Standard

Standard for Light Water Reactor Coolant Pressure Boundary Leak Detection
This preface is included for information purposes and is not part of S67.03.

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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.

The following individuals served as members of the ISA Subcommittee SP-67.03 which prepared this standard:

<table>
<thead>
<tr>
<th>NAME</th>
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<tbody>
<tr>
<td>U. Shah, Chairman</td>
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</tr>
<tr>
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<tr>
<td>J. Hersey</td>
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</tr>
<tr>
<td>M. Hildenbrand</td>
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</table>
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W. C. Weston

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Pacific Gas & Electric Co.  
U.S. Nuclear Regulatory Comm.  
Stone & Webster Engr. Corp.

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<td>R. G. Marvin*</td>
<td></td>
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<tr>
<td>W. B. Miller*</td>
<td></td>
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<tr>
<td>R. L. Nickens*</td>
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</table>

*Director Emeritus
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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.

*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).
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 value to a recognized accepted standard value, or ideal value." Reference: 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.

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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


c) Assumptions for design computations

These assumptions provide a uniform design basis and shall be used to estimate the capabilities of radiation monitors to detect coolant leakage from RCPB and to show compliance with the design requirements of Section 6. A model to determine the radioactivity concentrations is given in Appendix B. Due to the range of operating conditions which may be expected from plants, several calculations will be necessary to cover most situations. These calculations will cover the range of expected equilibrium containment airborne concentrations. The following assumptions shall be used unless technical justification is provided.

1) Expected coolant and RCPB leakage activity levels shall be taken from the American National Standard Source Term Specification (ANSI N237). If particulate monitors are used, the situation in which there is no failed fuel, i.e., only corrosion products in the coolant, shall be included. Coolant concentrations will vary by orders of magnitude within short time periods due to changes in operating conditions.

2) For particulate monitors, owing to differences in source terms in PWRs, only Rb-88 which is in secular equilibrium with its parent isotope Kr-88 need be considered. For BWRs, a spectrum of isotopes shall be used. For the case with no fission products, several of the corrosion products will have to be considered since no single isotope dominates.
For gaseous monitors, Xe-133 gives over 95 percent of the dose and is sufficient for PWR analyses. For BWRS, a spectrum of isotopes shall again be used.

For iodine monitors, the five radioiodines I-131 through I-135 should be considered because of their abundance as fission products.

3) Coolant leakage shall be assumed to be uniformly mixed in the appropriate containment or dry-well free volume, unless HVAC and building design indicate that uniform mixing will not occur within one hour. If the containment is continuously purged then this effect shall be included.

4) Plateout factors of 0.999 for particulates, 0.99 for iodines, and zero for noble gases as a conservative design basis shall be applied to the activity in the coolant leakage. See Reference (16) for additional information.

5) The equilibrium containment airborne activity levels shall be based on available operating data or other documented basis such as Reference (5). The concentrations at equilibrium in a containment from a continuous leak of 1 to 1.5 gpm approximate the observed data. These activity levels are in the range of the Maximum Permissible Concentrations (MPC) of 10CFR20, Table 1 for Xe-133 and I-131.

For maximum monitor sensitivity cases, e.g., when failed fuel levels are low and the containment airborne concentrations are low shortly after a startup, the airborne activity levels can be neglected. However, it should be realized that increases in containment activity may be due to temporary spiking increases in the coolant concentrations rather than due to increases in leakage following startups and power transients.

6) Monitor background count rates shall be based on the activity and radiation levels expected at the detector location.

7.2.2 Intersystem leakage monitoring

Intersystem leakage of coolant through the RCPB into other systems, e.g., primary to secondary system leaks in heat exchangers, is detectable by secondary system liquid radiation monitoring or secondary system off-gas monitoring.

Radiation monitoring does provide the capability for detection of small intersystem leakages of coolant through the RCPB, but sensitivity requirements are not defined by this standard. Some of the factors affecting sensitivity and response time are the concentration of the detectable isotopes in the secondary fluid, proximity of the sampling point to the leak, and required cooling of high temperature samples for proper detection functioning.

The quantification of leakage can be accomplished if correlated with the known secondary system parameters such as flow, volume, activity, blowdown, and background activity along with the primary system activity.

Actual leak location can be identified only as being in the common barrier area between systems, or possibly, to a particular part of multibarrier systems by use of isolating valves or the type of detectable isotopes.

7.3 Containment air cooler condensate flow collection for leakage detection

The condensate flow-monitoring method consists of measuring the flow rate of the liquid runoff from the drain pans under each containment air cooler unit. The increase of such condensate runoff can be indicative of increased vapor phase leakage into the containments[9].
The response and sensitivity characteristics of the instrumentation system used for condensate flow monitoring shall be estimated for determining the ability to detect one gpm leakage within one hour. The baseline of normal condensate flow shall be derived from the range of normal operating parameters anticipated including the expected normal leakage from both the RCPB and auxiliary systems which could affect normal condensate flow.

7.4 Reactor coolant inventory

The reactor coolant closed loop design of PWR plants permits the maintenance of a coolant inventory which is constant except for controlled additions, controlled discharges, and uncontrolled leakage. Controlled coolant additions and discharges can be measured, recorded, and corrected to maintain the inventory balance. The resulting information is useful in evaluating the integrity of the RCPB. This surveillance method cannot generally be used on BWR plants with sufficient accuracy to be of value in detecting small RCPB leakage.

In establishing this method for PWR plants the following parameters must be at least considered:

a) Density (temperature and pressure) of each fluid being measured.

b) Water levels in pressurizer and all collection points.

c) Duration of monitoring period.

7.5 Humidity monitoring leakage detection

Humidity monitoring can detect the increased vapor content of air produced by the vapor phase portion of coolant leakage. Humidity detectors placed within the primary containment have the potential to detect leakage but suffer the quantitative uncertainty of the unknown proportion of liquid to vapor from any leak source. When used in large volume containment areas, the sensitivity may be on the order of several gpm\(^{[5,9]}\). These detectors cannot locate leakage except for area localization of the source, thus responding best in small contained volume areas.

The response and sensitivity characteristics of the humidity detectors shall be considered in estimating system capability to meet the criterion of detecting a one gpm leakage within one hour. The baseline or normal specific humidity shall be based upon the range of normal operation parameters anticipated including the expected normal leakage rate.

7.6 Temperature monitoring leakage detection

The sensitivity and system response time of this leakage detection method is highly dependent upon the following application conditions:

a) The volume of space to be monitored by each temperature sensor.

b) The thermal transport distance and conditions between the sensor and the potential leak locations.

c) Potential heat losses from the measured volume.

d) Normal temperature fluctuations expected in the absence of coolant leakage.

e) The presence, or potential presence, of abnormal heat sources other than coolant leakage.

f) The temperature sensor time constant (including the time interval between monitoring each point in multipoint sequential monitoring systems).

Multiple temperature sensor locations are usually necessary to monitor large volumes such as equipment rooms or containment building areas to provide useful leakage measurement sensitivity\(^{[8]}\). Temperature response and sensitivity can be optimized by mounting sensors in
confined spaces such as relief valve or seal leakoff lines and contained spaces around piping and equipment, e.g., thermocouples attached to the metal sheathing of thermally insulated RCPB piping. False alarms are also minimized in this manner.

