



# DRAFT REGULATORY GUIDE

Contact: M. Srinivasan  
(301) 415-6386

## DRAFT REGULATORY GUIDE DG-1173

(Proposed Revision 1 of Regulatory Guide 1.45, dated May 1973)

# GUIDANCE ON MONITORING AND RESPONDING TO REACTOR COOLANT SYSTEM LEAKAGE

## A. INTRODUCTION

General Design Criterion (GDC) 14, "Reactor Coolant Pressure Boundary," as set forth in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, of the *Code of Federal Regulations* (10 CFR Part 50), "Domestic Licensing of Production and Utilization Facilities" (Ref. 1), requires that the reactor coolant pressure boundary (RCPB) shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture. As a result, these nuclear components are normally designed to the criteria established in Section III of the Boiler and Pressure Vessel Code (Ref. 2) promulgated by the American Society of Mechanical Engineers (ASME), hereinafter referred to as the ASME Code.

During the design phase, degradation-resistant materials are normally specified for reactor coolant system (RCS) components. However, materials can degrade as a result of the complex interaction of the materials, the stresses they encounter, and the normal and upset operating environments in which they are used. Such material degradation could lead to the leakage of the reactor coolant. Consequently, GDC 30, "Quality of Reactor Coolant Pressure Boundary," of Appendix A to 10 CFR Part 50 (Ref. 1), requires that means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage. Additionally, 10 CFR 50.55a, "Codes and Standards" (Ref. 1), requires the performance of inservice inspection and testing of nuclear power plant components. Thus, the concept of defense-in-depth is used to provide assurance that structural integrity of the RCPB is maintained. This guide describes methods that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for implementing these requirements, with regard to selecting reactor coolant leakage detection systems, monitoring for leakage, and responding to leakage. This guide applies to light-water cooled reactors.

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## **B. DISCUSSION**

### **Background**

Every effort should be made in reactor design and construction to use materials and environments that limit the potential for degradation. During the operational life of a plant, reactor components can degrade through normal operational wear, mechanical deterioration, corrosion, and/or fatigue. This degradation can lead to reactor coolant leakage. A limited amount of leakage inside containment may occur from reactor coolant systems that cannot practically be made 100% leaktight.

The safety-significance of leakage from the RCS can vary widely, depending on the source of the leakage as well as the leakage rate and duration. Operating experience and research have indicated that very low levels of leakage could cause (or indicate) material degradation arising, for example, as a result of boric acid corrosion, primary water stress-corrosion cracking (PWSCC), and intergranular stress-corrosion cracking (IGSCC). Such forms of degradation could potentially compromise the integrity of a system, leading to a loss-of-coolant accident (LOCA). To minimize the probability of rapidly propagating failure attributable to material degradation and gross rupture of the RCPB, the leakage should be kept to a level that is as low as practical, and prompt action should be taken in responding to leakage to limit the safety consequences.

Taking prompt corrective action may require continuous online monitoring for leakage. Continuous leakage monitoring is important in ensuring the safe operation of a facility, in that it provides an indicator during reactor operation that a potentially adverse condition may exist. In addition to monitoring for leakage, it is important to quantify the reactor coolant leakage and locate its source, in order to assess its safety-significance. Detecting and effectively responding to leakage, as early as possible, provides defense-in-depth for the integrity of the RCPB.

## **Types of Leakage**

Leakage from the RCS can be divided into two main categories, namely, “identified leakage” and “unidentified leakage.” Identified leakage is defined as follows:

- (1) leakage (such as pump seal or valve packing leakage except for reactor coolant pump seal water injection or leakoff) that is captured, flow-metered, and conducted to a sump, collecting tank, or collection system,
- (2) leakage into the containment atmosphere from a known source, which does not interfere with the operation of unidentified leakage monitoring systems and is not attributable to a leakage in the RCPB (as defined below), and
- (3) intersystem leakage from the RCPB to other systems across passive barriers or valves [e.g., primary-to-secondary leakage in pressurized water reactors (PWRs)]; intersystem leakage is not considered RCPB leakage (as defined below).

Unidentified leakage encompasses all other leakage (except for reactor coolant pump seal water injection or leakoff). Until the source of any unidentified leakage is located, such leakage may be RCPB leakage (as defined below) and, therefore, should be identified as quickly as possible.

RCPB leakage is considered leakage from a nonisolable fault in the material of an RCS component, pipe wall (including welds), or vessel wall. Leakage from seals, gaskets, and mechanical connections (e.g., bolts, valve seals) is not considered RCPB leakage although these are included in the RCPB, as defined in 10 CFR 50.2, “Definitions” (Ref. 1). Thus, leakage that is potentially from seals, gaskets, and mechanical connections is classified as either identified or unidentified leakage, as defined above.

## **Leakage Separation**

Procedures for separating the sources of leakage (i.e., leakage from an identified source versus leakage from an unidentified source) are necessary to promptly identify potentially adverse conditions, assess the safety-significance of the leakage, and take prompt corrective action.

