These methods and equations can and should be modified and refined as needed to fit specific cases, e.g., purge versus nonpurge containment, containment atmosphere mixing and transport time, recirculation, filtration for calculation of estimated leakage rates.

Table 1 summarizes the capabilities of detection methods presented in this standard for detecting, measuring, and locating leakage from the RCPB. Current general practice is to provide at least three principal detection methods, one of which is sump monitoring.

7.1 Sump Level and Sump Pump Discharge Flow Monitoring Leakage Detection

Reactor coolant pressure boundary leakage can be detected and measured by monitoring open containment sump levels and/or sump pump discharge flow rates⁽¹⁰⁾. The following requirements apply:

- (A) Identified equipment leakage from large valve stem packing glands and other readily identifiable sources shall be monitored by piping the flow to closed equipment drain tanks or sumps so that an average background identified leakage rate can be established.
- (B) Open containment sumps shall collect unidentified

containment leakage including containment cooler condensate (See Section 7.3.). Sensitivity and response time shall be such that a one gpm (3.8 liters/min) of liquid collected into the sump can be detected in less than one hour. For an instrumentation method to be acceptable for a given configuration, verification by calculation that the above requirements will be satisfied is required.

The leak location is not identifiable by this method unless relatively small areas of piping are draining into different sumps for each area. Both sump level change and sump discharge flow can be monitored to detect a leak.

Gaseous releases from identified leakage collection points shall be controlled so that they do not decrease the effectiveness of the radioactivity monitors.

7.2 Radiation Monitoring Leakage Detection

Monitoring the containment for radioactivity is a requirement specified in 10CFR50 Appendix A⁽⁷⁾. Monitors used to meet this requirement may also be used for RCPB leak detection provided the monitors meet the requirements of this standard. The response and sensitivity characteristics of monitor outputs shall be correlated to leakage rates and coolant activity.

7.2.1 Air Radioparticulate and Radiogas Activity Monitors

(A) Description

Air radiation monitors have the potential for detection of coolant leakages from the RCPB. The sensitivity and response time depends, among other things, on the sampling system design, containment atmosphere mixing characteristics, the radiation detector characteristics, the ambient radiation background, and the concentrations of detectable isotopes in the coolant and in the containment atmosphere.

The quantitative measurement of coolant leakage may sometimes be feasible by this method, but extensive current information about plant physical parameters and coolant radioisotope inventory are required in order to perform the computations. Graphical representation of the relationship of leakage rate to the principal parameters can be used to estimate leakage. However, plant process computers are a potentially more useful tool for rapid reduction and interpretation of the monitored data. Sufficient data and understanding of the principles are needed to properly interpret an increase in radiation monitor readout in terms of coolant leakage. For example, a decrease in reactor power level may cause an increase in the primary coolant radioactivity burden, and thus an apparent increase in leakage rate that is actually a false indication.

(B) Sampling System Design

The piping between the sample line inlet and the detector location shall be designed in accordance