Differential temperature measurement may be used where ambient temperature can be measured entering and exiting from rooms or areas containing RCPB equipment and piping, e.g., with sensors located in heating and ventilating ducts. This application method minimizes the effects of inlet temperature variations and thus may increase measurement sensitivity, provided that measurement response time does not become too long. The same application principles described previously for absolute temperature measurement also apply to the differential temperature measurement.

7.6.1 Sensor time response characteristics
Temperature sensor response characteristics expressed in time units that are quoted by instrument manufacturers are usually based on tests in moving fluids at stated flow conditions, most commonly, in water flowing at 3 ft/sec (0.914 m/s) past the sensor. Sensor response used for leakage detection shall be stated in terms of the anticipated fluid conditions that correspond to the intended measurement application. Sensor time response characteristics in a moving air stream will usually be several orders of magnitude longer than for the same sensor using 3 ft/sec (0.914 m/s) water flow velocity past the sensor.

7.6.2 Sensor temperature response to coolant leakage
Temperature sensor response to a one gpm coolant leakage rate shall be estimated for each unique measurement application by one of the following methods:

a) Calculation of sensor response time from fabrication details of the sensor and the surrounding enclosed fluid conditions that result from coolant leakage.

b) Correction and correlation of manufacturer sensor time response characteristics under stated fluid conditions to agree with the anticipated application fluid conditions.

c) Test measurement of the overall temperature sensor system response under conditions which simulate the anticipated leakage detection application conditions.

Suggested procedures for methods (a) and (b) above are given in Reference (13) and Appendix B of this standard. Temperature sensors with remote electronic indication and trip devices shall have provisions for calibrating the trip device by insertion of a calibrating signal of known value. This method will usually permit ready identification of trip devices which are not functioning or are out of calibration.*

7.7 Primary containment pressure monitoring
RCPB leakage will cause a pressure increase in the primary containment structure. The detection capability of a pressure monitoring system is on the order of large leakage because of the large size of the containment volume. Small leakage may cause pressure changes that fall within the range of normal containment pressure fluctuations for considerable periods of time.

Quantitative measurement of leakage by pressure monitoring methods is of questionable value for small leaks due to the large number of variables which can influence the measurement. Also

*A number of operating nuclear power plants have issued Abnormal Occurrence Reports in which drift of setpoints for temperature switches (ranging from 0.5 to greater than 6 percent error) occurred in leakage detection applications. See USAEC office of Operations Evaluation Study: “Setpoint Drift in Nuclear Power Plant Safety-Related Instrumentation,” OOE-ES-003, dated August 1974.
this method provides no information on the leakage source location within the monitored containment volume.

### 7.8 Tape moisture sensors for leakage detection

The moisture sensitive tape method is a continuous monitoring system consisting of a sensing element which is normally placed next to the insulation of process piping. The element provides an electrical signal when activated by moisture (as produced by a leak) which may be used with an indicating device that generates an alarm signal. These sensors can quickly detect leakage from the piping on which they are mounted and fairly precisely localize the leak area. However, the amount of leakage cannot be measured. Typical design criteria are given in Appendix B.5.

### 7.9 Visual observation

This is the most flexible of all monitoring methods, but detection sensitivity is heavily dependent upon the frequency of inspection and accessibility of equipment areas. The American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section XI, covers periodic mandatory inspection requirements of the RCPB. Inclusion of devices such as closed circuit television, temperature sensitive tapes and paint can be valuable aids in locating and identifying leakage sources. This method is not recommended as one of the principal monitoring systems; however, it can be used to augment other detection methods with respect to leak location.

#### Table 1 — Capabilities of leakage monitoring methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Leakege detection sensitivity</th>
<th>Leakege measurement accuracy</th>
<th>Leak location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sump Monitoring</td>
<td>G a</td>
<td>G</td>
<td>P b</td>
</tr>
<tr>
<td>Condensate Flow Monitors</td>
<td>G</td>
<td>F c</td>
<td>P</td>
</tr>
<tr>
<td>Radiogas Activity Monitor</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Radioparticulate Activity Monitor</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Primary Coolant Inventory d (Based on Makeup Flow Integrator)</td>
<td>G</td>
<td>G</td>
<td>P</td>
</tr>
<tr>
<td>Humidity-Dew Point</td>
<td>F</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Tape Moisture Sensors</td>
<td>G</td>
<td>P</td>
<td>G</td>
</tr>
<tr>
<td>Temperature</td>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td>Pressure</td>
<td>F</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Liquid Radiation Monitor e</td>
<td>G</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Visual f</td>
<td>F</td>
<td>P</td>
<td>G</td>
</tr>
</tbody>
</table>

a G (Good) - can generally be applied to meet intent of this standard if properly designed and utilized.
b F (Fair) - may be acceptable, marginal, or unable to meet intent of this standard depending upon application conditions and the number of measurement points or locations.
c P (Poor) - not normally recommended but might be used to monitor specific confined locations.
d For PWR during steady state conditions.
e For detection of intersystem leakage; may also be used for location function in sump or drain monitoring.
f Provided that the leakage area is visible.
8 References


13) Rosemount Engineering Company Bulletin 9612, Rev. B, Appendices C and E.


These appendices are included for information purposes and are not a part of the standard.

Appendix A — Leakage not into the containment

A.1 Intersystem leakage detection

Process systems connected to the portion of the reactor coolant system pressure boundary that is inside containment up to the second system isolation valve should be monitored for the detection of intersystem leakage. If these systems or components are not isolated from the reactor coolant system during normal operation* the interface between components of these systems and secondary systems should be monitored for intersystem leakage (i.e., heat exchangers in reactor coolant cleanup or chemical and volume control systems). If these systems are isolated from the reactor coolant system during normal operation then the leakage into these systems (past the isolation valves) should be monitored. Table A-1 identifies the systems or components for PWRs and BWRs connected to the reactor coolant system that should be monitored for the detection of intersystem leakage. Table A-2 identifies the typical methods used for intersystem leakage detection.