The reactor vessel closure seals and safety and relief valves should not have significant leakage; however, if leakage occurs through these paths or through pump and valve seals, it should be detectable and collectable and, to the extent practical, should be isolated from the containment atmosphere so as not to mask any potentially serious leakage that may occur. This leakage is “identified leakage,” and should be conducted to tanks or sumps so that the flow rate and the trend in flow rate can be measured or calculated, monitored, and analyzed, during plant operation.

Leakage to the containment atmosphere, which is not collected (such as from valve stem packing glands and other sources), increases the humidity of the containment. The moisture removed from the atmosphere by air coolers, together with any associated liquid leakage to the containment is known as “unidentified leakage,” and should be collected in tanks or sumps separate from the identified leakage so that the flow rate and the trend in flow rate of the unidentified leakage can be established, monitored, and analyzed during plant operation.

## Methods for Monitoring Leakage and Identifying Its Source

Effective methods for monitoring (including detecting) any leakage and locating its source are important because leakage may have the following implications.

- (1) Indicate that a component no longer has adequate structural integrity.
- (2) Cause degradation or corrosion of a component (other than the leaking component) as a result of the interaction between the leaking coolant and the other component.
- (3) Indicate that there is an accumulation of chemical compounds (e.g., boric acid) that could invalidate various design assumptions.
- (4) Contaminate work surfaces.
- (5) Affect the capability of other instruments (including leakage monitoring instruments) or components.

A variety of instruments and methods is available for monitoring RCS leakage. The capabilities of these instruments and methods vary in terms of their response time, sensitivity, and accuracy. In addition, some instruments and methods continuously monitor for leakage, while others are only used periodically. An effective leakage monitoring strategy will include a combination of leakage monitoring instruments and methods. Monitoring changes in the following parameters can be useful in detecting a leak, as well as quantifying the flow rate:

- (1) level or flow rate to tanks and sumps,
- (2) airborne particulate radioactivity,
- (3) airborne gaseous radioactivity,
- (4) containment atmosphere humidity,
- (5) containment atmosphere pressure and temperature, and
- (6) condensate flow rate from air coolers.

Because of the need to identify the source of leakage to assess the safety-significance of the leak, leakage monitoring systems should be installed to assist in locating the source of leakage during reactor operation. This can be accomplished, in part, by installing a number of instruments throughout containment and monitoring the response of each of these instruments to leakage [e.g., an instrument that is closer to a leak should respond sooner than an instrument that is further away, assuming that the two instruments have similar capabilities (e.g., sensitivity)]. The following examples illustrate some other methods that could be used to identify the source of leakage:

- (1) humidity sensors mounted on specific component surfaces,
- (2) acoustic emission monitoring systems mounted on specific component surfaces, and
- (3) online surveillance using radiation-resistant video cameras throughout the containment.

Intersystem leakage from the RCPB to other systems across passive barriers or valves may be possible. Monitoring intersystem leakage is important because it provides information on the following:

- (1) loss of coolant inventory,
- (2) potential release outside containment, and
- (3) potential location of contamination.

Intersystem leakage may not be detectable through the above-mentioned detection systems; therefore, other alarm and leakage monitoring methods should be employed. Monitoring methods should include monitoring the activity of water flowing through the containment boundary into the connected systems, as well as monitoring airborne radioactivity, where such systems are vented outside the containment boundary. Another method of obtaining indications of uncontrolled or undesirable intersystem flow is to perform a water inventory balance, designed to provide appropriate information (such as abnormal water levels in tanks and abnormal flow rates). The primary-to-secondary leakage in PWRs should be monitored through various continuous (steam line nitrogen-16 monitors, condenser offgas monitors) and periodic (water chemistry grab samples) monitoring techniques.

Potential discharges from closed safety and relief valves are usually piped to tanks or water pools and are considered part of identified leakage, within the containment. Temperature sensors in the discharge path of safety and relief valves or flow meters in the leakoff lines would provide an acceptable method of signaling leakage from these valves.

While the above-mentioned leakage monitoring systems reflect the present state of technology, it is recognized that other more advanced monitoring methods may be developed and used. Among such methods are boric acid detection systems using a Fourier Transform Infrared (FT-IR) Spectrometer and crack growth monitoring systems, such as acoustic emission (AE) or electrochemical potential (ECP) measurement systems. Because of the potential importance of early leak detection in the prevention of accidents, continued improvements in leakage monitoring and locating techniques should be sought and employed.

It is not necessary that all of the above-mentioned leakage monitoring methods or systems be employed in a specific nuclear power plant. However, because the methods differ in sensitivity and response time, prudent selection of monitoring methods should include sufficient diversity to ensure effective monitoring during periods when some monitoring systems may become less effective or entirely ineffective. Such (ineffective) systems may confirm leakage identified by other methods and serve as early indicators of a potential problem that would prompt closer examination of other leakage detection systems to determine the extent of any corrective action that may be needed.

## **Monitoring System Performance**

### **Capability**

It is essential that leakage monitoring systems have the capability to detect a degradation of the RCPB as soon as practical after occurrence, in order to limit the potential for a gross failure of the pressure boundary. It is possible that some flaws might develop and penetrate the RCPB wall, exhibit very slow growth, and afford sufficient time for a safe and orderly plant shutdown after a leak is detected.

Nonetheless, rapidly growing flaws leading to a larger leakage rate may require more rapid detection, more frequent monitoring, and more urgent corrective action based on safety-significance.

For critical components and critical areas, monitoring methods with the capability to locate the source of the leakage as soon as practical after the leakage begins will limit the potential safety-significance of the leak.

An increase in humidity of the containment atmosphere would indicate release of water vapor to the containment. Dewpoint temperature measurements can be used to monitor humidity levels of the containment atmosphere. A 1 °F increase in dewpoint is well within the sensitivity range of available instruments. Since the humidity level is influenced by several factors, a quantitative evaluation of an indicated leakage rate may be questionable and should be compared with observed increases in liquid flow from sumps and condensate flow from air coolers. Humidity level monitoring is considered most useful as an alarm or indirect indicating device to alert the operator to a potential problem.

Methods that monitor air temperature and pressure may also be used to infer leakage of the coolant to the containment. Containment temperature and pressure fluctuate slightly during plant operation, but a rise above the normally indicated range of values may indicate leakage of the reactor coolant into the containment. The accuracy and relevance of temperature and pressure measurements depend on containment free volume and detector location. Alarm signals from these instruments can be valuable in recognizing rapid and sizable leakage into the containment.

Reactor coolant normally contains sources of radiation which, when released to the containment, can be detected by the monitoring systems. However, reactor coolant activity should be low during initial reactor startup and for a few weeks thereafter until activated corrosion products have formed and fission products have potentially been released from fuel elements. During this period, radioactivity monitoring instruments may be of limited value in providing an early warning of very small leaks in the RCS. However, radioactivity monitoring systems (especially particulate activity monitoring) should be included for every plant because of their sensitivity and rapid response to coolant leakage.

The effectiveness of airborne gaseous radioactivity monitors depends primarily on the activity of the reactor coolant and also, in part, on the volume of the containment and the background activity level. It has been estimated that a leakage rate of 1 gallon per minute (gpm) [3.8 liters per minute (lpm)] could be detected in approximately 80 minutes by monitoring the activity of noble gases.<sup>1</sup> However, because of the improvement in fuel integrity, many operating plants have reported experiencing much longer response times by using realistic activities.<sup>2</sup> Therefore, it may no longer be appropriate to reference gaseous radioactivity monitors in the plant technical specifications. Gaseous radioactivity monitoring, like humidity, pressure, and temperature monitoring, which are not referenced in plant technical specifications, may still be desirable for providing a diverse and independent method and giving qualitative warning signals to operators.

Since the 1970s, there have been improvements in both the available instruments and methods for monitoring leakage, as well as our understanding of the capabilities of those instruments and methods. Plants have used leakage monitoring methods that can detect flow rates lower than 0.05 gpm (0.19 lpm). Industry practice has shown that several monitoring methods are capable of detecting a leakage rate of

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<sup>1</sup> See Chu, S., "Materials Reliability Program: Survey of Online PWR Primary Coolant Leak Detection Technologies (MRP-187)," EPRI Report #1012947, Electric Power Research Institute, Palo Alto, CA, November 2005.

<sup>2</sup> See NRC Information Notice 2005-24, "Nonconservatism in Leakage Detection Sensitivity" (Ref. 4)

1 gpm (3.8 lpm) within 1 hour [i.e., instrument sensitivity is 1 gpm (3.8 lpm) in 1 hour]. Currently, it is estimated that airborne particulate radioactivity monitors can detect a leakage rate of 1 gpm (3.8 lpm) in approximately 10 minutes when there is leakage of fission products from fuel elements. Similarly, containment air cooler condensate flow meters are reportedly capable of detecting a leakage rate of 1 gpm (3.8 lpm) within 1 hour, although this capability varies depending on plant conditions.

Advanced local humidity monitoring (e.g., FLUS™) and acoustic emission systems are also currently used (or have previously been used) at some plants. In general, these methods have better detection sensitivity than those discussed above. For example, humidity sensors reportedly have a specified sensitivity of 0.005 – 0.5 gpm (0.02 – 1.89 lpm), and acoustic emission sensors have a specified sensitivity of 0.003 – 0.25 gpm (0.01 – 0.95 lpm). (The operational sensitivities of these devices may be different from the vendors' specifications as a result of plant-specific containment conditions.) These methods also permit identification of the general (if not exact) location of a leak and, therefore, can be used to monitor critical components. In addition, acoustic emission systems may permit monitoring the progression of material degradation (i.e., growth of a crack), which could provide the operator an early indication of an impending leak. Such sensors have been used under plant conditions to monitor the propagation of cracks.

The operational (as compared with vendor-specified) sensitivity of an instrument at various leakage rates is an important factor in determining the instrument's usefulness and functionality. At very low leakage rates, an instrument should have adequate sensitivity to reliably determine the leakage rate. The sensitivity at the high end of the range of leakage rates is equally important because the instrument should provide reliable leakage rate information during an accident involving a loss of coolant. In determining the upper limit of an instrument's sensitivity range, it is important that the saturation limits of the detector are not exceeded. These concerns pertain to all types of leakage monitoring techniques, whether direct (such as flow rate measurements) or indirect (such as detection of radioactivity in the containment atmosphere).