Table A-1 — Systems and components connected to reactor coolant pressure boundary

<table>
<thead>
<tr>
<th>A. Pressurized Water Reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Accumulators</td>
</tr>
<tr>
<td>2) Safety Injection Systems (High and Low Pressure)</td>
</tr>
<tr>
<td>3) Pressurizer Relief Tank</td>
</tr>
<tr>
<td>4) Secondary Side of Steam Generators</td>
</tr>
<tr>
<td>5) Residual Heat Removal System (Inlet and Outlet)</td>
</tr>
<tr>
<td>6) Secondary Side of Reactor Coolant Pump Thermal Barriers</td>
</tr>
<tr>
<td>7) Secondary Side of Residual or Decay Heat Removal Heat Exchangers</td>
</tr>
<tr>
<td>8) Secondary Side of Letdown Line Heat Exchangers</td>
</tr>
<tr>
<td>9) Secondary Side of Reactor Coolant Pump Seal Water Heat Exchangers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Boiling Water Reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Safety Injection Systems (High and Low Pressure Core Spray and Coolant Injection Systems)</td>
</tr>
<tr>
<td>2) Residual Heat Removal System (Inlet and Outlet)</td>
</tr>
<tr>
<td>3) Reactor Core Isolation Cooling System</td>
</tr>
<tr>
<td>4) Steam Side of High Pressure Coolant Injection (BWR-4 only)</td>
</tr>
<tr>
<td>5) Secondary Side of Reactor Water Cleanup System Heat Exchangers</td>
</tr>
<tr>
<td>6) Secondary Side of Reactor Coolant Pump Integral Heat Exchangers</td>
</tr>
<tr>
<td>7) Secondary Side of Residual Heat Removal Heat Exchangers</td>
</tr>
</tbody>
</table>

*As limited in Section 6.6 of the Standard.
### Table A-2 — Typical intersystem leakage detection methods

<table>
<thead>
<tr>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Lifting of Relief Valves</td>
</tr>
<tr>
<td>2) Leak-Off Temperature or $\Delta T$</td>
</tr>
<tr>
<td>3) Tank or Sump Level Indication</td>
</tr>
<tr>
<td>4) Flow Rate or $\Delta$Flow or Level Rate</td>
</tr>
<tr>
<td>5) Pressure or $\Delta P$</td>
</tr>
<tr>
<td>6) Coolant Sampling</td>
</tr>
<tr>
<td>7) Radiation Monitoring</td>
</tr>
<tr>
<td>8) Cooling Water Temperature or $\Delta T$</td>
</tr>
</tbody>
</table>

### A.2 Primary coolant leak detection outside of the containment

Boiling water reactor plants have some systems outside the containment, such as feedwater and main stream lines, which contain reactor coolant at or near reactor operating pressure and temperature. These systems are not a part of the RCPB, although they contain reactor coolant. Leakage in such connecting systems is presently detected by methods similar to those described in Section 7.0 of this standard. Such detection methods may initiate a safety related isolation from the reactor coolant system. Table A-3 indicates potential reactor coolant leak sources outside of the containment structure and leak detection methods used for their detection. This type of leakage is not covered by the scope of this standard (see definition of RCPB).

### Table A-3 — Potential leak sources and typical leak detection methods

<table>
<thead>
<tr>
<th>A. Potential Leak Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Residual Heat Removal System</td>
</tr>
<tr>
<td>2) Reactor Core Isolation Cooling System</td>
</tr>
<tr>
<td>3) Feedwater System Outside Containment</td>
</tr>
<tr>
<td>4) Main Steam Lines and Equipment Outside Containment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Typical Leak Detection Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Leakoff Temperature or $\Delta T$</td>
</tr>
<tr>
<td>2) Airborne Radioactivity</td>
</tr>
<tr>
<td>3) Sump Level, Flow Rate, or $\Delta$Flow or Level Rate</td>
</tr>
<tr>
<td>4) Humidity Measurement</td>
</tr>
<tr>
<td>5) Pressure or $\Delta P$</td>
</tr>
<tr>
<td>6) Liquid Radiation Monitor</td>
</tr>
<tr>
<td>7) Cooling Water T or $\Delta T$</td>
</tr>
<tr>
<td>8) Cooling Air T or $\Delta T$</td>
</tr>
</tbody>
</table>
Appendix B — Suggested methods and procedures for leakage detection systems

B.1 Sump level and flow measuring methods

B.1.1 Purpose

This Appendix outlines suggested instrumentation methods for measuring sump level and leakage flow monitoring. It contains general equations for measurement resolution and response time. These equations are based on simplifying assumptions and may require some modification for a given configuration.

B.1.2 Methods

B.1.2.1 Analog level transmitters and level memory method

a) General description

This method uses a sensing well as a hydraulic level memory device and compares present with previous values on timed cycles. Data recording and alarms for several measurements are provided. See Figures B-1 and B-2 and general equations in B.1.3.1 for this method.

b) Details of operation

Leakage inside the containment, other than identified leakage which is piped to the equipment drain sump, drains into the containment sump as unidentified leakage. The sump level is measured continuously by level transmitter LT-1A. The output of this transmitter is recorded on one pen of the dual pen recorder LR-1/FR-2.

A hydraulic level memory is provided by using a sensing well which is piped to the sump at an elevation below the lowest operating level in the sump. The well is isolated from the sump by solenoid-actuated valve, KV-3 which is operated by time-cycle controller, KC-3. Valve KV-3 is closed most of the time. However, it opens periodically to equalize the level in the sensing well with the level in the sump. The level in the sensing well is measured by level transmitter LT-1B. The time period between valve KV-3 closing and KV-3 opening is referred to hereafter as the measurement period, T. The output of level transmitter LT-1A is adjusted by electronic converter LY-1 to compensate for any nonlinear level-to-volume characteristics of the sump, if applicable.

The difference in the outputs from electronic converter LY-1 and level transmitter LT-1B is provided continuously by subtracting relay, LDY-2. The output of LDY-2 is transmitted to gain relay FY-2A, which is used to calibrate the loop by compensating for the measurement period and sump dimensions. The output of FY-2A, at the end of each measurement period, provides a pseudo-instantaneous leak rate measurement. This output is recorded on pen 2 of recorder LY-1/FR-2.
Figure B-1 — Analog level transmitters and level memory
The sump level is controlled by electronic level switch LS-1. When the level in the sump increases to the upper setpoint $\ell_2$, LS-1 opens valve HV-4 and turns the sump pump on. When the sump level decreases to low level $\ell_1$, LS-1 resets which turns the sump pump off, and momentarily opens valve KV-3, resetting the sensing well. Also, the peak-memory device, FY-2B, is reset at this time. Thus, the pseudo-instantaneous and increase leak rate measurement cycles are restarted. The sump and level memory levels are shown as a function of time in Figure B-2.

One alarm branch, FDAH-2, monitors the increase in the rate of unidentified leakage into the sump. This branch provides an alarm when the increase in leak rate exceeds 0.5 gpm to 1.0 gpm within one hour. The output of FY-2A is passed to peak-memory device FY-2B, which remembers the highest value attained by the input until its memory is reset. However, the input to FY-2B is interrupted by a time-delay relay that is activated once every 40 to 60 minutes by time-cycle controller KC-2. The same timer opens valve KV-3 momentarily, and then closes valve KV-
3 to start a new measurement cycle. The time delay relay is adjusted so that as soon as the first measurement period is completed the input to FY-2B is interrupted. In this way the pseudo-instantaneous leak rate for the first measurement period is retained by FY-2B. The leak rate measuring cycle is repeated, during which time the output of FY-2B remains constant at the highest value during the first measurement period. Receiver switch FDH-2 subtracts the output of FY-2B from the output of FY-2A. The resulting difference represents the increase in leak rate. If this difference exceeds the set point of 0.5 to 1.0 gpm, FDH-2 actuates a high unidentified leak rate alarm, FDAH-2.

Another alarm branch, FAH-2, monitors the total rate of identified and unidentified leakage into the sump. This branch has receiver switch FSH-2, which receives the output from FY-2A. The set point for FSH-2 is set to correspond to the total leak rate limit defined in the Plant Technical Specification (typically 5 gpm). If this set point is exceeded, FSH-2 actuates a high leak rate alarm, FAH-2.