### **Detector Response Time**

Evaluating an alarm or indication of leakage is important, and the ability to compare indications of leakage from a variety of monitoring methods is necessary. The detector response time should, therefore, be included in the functional requirements for leakage monitoring systems. Except for the limitations during the initial few weeks of unit operation (as previously discussed), all monitoring systems referenced in the technical specifications should respond to a leakage increase of 1 gpm (3.8 lpm) in 1 hour or less. Multiple instrument locations should be used to ensure that the transport delay time of the leakage effluent from its source to the detector (or instrument location) will yield an acceptable overall system response time. An acceptable overall system response time should ensure that there are no adverse safety consequences associated with a leak. A useful technique in identifying the general location of a leak is to locate several sensors within the containment area and evaluate any differences in response from these sensors (as previously discussed). This technique, in combination with the other methods discussed above, may be used to satisfy the related requirement of GDC 30 (Ref. 1).

In analyzing the capabilities of leakage monitoring systems that measure radioactivity, a realistic primary coolant radioactivity concentration assumption, consistent with plant normal operations, should be used (as opposed to the maximum concentration permitted by technical specifications or used in accident analysis).

## **Signal Correlation and Calibration**

It is important to be able to quantify the leakage rate. The flow rate or level change measurements from tanks, sumps, or pumps provide information that can be readily converted to a leakage rate. However, signals from other leakage monitoring systems may not be readily converted to a leakage rate. As a result, it is necessary to formulate and provide to the operator methods/techniques for converting the signals from these other leakage monitoring systems to a leakage rate (or programmed into a computer so that the operators have a real-time indication of the leak rate measured by these monitors). In addition, because operating conditions may influence some of these methods/techniques, the procedures should appropriately account for these operating conditions. To ensure continued reliability of the leakage monitoring systems, the equipment used should meet with the standards provided in Section 5.7 of the Institute of Electrical and Electronics Engineers (IEEE) Standard 603-1998, "Criteria for Safety Systems for Nuclear Power Generating Stations" (Ref. 5), for tests and calibration.

## **Seismic Qualification**

Because nuclear power plants may be operating at the time an earthquake occurs and may continue to operate after an earthquake ceases, it is prudent that the functionality of the leakage detection systems during and after an earthquake be assured. If a seismic event comparable to a safe-shutdown earthquake (SSE) occurs, it would be important for the operator to quickly assess the condition within the containment. At least one leakage monitoring system should be capable of evaluating the magnitude of any leakage that may develop in the containment as a result of a seismic event.

## **Leakage Management**

A small amount of unidentified leakage may be impractical to eliminate, but it should be reduced to a very small flow rate, preferably within the lower ranges of the detection sensitivities of the leakage detection and monitoring systems. The guiding principle should be to keep the unidentified leakage to a level that is as low as practical, and to ensure that a small unidentified leakage rate is not masked by a larger, acceptable identified leakage rate.

## **Leakage Monitoring of Risk-Significant Areas in RCS**

Critical components of the RCPB should be monitored for leakage. This will ensure prompt identification of a leak that could potentially compromise safety. "Critical components" are considered to be those that are risk-significant or potentially susceptible to material degradation. In currently operating reactors, the critical RCPB components include, but may not be limited to, the reactor vessel head (RVH), control rod penetration nozzles, pressurizer nozzles, and dissimilar metal weld regions. The critical components may change over time as a result of operating experience, improvements in the understanding of corrosion mechanisms, and mitigative actions (e.g., pipe replacement). Timely identification of the source of leakage is necessary to determine its safety-significance.

## **Capability, Operability, and Availability of Monitoring Instruments**

The leakage monitoring system is important in order to detect potentially adverse conditions. As a result, the system should be capable of detecting leakage in a timely manner and identifying the location of the leak to ensure that the leakage has no adverse safety consequences (i.e., a component or system can continue to function with its required regulatory margins/factors of safety). The capability of the leakage monitoring system includes the overall response time (which includes the transport delay time and detector response time), detector sensitivity and accuracy, the ability to identify the location of the leak, and the operator response to leakage. The capability of the leakage monitoring system should be periodically determined and may need to change (improve) with time (e.g., as a result of the onset of new forms of degradation) to ensure that leakage is effectively managed (i.e., there are no adverse safety consequences associated with leakage). In addition, the capabilities of the leakage monitoring systems should be known for the range of environmental parameters (e.g., temperature, humidity, radiation level) that are expected during plant operation.

Multiple, diverse, and redundant detectors, at various locations in the containment, should be used, as necessary, to ensure that the transport delay time of the leakage from its source to the detector (instrument location) will yield an acceptable overall response time. The overall response time of at least one leakage monitoring system should be sufficient to support leak-before-break (LBB) monitoring (if LBB is approved for the plant), such that sufficient time will be available for operators to place the facility in a safe condition prior to any potential gross structural failure of the leaking component. Under certain circumstances (e.g., to support LBB for smaller-diameter pipes), leakage monitoring system specifications may need to exceed the quantitative criteria in this regulatory guide.