In addition to those described above, this system has the following features:
1) The sump pump may be started and stopped by hand switch HS-4.
2) An additional level switch, LSHH-5, which is independent of level transmitter LT-1A, actuates an alarm in case of pump failure.
3) An additional timer, KC-4, is provided to generate an alarm in the event that the pump-out time exceeds the normal pumpout time plus 10 percent.

B.1.2.2 Integrated level switches method

This method employs the use of several level switches with slightly different set points. An average leak rate is determined by measuring the time it takes for the sump level to increase from one set point to the next, taking into account the identified leak rate and the sump geometry. One of the following methods may be used:
1) Level transducer with electronic switches
2) Individual independent level switches, or
3) Float-type transducers with magnetically coupled switches

The general equations related to this method are described in B.1.3.2.

B.1.2.3 Drain pan with monitoring of flow into sump method

If the sump design can be coordinated before construction, it would be possible to install a shallow drain pan just below the floor level in which the sump is installed. This would collect all of the leakage coming into the sump and direct it to a central point in the drain pan that would allow the total sump flow to pass through a 0-10 gpm flowmeter. Depending on the type of flowmeter, it may be necessary to provide a trap so that the meter is filled. This method will provide an actual instantaneous measurement of the leakage flowing into the sump. With additional instruments such as those described above, the increase in leak rate can be determined and the sump emptied.

B.1.2.4 Pump controlled by timer and level switch method

For this method it is necessary that the sump pump discharge flow be accurately measured. This method employs a timer to turn the sump pump on and a level switch to turn it off. By measuring the time it takes to pump the sump down and the pump discharge flow rate, an average leak rate can be determined. The pump frequency established by the timer must be selected such that the
requirements of Section 7.1 of this standard can be satisfied. The general equations related to this method are described in B.1.3.3.

### B.1.2.5 Sump level or flow monitoring with microprocessor method

This method employs a single level or flow measuring device and a microprocessor. The microprocessor can be programmed to do all of the memory comparison, pump control, recording display, alarm functions described above. In addition, the microprocessor can simplify the calibration procedures for the leak detection systems.

**NOTE:** Presently supplied radiation monitors usually include field located microprocessors that can be programmed for these additional functions.

### B.1.3 General equations

#### B.1.3.1 Analog level transducer and level memory

##### a) Definitions

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>Sump capacity</td>
<td>gallons</td>
</tr>
<tr>
<td>q</td>
<td>Actual volume of liquid in the sump</td>
<td>gallons</td>
</tr>
<tr>
<td>L</td>
<td>Sump level (depth of sump)</td>
<td>inches</td>
</tr>
<tr>
<td>Lfs</td>
<td>Span of level device</td>
<td>inches</td>
</tr>
<tr>
<td>T</td>
<td>Measurement period (period of time that the sump level is measured to determine an average leak rate): minutes</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>Percent of level capacity to which sump is allowed to fill (between high &amp; low set points): %</td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>Pump discharge flow rate</td>
<td>gpm</td>
</tr>
<tr>
<td>Δli</td>
<td>Change in level during ith measurement period</td>
<td>inches</td>
</tr>
<tr>
<td>R</td>
<td>Resolution (degree to which measuring system can detect leak rate): gpm</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>Level measurement loop error: ±% of full scale</td>
<td>gpm</td>
</tr>
<tr>
<td>E</td>
<td>Level measurement loop error: ± inches</td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>Leakage rate (when assumed constant)</td>
<td>gpm</td>
</tr>
<tr>
<td>xim</td>
<td>Measured average leak rate for the ith measurement period</td>
<td>gpm</td>
</tr>
<tr>
<td>xi</td>
<td>Actual average leak rate for ith measurement period</td>
<td>gpm</td>
</tr>
<tr>
<td>t1</td>
<td>Sump fill time</td>
<td>minutes</td>
</tr>
<tr>
<td>t2</td>
<td>Sump drain time</td>
<td>minutes</td>
</tr>
<tr>
<td>k</td>
<td>Number of measurement periods that are completed before the pump starts running: integer</td>
<td></td>
</tr>
<tr>
<td>tΔ</td>
<td>Time from last level memory reset prior to beginning to drain the sump</td>
<td>minutes</td>
</tr>
</tbody>
</table>

**NOTE:** For metric units, substitute litres per second for gpm, meters for inches, and seconds for minutes in these definitions.

##### b) Assumptions

1. The measurement period starts immediately after the sump pump stops.
2. The error in determining the measurement period, T, is not significant.
c) Expression for measurement error

In general, the level measurement loop error, e, may be expressed as:

\[ e = \left[ \sum_{i=1}^{n} (e_i)^2 \right]^{1/2} \]  \hspace{1cm} (B-1)

where:

- \( e_i \) = accuracy of the ith instrument used in the level measurement loop (± % of span)
- \( n \) = number of instruments used in the level measurement loop (integer)

Since, for this method, the hydraulic level memory is allowed to equalize with the actual sump level when the sump is being pumped down, the accuracy of the level switch controlling the sump pump will have no effect on the total system error for average leak rate detection. Therefore, it is not necessary to include the accuracy of the level switch in the above equation for level measurement loop error.

d) Resolution

The measured average leak rate for the ith measurement period may be expressed as follows:

\[ \bar{x}_{im} = \bar{x}_i \pm R \]  \hspace{1cm} (B-2)

where the resolution, R, may be expressed as

\[ R = \frac{qe}{100T} \]  \hspace{1cm} (B-3)

As indicated in this standard, a resolution of 1.0 gpm or better is required, therefore,

\[ R \leq 1.0 \]  \hspace{1cm} (B-4)

The maximum number of gallons that can be collected in the sump in one measurement period may be expressed by:

\[ q_{max} = \frac{M_{max}Q}{100} \]  \hspace{1cm} (B-5)

When the sump is filled to the high level set point in one measurement period, Equations (B-3) and (B-5) give a maximum value for resolution as follows:

\[ R_{max} = \frac{M_{max}Qe}{10,000T} \]  \hspace{1cm} (B-6)

Substituting Equation (B-6) into Equation (B-4) gives the following limiting equation for the measurement period, T:

\[ T \geq \frac{M_{max}Qe}{10,000} \]  \hspace{1cm} (B-7)

e) Level Change to Measurement Error Relationship

The sump level for this method is allowed to increase until it reaches the high level, then the pump is activated and will run until the sump level drops down to the low level. Prior to primary pump activation, the change in sump level for a given measurement period may be expressed as:
\[ \Delta l_i = \frac{\bar{x}_i TL}{Q} \quad \text{(B-8)} \]

The level measurement loop error may be expressed as:

\[ E = \frac{eL_{fs}}{100} \quad \text{(B-9)} \]

Note that the above equation is equivalent to the resolution expressed in terms of inches. Therefore, to be detectable, a level change must be greater than the level measurement error.

\[ \Delta l_i > E \quad \text{(B-10)} \]