## **Trend Analysis of Leakage Data**

Plant operating experience has shown that significant increases in the leakage rates below the limits set forth in the technical specifications, but above the baseline values, may indicate a potentially adverse condition. Plants should periodically analyze the trend in the unidentified and identified leakage rates. Evaluating the rate of increase in the leakage rates is important in verifying that the plant will continue to be operated within acceptable limits. In addition, the rate of increase in the leakage rate may indicate a potentially adverse condition. As a result, operators should analyze the trend in the unidentified and identified leakage rates to ensure timely response to any adverse trend.

## **Responding to Leakage**

To ensure timely response to leakage, plants should establish a stepwise approach with action levels for responding to leakage. This stepwise approach should include evaluating the data from all leakage monitoring systems to confirm the existence of a leak, identifying possible sources of the leakage (based on operating and maintenance experience), increasing the frequency of verifying/quantifying the leakage rate, performing trend analyses, performing walkdowns outside containment, planning a containment entry, and identifying the source of the leakage (e.g., through containment entry or remote inspections). The frequency of monitoring and verifying the leakage rate should be increased as the leakage rate increases.

Plant procedures should establish time limits for continued plant operation without identifying the source of leakage because the safety-significance of the leakage may not be able to be determined without knowing its source. These time limits should be established to limit (1) the potential for a loss of structural integrity, (2) the accumulation of chemical species that may adversely affect the assumptions in various

design-basis analyses, (3) the contamination of work areas, and (4) the potential for leakage to affect other instruments or components.

During maintenance and refueling outages, efforts should be made to identify the source of any unidentified leakage. In addition, corrective action should be taken to eliminate the condition resulting in the leak. For PWRs, this includes a walkdown of systems and instrumentation lines that contain borated water at the start of outages and during the return to power. This will help ensure that there are no adverse safety consequences associated with the leakage and will permit timely identification of new sources of leakage.

## **C. REGULATORY POSITION**

### **General Positions**

1. The source and location of reactor coolant leakage should be identifiable to the extent practical, and the leakage rate should be established.
2. Leakage to the primary reactor containment from identified sources should be collected or otherwise isolated so that the following criteria are fulfilled:
  - (a) the flow rates are monitored separately from unidentified leakage, and
  - (b) the total flow rate can be established and monitored.
3. Critical components of the RCPB should be monitored for leaks.
4. Provisions should be made to monitor intersystem leakage for systems connected to the RCPB.
5. The capabilities of the leakage monitoring systems should be known. In addition, the capabilities should ensure that leakage is effectively managed.

### **Leakage Monitoring-Related Positions**

6. Leakage to the primary reactor containment from unidentified sources should be collected so that the total flow rate can be detected, monitored, and quantified for flow rates greater than or equal to 0.05 gpm (0.19 lpm).
7. The response time of the instrument(s) used to detect leakage should be 1 gpm (3.8 lpm) in 1 hour, or better.
8. The plant technical specifications should specify at least two independent and diverse instruments and/or methods that have the detection and monitoring capabilities specified above. The methods to consider for inclusion in the technical specifications include, but are not limited to, the following:
  - (a) monitoring sump level and flow, and
  - (b) monitoring airborne particulate radioactivity.

In addition to the monitoring systems specified in the technical specifications, others should be used to detect and monitor for leakage (even if they do not have the capabilities specified above). These supplemental instruments/methods may include, but are not limited to, the following:

- (a) monitoring condensate flow rate from air coolers,
  - (b) monitoring airborne gaseous radioactivity,
  - (c) monitoring humidity of the containment,
  - (d) monitoring temperature of the containment,
  - (e) monitoring pressure of the containment,
  - (f) monitoring acoustic emission, and
  - (g) conducting video surveillance.
9. At least one of the leakage monitoring systems required by the plant technical specifications (as described in Regulatory Position 8) should be capable of performing its function(s) following any seismic event that does not require plant shutdown. In addition, if LBB is approved for the facility, the overall response time of at least one leakage monitoring system should be consistent with the assumptions made and specifications associated with the LBB approval.
10. The leakage monitoring systems, including those with location capability, should be equipped with provisions to permit calibration and testing during plant operation to ensure functionality or operability, as appropriate.

### **Operations-Related Positions**

11. Plants should periodically analyze the trend in the unidentified and identified leakage rates. When the leakage rate increases noticeably from the baseline leakage rate, the safety-significance of the leak should be evaluated. The rate of increase in the leakage rate should be determined to verify that plant actions can be taken before technical specification limits are exceeded.
12. Procedures should be established to describe the plant's response to leakage. These procedures should address the following considerations, and should ensure that no adverse safety consequences result from the leakage.
- (a) Specify operator actions in response to leakage rates less than the limits set forth in the plant technical specifications. Include actions for confirming the existence of a leak, identifying its source, increasing the frequency of monitoring and verifying the leakage rate (through a water inventory balance), responding to trends in the leakage rate, performing a walkdown outside containment, planning a containment entry, adjusting alarm set points, limiting the amount of time that operation is permitted without identifying the sources of the leakage, and determining the safety-significance of the leakage.

- (b) Specify the amount of time the leakage detection and monitoring instruments (other than those required by technical specifications) may be out of service to ensure that the leakage rate is effectively monitored during all phases of plant operation (i.e. hot-shutdown, hot-standby, startup, transients, and power operation).
  - (c) Plant procedures should establish time limits for continued plant operation without identifying the source of leakage.
13. Output and alarms from leakage monitoring systems should be provided in the main control room. Procedures for converting the instrument output to a leakage rate should be readily available to the operators. (Alternatively, these procedures could be programmed into a computer so that the operators have a real-time indication of the leakage rate as determined from the output of these monitors.) Leakage monitoring systems should be periodically calibrated and tested. The alarm should provide operators an early warning signal so that actions can be taken, as discussed in Regulatory Position 12.
14. During maintenance and refueling outages, efforts should be made to identify the source of any unidentified leakage. In addition, corrective action should be taken to eliminate the condition resulting in the leakage.

#### **Technical Specification Position**

15. The technical specifications should include the limiting conditions for identified, unidentified, RCPB, and intersystem leakage, and should address the availability of various types of instruments to ensure adequate coverage during all phases of plant operation.

### **D. IMPLEMENTATION**

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this draft regulatory guide. No backfit is intended or approved in connection with its issuance.

The NRC has issued this draft guide to encourage public participation in its development. Except in those cases in which an applicant or licensee proposes or has previously established an acceptable alternative method for complying with specified portions of the NRC's regulations, the methods to be described in the active guide will reflect public comments and will be used in evaluating (1) submittals in connection with applications for construction permits, standard plant design certifications, operating licenses, early site permits, and combined licenses; and (2) submittals from operating reactor licensees who voluntarily propose to initiate system modifications if there is a clear nexus between the proposed modifications and the subject for which guidance is provided herein.

# REGULATORY ANALYSIS

## 1. Statement of the Problem

The U.S. Atomic Energy Commission (AEC) issued the original version of Regulatory Guide 1.45, “Reactor Coolant Pressure Boundary Leakage Detection Systems” (Ref. 6), in May 1973 to provide guidance on acceptable methods to detect leakage and the selection of leakage detection systems for the RCS. The criterion used in that version of this guide (and proposed for use in Revision 1), is that the leakage detection systems should be capable of detecting a leakage rate of 1 gpm (3.8 lpm) in 1 hour. However, improved leakage monitoring systems are now available. Operating plants are monitoring leakage rates at substantially below 1 gpm (3.8 lpm), and typically take actions before technical specification limits are exceeded. Although the regulatory position in the original version of Regulatory Guide 1.45 was based on the instrument capabilities at the time, together with then-current insights regarding the leakage rate from a critical-sized flaw, subsequent operating experience and analyses have shown that there are safety concerns associated with leakage rates at substantially below 1 gpm (3.8 lpm). For example, for PWRs, boric acid corrosion can cause substantial material degradation and wastage even at very low levels of prolonged RCS leakage. Therefore, revision to this regulatory guidance is necessary to include updated information.

## 2. Objective

The objective of this regulatory action is to update the NRC’s guidance with respect to determining the RCS leakage rate and, the sensitivity and accuracy needed for detection systems to monitor low levels of leakage, conducting trend analyses of the leakage rates, and taking graded actions on observing any adverse trend in the leakage rate. This updated guidance will give applicants and licensees the opportunity to take early corrective actions, which should lead to increased regulatory effectiveness.

## 3. Alternative Approaches

The NRC staff considered the following alternative approaches to the problem of outdated guidance regarding RCS leakage detection:

- (1) Do not revise Regulatory Guide 1.45.
- (2) Update Regulatory Guide 1.45.

### 3.1 Alternative 1: Do Not Revise Regulatory Guide 1.45

Under this alternative, the NRC would not revise this guidance, and licensees would continue to use the original version of this regulatory guide. This alternative is considered the baseline or “no action” alternative and, as such, involves no value/impact considerations.

### 3.2 Alternative 2: Update Regulatory Guide 1.45

Under this alternative, the NRC would update Regulatory Guide 1.45, taking into consideration the advances in leakage detection and operating experience, potential for boric acid corrosion at low leakage rates for prolonged periods, the industry’s efforts to develop standard guidelines for response to low-levels of detected leakage, and the capability of existing leakage detection systems to detect leaks at rates below 0.1 gpm (0.38 lpm). The revised guidance will also clarify the terminology used for leakage detection and

measurement and provide guidance on the use of gaseous radiation detectors, which have proven to be less useful with better fuel cladding.

One benefit of this action is that it would enhance reactor safety by properly considering the RCS component degradation mechanisms, including corrosion and wastage, and more timely intervention, when these mechanisms are determined to be safety-significant. Although there may be some minor incremental costs associated with this action, any increase should be offset by the safety benefit and the potential improvement in operational performance (e.g., through the use of on-line monitors for locating the source of leakage during operation and preventing significant degradation of critical components).

The costs to the NRC would be the one-time cost of issuing the revised regulatory guide (that is, relatively small), and applicants and licensees would incur minor incremental costs that would be offset by the safety benefit and the potential improvement in operational performance.

#### **4. Conclusion**

Based on this regulatory analysis, the staff recommends that the NRC should revise Regulatory Guide 1.45. The staff concludes that the proposed action will enhance reactor safety by properly considering the RCS component degradation mechanisms, including corrosion and wastage. It could also lead to cost savings for the industry, especially with regard to applications for standard plant design certifications and combined licenses.