Substituting Equations (B-8) and (B-9) into equation (B-10) gives:

\[ \frac{\bar{x}_i TL}{Q} > \frac{eL_{fs}}{100} \quad \text{(B-11)} \]

or

\[ T > \frac{eQL_{fs}}{\bar{x}_i L 100} \quad \text{(B-12)} \]

and

\[ \bar{x}_i > \frac{eQL_{fs}}{LT100} \quad \text{(B-13)} \]

f) Determining the Measurement Period, T

In order to meet the requirements of this standard, the measurement period, T, must be determined carefully. The following equations are provided for this purpose. Referring to the Typical Sump Fill/Drain Operation (See Figure B-2), it can be seen that \( T \Delta \) is considered dead time so far as leak detection is concerned since it is not a part of a complete measurement cycle. Likewise, \( t_2 \) is leak detection dead time since the pump is draining the sump at this time. Any leakage that may occur during these two time periods (\( t_\Delta, t_2 \)) must be taken into account when determining the measurement period, T. To accomplish this, the dead time plus the measurement period must be less than 60 minutes to be able to detect a one gpm increase of leakage in one hour. This equation may be written as:

\[ t_\Delta + t_2 + T < 60 \quad \text{(B-14)} \]

or

\[ T < 60 - t_2 - t_\Delta \quad \text{(B-15)} \]

Assuming that the leak rate is constant \((x = \text{constant})\), we have:

\[ t_1 = \frac{mQ}{100x} \quad \text{(B-16)} \]

\[ t_2 = \frac{mQ}{(p-x)100} \quad \text{(B-17)} \]

Since \( t_\Delta = t_1 - kT \), Equation (B-15) may be expressed as:

\[ T < 60 - \frac{mQ}{(p-x)100} - \frac{mQ}{100x} + kT \quad \text{(B-18)} \]
B.1.3.2 Integrated level switches

a) Definitions
The definitions of Paragraph B.1.3.1A apply. The following definition also applies to this method:

\[ N = \text{Number of level switches employed in an integrated level switch method.} \]

b) Assumptions
Assume that the leak rate is directly proportional to the associated change in sump level.

c) Expression for Measurement Error
Equation (B-1) of Paragraph B.1.3.1C applies.

d) Resolution
To detect an unidentified leak rate of one gpm within one hour, the difference in set points of adjacent level switches must not exceed the level change that would occur for a one gpm leak rate at the end of a one hour period.

\[ \Delta l < \frac{(1.0 \text{ gpm}) (60 \text{ min}) L}{Q} \]  \hspace{0.5cm} \text{(B-21)}

or

\[ \Delta l < \frac{60L}{Q} \]  \hspace{0.5cm} \text{(B-22)}

e) Level Change to Measurement Error Relationship
Equations of Paragraph B.1.3.1E apply.

f) Determining the Number of Level Switches Required to Satisfy Standard
In order for this method to detect a one gpm leak rate within one hour, a sufficient number of switches must be provided such that the difference in set points of adjacent level switches is equal to the level change that would be caused by a one gpm leak rate in one hour.

\[ N \geq \frac{Q}{60} \]  \hspace{0.5cm} \text{(B-23)}

B.1.3.3 Equations for pump controlled by timed and level switch

a) Definitions
The definition of Paragraph B.1.3.1a apply.

b) Assumptions
1) The sump pump discharge flow rate is constant and is independent of sump level.
2) The error in measuring pump down time is not significant.

c) Expression for Measurement Error
The equations of Paragraph B.1.3.1c apply.

d) Resolution
Resolution may be expressed as Equation (B-6) of Paragraph B.1.3.1d.

\[ R_{\text{max}} = \frac{mQe}{10,000} t_2 \]  

(B-24)

for the sump pump controlled by level switches method. For the sump pump controlled by a timer and a level switch method, the sump could possibly fill completely. For this case, \( m = 1 \).

B.2 Condensate flow monitors

Containment air coolers have drain pans that duct containment atmosphere condensate to a sump. Other liquids coming to the same sump can come from liquid sources in the containment, e.g., service water. It is useful to measure the chiller condensate in order to distinguish it from these other liquids because the principal source of humidity in the containment is primary coolant flashing. One method of measuring condensate flow is to provide the drain pan with level switches. Then the measurement is made in the same manner as for the sumps described previously. The pans usually have gravity flow to the sump; thus, a valve can be used to control when the pan is emptied.

Depending on the cooler size and expected flow, it may be possible to find a flow meter for this application. However, it is cautioned that these are relatively small flows and the flow meters may be susceptible to becoming plugged.

B.3 Radioactivity monitoring methods

B.3.1 Airborne radiation monitoring coolant leakage measurement

The instantaneous containment atmosphere radioactivity concentration due to reactor coolant leakage, for a single radioisotope, may be expressed as:

\[ \frac{dA}{dt} = LC - \lambda AV - P_f LC - QA \]  

(B-25)

where

- \( V \) = containment free volume, cc
- \( A \) = concentration of radioisotope in the containment atmosphere, \( \mu \text{Ci/cc} \)
- \( C \) = concentration of radioisotope in the reactor coolant, \( \mu \text{Ci/cc} \)
- \( L \) = leakage rate of reactor coolant to containment atmosphere, liters/min.
- \( \lambda \) = decay constant of isotope, min
- \( P_f \) = plateout factor, fraction of leaking radioisotope that is removed by plateout, dimensionless
- \( Q \) = atmosphere removal rate (purge rate) of containment, cc/min (\( Q \) is zero for a containment without purge)

Simplifying equation (B-25) yields:

\[ \frac{dA}{dt} = \frac{LC}{V} (1 - P_f) - \lambda A - \frac{QA}{V} \]  

(B-26)
Solution of this differential equation gives the isotope activity concentration in the containment atmosphere as a function of time for a given leakage rate.

For \( A = A_0 \) at \( t = 0 \), the solution is

\[
A = \frac{LC(1 - P_f)}{\lambda V + Q} - \left[ \frac{LC(1 - P_f)}{\lambda V + Q} - A_0 \right] e^{-(\frac{\lambda + Q}{V})t} \quad (B-27)
\]

This equation may be used to estimate the radioactivity transient in the containment atmosphere due to a reactor coolant leak, and thus form the basis for estimating monitor response to a leak.

**B.3.2 Airborne radioactivity monitor sensitivity**

Coolant leakage from the RCPB that does reach the containment atmosphere vaporizes and is diluted by the air in the containment free volume. The containment air is continuously sampled, ducted through detectors designed to measure radioactivity in the form of gases, particulates, iodides, or a combination of these and returned to containment. Typical minimum detectable concentrations at a 95 percent confidence level in a 1.0 mr/hr Co-60 gamma field for detectors currently available are as follows:

<table>
<thead>
<tr>
<th>Detector Type</th>
<th>Concentration</th>
<th>Isotope***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiogas</td>
<td>( 1 \times 10^{-6} ) µCi/cc</td>
<td>Kr-85</td>
</tr>
<tr>
<td>Radioparticulate</td>
<td>( 1 \times 10^{-10} ) µCi/cc*</td>
<td>Cs-137</td>
</tr>
<tr>
<td>Radioiodine</td>
<td>( 1 \times 10^{-9} ) µCi/cc**</td>
<td>I-131</td>
</tr>
</tbody>
</table>

**B.3.3 Liquid radiation monitor sensitivity**

A typical liquid radiation monitor is capable of responding to a minimum detectable concentration of \( 10^{-5} \) µCi/cc of Zn-65 in a 1.0 mr/hr Co-60 gamma field with a 95 percent confidence level.

**B.3.4 Typical system factory checkout calibration and field installation specification for radiological monitoring systems**

Before delivery, the complete radiological monitoring system should be calibrated and tested by the supplier in the order specified below to ensure that the complete system and all components conform to this specification.

The test procedure should provide a step-by-step method of verifying that all adjustments have been made, and that all functions operate properly. High and low limits shall be specified for all adjustments, and should be listed on a system checkout sheet. The actual value of the adjusted variable should be recorded on the system checkout sheet.

Any of the tests or calibrations may be witnessed by the reactor owner's representative at his discretion.

a) **ELECTRICAL CHECKOUT** - The electrical checkout should include point-to-point continuity tests and electrical insulation tests in accordance with the requirements of Section 20-5.3.4.1 and 20-5.3.4.2 of ANSI C37.20, Standard for Switchgear Assemblies. However, coaxial and shielded cables should not have high voltages applied to them,

---

* For a one hour collection time or less with a moving filter tape at 1 to 1.5 inches per hour tape speed.
** For a one hour collection time or less with a fixed filter.
***These referenced isotopes are used for instrument calibration, therefore, monitor sensitivity should be cross-calibrated to the isotopes listed in Paragraph 7.2.1C.
nor should they be tested with megohmmeters. The manufacturer should be responsible for protecting instruments and devices that may be damaged by high voltage tests.

b) OPERATIONAL TESTS - The completely assembled, piped, and wired racks should be tested at the factory in the presence of witnesses. (It is recommended that prior agreement be reached that any costs arising from these tests, including the repair of leaks or the replacement of defective materials, will be borne by the manufacturer).

c) CALIBRATION - After the instruments have been accepted by the witness of a) & b) above, but before shipment, each sampler-detector-readout system should be factory calibrated with appropriate liquid or gas sources. Aerosol detectors are calibrated by cross-referenced standards. The sources should be traceable to the National Bureau of Standards and calibrated according to ASTM D 1690-67, D 2459-72, and D 2577-72, as applicable. This calibration should consist of:

1) Operating the system to reach thermal stability.

2) Recording the background counting rate in a specified Co-60 gamma field, usually 1.0 mR/hr.

3) Introducing a laboratory-calibrated concentration of the reference or control isotope into the sampler, and recording the counting rate above background.

4) Recording pertinent environmental conditions and operating parameters, such as detector high voltage, spectrometer and amplifier gain settings, ratemeter time constant, ambient temperature, sampling system temperature, sampling system pressure, and actual gamma field intensity.

The calibration procedure should be performed with three concentrations. The lowest should produce counting rate in the lowest decade of response, the median shall be approximately midscale between the lowest and highest concentrations, and the highest should produce a counting rate in the last decade of response.

A plot of the concentration of the reference isotope in terms of micro-curies/cc versus the net counting rate produced should then be drawn on log-log scales. This plot should be used as a calibration curve in the field. The three concentrations should lie on a straight line within one standard deviation of the net count rate. Following the dispersion of each concentration into the sampler, a sample of the concentration should be extracted into a glass vial for separate verification of each concentration, at a place designated by the reactor owner or his representative.

The following procedure should be used to demonstrate that the system meets radiological sensitivity specifications:

1) Determine the standard deviation of the background counting rate under the specified operating conditions (including 1.0 mR/hr Co-60 gamma field) by taking the square root of the background counting rate.

2) Multiply this standard deviation of the background counting rate by the specified factor, usually 2.56 (2.56 corresponds to 99 percent statistical confidence; for 95 percent confidence, multiply by 1.96).

3) From the calibration curve plotted as described above, determine the net counting rate resulting from the specified minimum detectable concentration. The counting rate so determined must be greater than 2.56 (or 1.96 if so specified) times the standard deviation of the background counting rate for the system sensitivity to be acceptable.
An auxiliary Co-60 or Cs-137 calibration source should be supplied as a field calibration aid. For the scintillation detector instrument, the calibration sources should be taped to the detector crystal and the detector inserted into its shielded sampler that has been purged, and the resultant counting rate data recorded on the calibration curve.

The position of the calibration source should be clearly recorded by the use of identifying reference marks on the sampler and on the source. The system should be calibrated in the field by using the auxiliary calibration source data. Calibration data and decay curves for the auxiliary calibration sources should be supplied with the system manuals.

After the auxiliary calibration source is removed, the detector is replaced in the purged shielded chamber, and the check source is actuated. The counting rate data resulting from the actuation of check sources should also be recorded on the calibration curve.

d)  SYSTEM OPERATION - The radiological monitoring system shall be calibrated and operated as a system at the manufacturer’s plant. The system should be operated for 200 hours continuously, and the last 100 hours must be without any failure or drift greater than specified. During the first 100 hours the system shall be thermally cycled twice each 24 hours to 120 ± 10°F and 70 ± 10°F with at least 2 hours at each nominal temperature. The detectors shall be placed in a radiation field that causes the readout to indicate in the second or third decade of the detector range. Compliance with the drift specification may be checked by recalibration.

e)  FIELD CHECKOUT AND CALIBRATION - The onsite checkout should consist of using the auxiliary calibration source and/or the check sources to check the calibration of each detector and, unless exception has been granted, to exercise all equipment functions such as alarms and remote readouts. When the system and accessory instruments meet the functional requirements and the performance guarantees, the system may be accepted. (It is recommended that the manufacturer be requested to submit a quotation to provide a field engineer, if needed, to repair any shipping damage, make final connections, and check out and calibrate the system.)

B.4 Humidity monitoring

B.4.1 Calculation of leakage rate

The instantaneous change in containment atmosphere specific humidity due to coolant leakage can be expressed by the following relation:

\[
M \left( \frac{dw}{dt} \right) = xL - \sum_{i=1}^{n} c_i \]  \hspace{1cm} (B-28)

where

- \( M \) = total mass of atmosphere in containment
- \( w \) = containment atmosphere specific humidity, mass of water vapor/mass of atmosphere
- \( L \) = total leakage flow rate into the containment, mass/time
- \( x \) = fraction of leak that flashes to vapor, lbm-vapor/lbm-liquid
- \( c_i \) = condensation rate of "ith" containment air cooling unit, mass/time
\[ n \text{ = number of operating containment air cooling units} \]

The fraction of leak that flashes to vapor can be determined from the isenthalpic relation:

\[ h = x h_g + (1 - x) h_f \quad (B-29) \]

where

\[ h \text{ = enthalpy of reactor coolant in RCPB, Btu/lbm, (J/Kg)} \]
\[ h_g \text{ = enthalpy of saturated vapor at containment temperature, Btu/lbm (J/Kg)} \]
\[ h_f \text{ = enthalpy of saturated liquid at containment temperature, Btu/lbm (J/Kg)} \]

**B.4.2 Estimation of humidity transient**

The following derivation is useful in estimating the humidity transient in a containment due to an RCPB leak and thus forms a basis for estimating monitor's response to a leak.