## REFERENCES

1. *U.S. Code of Federal Regulations*, Title 10, *Energy*, Part 50, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.<sup>3</sup>
2. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," American Society of Mechanical Engineers, New York, NY, 1992.<sup>4</sup>
3. NUREG/CR-6861, "Barrier Integrity Research Program: Final Report," Kupperman, D.S., et al., prepared by Argonne National Laboratory for the U.S. Nuclear Regulatory Commission, Washington, DC, December 2004.<sup>5</sup>
4. Information Notice (IN) 2005-24, "Nonconservatism in Leakage Detection Sensitivity," U.S. Nuclear Regulatory Commission, Washington, DC, August 3, 2005.<sup>6</sup>
5. IEEE Std 603-1998, "Criteria for Safety Systems for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers, Piscataway, NJ, 1995.<sup>7</sup>

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<sup>3</sup> All NRC regulations listed herein are available electronically through the Public Electronic Reading Room on the NRC's public Web site, at <http://www.nrc.gov/reading-rm/doc-collections/cfr/>. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; email [PDR@nrc.gov](mailto:PDR@nrc.gov).

<sup>4</sup> Copies may be purchased from the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990; phone (212) 591-8500; fax (212) 591-8501; [www.asme.org](http://www.asme.org).

<sup>5</sup> All NUREG-series reports listed herein were published by the U.S. Nuclear Regulatory Commission. Most are available electronically through the Public Electronic Reading Room on the NRC's public Web site, at <http://www.nrc.gov/reading-rm/doc-collections/nuregs/>. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; email [PDR@nrc.gov](mailto:PDR@nrc.gov). In addition, copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328, telephone (202) 512-1800; or from the National Technical Information Service (NTIS), at 5285 Port Royal Road, Springfield, Virginia 22161, online at <http://www.ntis.gov>, by telephone at (800) 553-NTIS (6847) or (703)605-6000, or by fax to (703) 605-6900.

<sup>6</sup> Information Notice (IN) 2005-24 is available electronically through the Public Electronic Reading Room on the NRC's public Web site, at <http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/2005/in200524.pdf>. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; email [PDR@nrc.gov](mailto:PDR@nrc.gov).

<sup>7</sup> Copies may be obtained from the Institute of Electrical and Electronics Engineers, Inc., IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855.

6. Regulatory Guide 1.45, "Reactor Coolant Pressure Boundary Leakage Detection Systems," U.S. Nuclear Regulatory Commission, Washington, DC.<sup>8</sup>
7. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)," Chapter 3, "Design of Structures, Components, Equipment, and Systems," Section 3.6.3, "Leak-Before-Break Evaluation Procedures," U.S. Nuclear Regulatory Commission, Washington, DC.<sup>5</sup>

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<sup>8</sup> Regulatory Guide 1.45 is available electronically through the Public Electronic Reading Room on the NRC's public Web site, at <http://www.nrc.gov/reading-rm/doc-collections/reg-guides/power-reactors/active/>. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room (PDR), which is located at 11555 Rockville Pike, Rockville Maryland; the PDR's mailing address is USNRC PDR, Washington, DC 20555-0001. The PDR can also be reached by telephone at (301) 415-4737 or (800) 397-4209 by fax at (301) 415-3548, and by email to [PDR@nrc.gov](mailto:PDR@nrc.gov).

## BIBLIOGRAPHY

“ASME Codes on Continuous Acoustic Emission,” ASME B&PV Code, Section V, Article 13, Appendix E,” American Society of Mechanical Engineers, New York, NY, 2001.<sup>9</sup>

Chu, S., “Materials Reliability Program: Survey of Online PWR Primary Coolant Leak Detection Technologies (MRP-187),” EPRI Report #1012947, Electric Power Research Institute, Palo Alto, CA, November 2005.<sup>10</sup>

Crane, S., and W.H. Cullen, Jr., “Survey of Boric Acid Corrosion Events,” Revision 9, U.S. Nuclear Regulatory Commission, Washington, DC, October 22, 2004 (available in ADAMS under Accession #ML043000274).

Cullen, W.H., Jr., and T. Mintz,, “A Survey of Worldwide Experience With the Cracking Susceptibility of Alloy 600 and Associated Welds,” U.S. Nuclear Regulatory Commission, Washington, DC, 2004 (available in ADAMS under Accession #ML040910354).

“Davis-Besse Reactor Vessel Head Degradation Lessons-Learned Task Force Report,” U.S. Nuclear Regulatory Commission, Washington, DC, 2002 (available in ADAMS under Accession #ML022760414).

Hunt, E.S., “Boric Acid Corrosion Guidebook, Revision 1: Managing Boric Acid Corrosion Issue at PWR Power Stations,” EPRI Report #1000975, Electric Power Research Institute, Palo Alto, CA, November 2001.<sup>11</sup>

IAEA-TECDOC-1361, “Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Primary Piping in PWRs,” International Atomic Energy Agency, Vienna, Austria, July 2003.<sup>12</sup>

ISA-S67.03-1982, “Standard for Light-Water Reactor Coolant Pressure Boundary Leak Detection,” Instrument Society of America, Durham, NC, 1982.<sup>13</sup>

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<sup>9</sup> Copies may be obtained from the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990; phone (212) 591-8500; fax (212) 591-8501; [www.asme.org](http://www.asme.org).