The condensation rate in a containment air cooling unit can be estimated by:

\[ q = m(h_1 - h_2) - m h_w (w_1 - w_2) \quad (B-30) \]

where

\[ q \text{ = heat removal rate of air cooling unit, Btu/min, (Watts)} \]
\[ m \text{ = air mass flow rate in cooling unit, lbm-air/min, (Kg/sec)} \]
\[ h_1 \text{ = enthalpy of air entering cooling unit, Btu/lbm, (J/Kg)} \]
\[ h_2 \text{ = enthalpy of air at condensing temperature, Btu/lbm, (J/Kg)} \]
\[ h_w \text{ = enthalpy of saturated liquid (condensate) at leaving temperature, Btu/lbm, (J/Kg)} \]
\[ w_1 \text{ = specific humidity of air entering air cooling unit, lbm-water vapor/lbm-air, (Kg vapor/Kg air)} \]
\[ w_2 \text{ = specific humidity of air leaving air cooling unit, lbm-water vapor/lbm-air, (Kg vapor/Kg air)} \]

This equation can be solved for \( w_1 \) by trial and error by assuming a final temperature, which determines the outlet conditions \( h_w \), \( h_2 \) and \( w_2 \), and seeking a balanced equation. Upon solution of this equation the condensation rate, \( c \), assuming no reevaporation is:

\[ c = m(w_1 - w_2) \quad (B-31) \]

It can be shown that over any practical range of concern the above relationship can be replaced by the mathematical approximation,

\[ c = \alpha w_1^2 + \beta w_1 + \gamma \quad (B-32) \]

Where: \( \alpha \), \( \beta \), and \( \gamma \) are constant coefficients determined from a fit to parametric data of \( w_1 \) versus \( c \), for the conditions of interest, calculated using Equations (B-30) and (B-31). These coefficients require derivation for each containment configuration.
Substituting Equation (B-32) into equation (B-28) with \( w_1 = w \) and for equal capacity cooling unit gives:

\[
M \frac{dw}{dt} = xL + \alpha w^2 - \beta w + \gamma \quad (B-33)
\]

The solution to this equation for \( w = w_0 \) at \( t = 0 \) is,

\[
w = \frac{\beta - K \left[ \frac{1}{\theta - \sqrt{K}} - e^{\left( \frac{K}{m} \right) t} \right]}{\frac{1}{\theta - e^{\left( \frac{K}{m} \right) t}} - \frac{K}{2\alpha}} \quad (B-34)
\]

for \( w \leq \frac{\beta - \sqrt{K}}{2\alpha} \)

where

\[
k = \beta^2 - 4\alpha(\gamma + xL)
\]

\[
\theta = \frac{2\alpha w_0 - \beta - \sqrt{K}}{2\alpha w_0 - \beta + \sqrt{K}}
\]

Equation (B-34) may be used to estimate the specific humidity transient in the containment due to an RCPB leak. The designer is cautioned that where other effects, such as mixing, condensation, etc. are significant, these factors should also be included in the equations used.

**B.5 Tape moisture sensor design criteria**

The following typical design criteria are recommended for moisture sensitive tape leak detection systems:

a) The tapes should be manufactured with halogen free chemicals and conductors should be stainless steel.

b) The resistance between two strips of conductor should be at least 10 megohms when the tape is dry. The resistance of the tape should be not more than 100,000 ohms when moistened in one spot with one drop of water. The length of separately monitored detector strips should not exceed approximately 20 feet (6 meters).

c) The tape should not be applied directly to an uninsulated surface if the surface temperature exceeds the boiling point of water. Weep holes in insulation and cover materials should be provided so that water leakage from the pipe or vessel will drain on the tape. The tape should be qualified for the ambient environmental conditions of the application.

d) A control unit which performs a continuity check each 30 seconds or less and is capable of identifying any single fault and of annunciating a zone alarm condition should be provided.

Figure B-3 illustrates a typical installation method. Other sensor and system designs are available.
B.6 Estimating temperature sensor time constant from sensor configuration and fluid conditions

Realistic time constant estimates for thermocouples, resistance thermometers and other types of temperature sensors can be computed since the sensor time constant is the active sensor mass heat capacity divided by the heat transfer rate to the sensor mass. This relationship is given by the following expressions:

\[ \tau = \frac{H}{Q} \quad \text{(B-35)} \]
\[ \tau = \frac{MC_{pm}}{hA} \quad \text{(B-36)} \]
\[ \tau = \frac{VC_{pv}}{hA} \quad \text{(B-37)} \]

where

- \( \tau \) = time constant: h (hrs), s (sec)
- \( H \) = heat capacity: \( \frac{\text{BTU}}{\text{°F}} \) (joules/°C, \( \text{j} \)/°C)
- \( Q \) = heat transfer: \( \frac{\text{BTU}}{\text{hr} \text{ °F}} \) (watts/°C, \( \text{w} \)/°C)
- \( h \) = heat transfer coefficient: \( \frac{\text{BTU}}{\text{ft}^2 \text{ °F hr}} \left( \frac{\text{w}}{\text{m}^2 \text{ °C}} \right) \)
- \( A \) = heat transfer area: \( \text{ft}^2 \) (\( \text{m}^2 \))
- \( M \) = mass of junction or sensor material: lb, (kg)
- \( C_{pm} \) = mass basis specific heat of junction material:
  \[ \frac{\text{BTU}}{\text{lb} \text{ °F}} \left( \frac{\text{J}}{\text{Kg} \text{ °C}} \right) \]
- \( C_{pv} \) = volume basis specific heat of junction material:
  \[ \frac{\text{BTU}}{\text{ft}^3 \text{ °F}} \left( \frac{\text{J}}{\text{M}^3 \text{ °C}} \right) \]
- \( V \) = volume of junction or sensor material: \( \text{ft}^3 \), (\( \text{m}^3 \))
Satisfactory estimates of sensor time constants can usually be computed, where $\Delta T$ between sensor and surrounding fluid is sufficiently low to make radiation effects negligible, by assuming that the major resistance to heat flow lies in the film coefficient between the sensor and fluid medium. This assumption is valid for a single time constant system such as a bare thermocouple. When the sensing element is inside a well, there may be two or more films to consider. The heat transfer area is assumed to be the average film surface area.

The heat transfer film coefficient ($h$) is determined by the existing fluid conditions as expressed in the following relationship.

$$h = \frac{kN_u}{d} \quad (B-38)$$
where

\[ k = \text{fluid conductivity: } \frac{\text{BTU}}{\text{hr ft}^2\text{°F} \text{m}^\circ\text{C}} \]  

\[ N_u = \text{Nusselt number: dimensionless} \]

\[ d = \text{sensor diameter: ft (meter)} \]

One expression for the Nusselt number is:

\[ N_u = 0.43 + X \text{Re} Y \text{Pr}^{0.31} \]

**Table B-1** below gives values of X and Y as a function of Reynold's number that apply in Equation (B-39) above.

**Table B-1 — Values of X and Y as function of Reynolds number**

<table>
<thead>
<tr>
<th>Reynolds number</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 - 4</td>
<td>0.989</td>
<td>0.330</td>
</tr>
<tr>
<td>4 - 40</td>
<td>0.911</td>
<td>0.385</td>
</tr>
<tr>
<td>40 - 4,000</td>
<td>0.683</td>
<td>0.466</td>
</tr>
<tr>
<td>4,000 - 40,000</td>
<td>0.193</td>
<td>0.618</td>
</tr>
<tr>
<td>40,000 - 400,000</td>
<td>0.0265</td>
<td>0.805</td>
</tr>
</tbody>
</table>

The Reynold's number (Re) and Prandtl number (Pr) are derived from the following expressions at the measurement fluid conditions.

\[ \text{Re} = \frac{dv\rho}{\mu} \text{ (dimensionless)} \]  

\[ \text{Pr} = \frac{\mu C_p}{k} \text{ (dimensionless)} \]

where:

\[ \rho = \text{fluid density: } \frac{\text{lb}}{\text{ft}^3} \left(\frac{\text{Kg}}{\text{m}^3}\right) \]

\[ v = \text{fluid velocity: ft/hr} \left(\frac{\text{m}}{\text{s}}\right) \]

\[ \mu = \text{fluid viscosity: lb/ft-hr} \left(\frac{\text{Kg}}{\text{ms}}\right) \]

\[ d = \text{sensor diameter: ft (m)} \]

\[ k = \text{fluid conductivity: } \frac{\text{BTU}}{\text{hr ft}^2\text{°F} \text{m}^\circ\text{C}} \]

\[ C_p = \text{specific heat: } \frac{\text{BTU}}{\text{lb °F}} \left(\frac{\text{J}}{\text{Kg °C}}\right) \]
B.6.1 Converting sensor time constant for different fluid conditions

When the manufacturer of a temperature sensor provides the instrument time constant for a given set of fluid conditions, the data can be converted to a new set of fluid conditions. This method usually is capable of more accurate estimates of time constants because manufacturers’ data is usually based on actual tests.

If the time constant $\tau_1$ is measured under one set of conditions and the $\tau_2$ is desired for another set of fluid conditions, then the relationship can be expressed as indicated in equation (B-42) since the heat capacity and transfer area of the thermometer remain unchanged.

\[
\frac{\tau_1}{\tau_2} = \frac{h_2}{h_1} = \frac{k_2 \left( 0.43 + X_2 Re_2 \Pr_2^{0.31} \right)}{k_1 \left( 0.43 + X_1 Re_1 \Pr_1^{0.31} \right)}
\]  

(B-42)

Calculated values for sensor time constants should correlate well with experimental results. Otherwise significant deviations from reality will have been made in the assumptions used in calculations. The values for $X$ and $Y$ in Equation (B-42) above are derived from Table B-1, as a function of Reynold’s number for the respective fluid conditions.

B.6.2 Temperature sensor response characteristics

The response of a single time constant ($\tau$) system to a step change input is given by the following expression:

\[
T_t = T_f (1 - e^{t/\tau}) + T_i
\]  

(B-43)

where

- $T_t$ = temperature at a time $t$
- $T_f$ = final step-change temperature value
- $\tau$ = sensor 63 percent response time constant
- $T_i$ = temperature before step change

When the response is exponential as for the above single time constant expression, it can be shown that the dynamic error of indicated temperature in degrees is simply the rate of change in temperature multiplied by the time constant ($\tau$).

After a time interval corresponding to three time constants, a sensor will have attained 95 percent of the response to a step change. Therefore, for a ramp or constant rate of temperature change, the instrument lag time in seconds is approximately equal to the time constant after elapse of a time equal to three time constants.

Some temperature sensor designs, e.g., a sensor with thermowell, constitute a multiple time constant system that includes one or more thermal lag time constants. General practice, and the intent of this standard, is to permit lumping of these sensor delays into a single time constant, see Reference (14). This procedure is not strictly correct in the mathematical sense, but will give satisfactory estimates of sensor response over relatively small temperature increments.

B.6.3 Coolant leakage measurement sensitivity estimates

The rate of change of temperature for the process fluid in a system can be estimated for an assumed coolant leakage rate or heat input rate from the following generalized equation:

\[
MC_p \left( \frac{dT}{dt} \right) = \sum Q(\text{input}) - \sum Q(\text{output})
\]  

(B-44)

Where $M$ and $C_p$ are the average mass and heat capacitance of the heat transfer fluid, $dT/dt$ is the rate of change of the fluid temperature, $\Sigma Q$ (input) is the summation of heat inputs within
measurement system boundaries and $\Sigma Q$ (output) is the summation of heat losses from the system boundary.

If initial conditions at $t = 0$ are assumed to be zero steady-state coolant leakage, constant environmental temperatures and the only new heat input to the system is a new coolant leakage flashing to steam vapor at a constant rate, then

$$MC_\rho \frac{dT}{dt} = Wh_g - \Sigma Q(\text{losses})$$

(B-45)

Where $W =$ coolant leakage rate and $h_g =$ flashing coolant or steam enthalpy.

If we substitute instrument indicated temperature rate of change, $\tau \frac{dT}{dt}$ for the equivalent fluid temperature rate of change after a time lapse of three sensor time constants (see Section B.6.2 above), and rearrange the equation, then an expression of coolant leakage rate in terms of rate of change of indicated temperature for finite time intervals is derived as follows:

$$W = \left( \frac{1}{h_g} \right) \left[ MC_\rho \tau \left( \frac{dT}{dt} \right) + \Sigma Q(\text{losses}) \right]$$

(B-46)

The summation of heat losses from the measurement system limits will be a nonlinear function of time as the system fluid (usually air and water vapor) temperature increases and as the heat sink masses increase in temperature. However, for leakage sensitivity prediction estimates of respective exposed surface areas ($A$), overall heat transfer coefficients ($U$) and differences in fluid temperature and heat sink area temperature ($\Delta T$) can be made for finite time increments so that the following equation for heat losses applies:

$$\Sigma Q(\text{losses}) = U_1 A_1 \Delta t_1 + \ldots + U_n A_n \Delta t_n$$

(B-47)

Where $n$ corresponds to the number of different heat sinks considered in the calculation. When additional heat removal and mixing mechanisms are significant these should also be included in the estimates. For the purpose of these calculations, justifiable simplifying assumptions are permissible in arriving at heat transfer coefficients, area, etc. For longer periods of leakage, iterative methods may be used for adjusting heat loss coefficients and temperature differences.

Using these methods, the leakage rate that will produce a finite and measurable temperature change (sensitivity) in a given unit of time can be estimated. With such backup design calculations, a coolant leakage detection system which alarms on rate of change of temperature rather than absolute or differential temperature may be justifiable. The above method of estimating sensitivity assumes complete and instantaneous mixing of flashing coolant and air volume in the measurement system. In cases where this assumption introduces large errors in the response calculations, i.e., large mixing volumes with considerable distances between sensor and postulated leakage, additional expressions defining the thermal transport mechanisms must be included in the calculations or the temperature sensor must be located closer to the postulated leakage in smaller mixing volumes.
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