<sup>10</sup> Copies may be obtained from EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520.

<sup>11</sup> Copies may be obtained from EPRI Customer Fulfillment, 1355 Willow Way, Suite 278, Concord, CA 94520.

<sup>12</sup> Available through the IAEA public Web site at [http://www-pub.iaea.org/MTCD/publications/PDF/te\\_1361\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/te_1361_web.pdf).

<sup>13</sup> This standard is available from the ISA Web site at [http://www.isa.org/Template.cfm?Section=Shop\\_ISA&Template=/Ecommerce/ProductDisplay.cfm&Productid=2614](http://www.isa.org/Template.cfm?Section=Shop_ISA&Template=/Ecommerce/ProductDisplay.cfm&Productid=2614).

Jax, P., “Leak Detection and Monitoring,” *Proceedings of the Joint CSNI/CNRA Workshop on Redefining the Large Break LOCA: Technical Issues and Its Implications, Zurich, Switzerland, June 23–24, 2003*, NEA/CSNI/R(2003)17/VOL2, Nuclear Energy Agency, Issy-les-Moulineaux, France, August 27, 2003.<sup>14</sup>

Kunze, U., and B. Bechtold, “New Generation of Monitoring Systems with Online Diagnostics,” *Progress in Nuclear Energy*, Vol. 29, No. 3/4, pp 215–227, Elsevier, Inc., New York, NY, 1995.<sup>15</sup>

Rahman, S., F.W. Brust, N. Ghadiali, and G.M. Wilkowski, “Crack-Opening-Area Analyses for Circumferential Through-Wall Cracks in Pipes — Part I: Analytical Models,” *International Journal of Pressure Vessels and Piping*, Vol. 75, pp. 357–373, Elsevier, Inc., New York, NY, 1998.<sup>16</sup>

Rahman, S., F.W. Brust, N. Ghadiali, and G.M. Wilkowski, “Crack-Opening-Area Analyses for Circumferential Through-Wall Cracks in Pipes — Part II: Model Validations,” *International Journal of Pressure Vessels and Piping*, Vol. 75, pp. 375–396, Elsevier, Inc., New York, NY, 1998.<sup>16</sup>

Rahman, S., N. Ghadiali, G.M. Wilkowski, F. Moberg, F., and B. Brickstad, “Crack-Opening-Area Analyses for Circumferential Through-Wall Cracks in Pipes — Part III: Off-Centered Cracks, Restraint of Pressure-Induced Bending, Thickness Transition, and Weld Residual Stresses,” *International Journal of Pressure Vessels and Piping*, Vol. 75, pp. 397–415, Elsevier, Inc., New York, NY, 1998.<sup>16</sup>

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<sup>14</sup> The proceedings are available electronically through the Nuclear Energy Agency’s public Web site at <http://www.nea.fr/html/nsd/docs/2003/csni-r2003-17-vol2.pdf>.

<sup>15</sup> This journal is available for purchase through the Elsevier Web site at [http://www.elsevier.com/wps/find/journaldescription.cws\\_home/478/description#description](http://www.elsevier.com/wps/find/journaldescription.cws_home/478/description#description).

<sup>16</sup> The *International Journal of Pressure Vessels and Piping* is available for purchase through the Elsevier public Web site at [http://www.elsevier.com/wps/find/journalbibliographicinfo.cws\\_home/405900/description#bibliographicinfo](http://www.elsevier.com/wps/find/journalbibliographicinfo.cws_home/405900/description#bibliographicinfo).

## APPENDIX A

### GLOSSARY OF TERMS USED IN LEAKAGE RATE MONITORING

The staff engaged in several in-depth discussions to define and clarify the measurement terms used in reactor coolant leakage monitoring and requirements. Earlier definitions are often not clear and, therefore, the staff attempted to research these terms and clarify their meanings and applicability to leakage detection. The following terminology is used throughout this document:

**accuracy:** The degree of conformity of the measured (indicated) leakage rate and the accepted true leakage rate.

**background leakage:** Very low leakage rates that exist following inspections that are intended to identify the source of any leakage. Normally, the background leakage rate should be zero (or below the threshold of detection for the instrument).

**capability:** The minimum leakage rate that can be measured within the accuracy and sensitivity requirements in a specified duration.

**critical area:** The portions of the RCPB that could potentially degrade and leak as a result of the interaction of the material with its environment. A critical area also includes risk-significant components.

**critical component:** A component within the containment that (1) may degrade as a result of its interaction with the environment, or (2) is risk-significant.

**critical flaw size** (or critical flaw or critical-sized flaw): The maximum flaw size that can exist in a component without compromising its structural integrity. In this context, structural integrity is defined as having margin to failure consistent with the original design objectives of the component for the range of operating conditions (including the full range of normal operating, transient, upset, and faulted conditions). This includes the loading conditions associated with design-basis accidents and combinations of accidents (e.g., loss-of-coolant accident and safe shutdown earthquake) included in the design and licensing bases. In addition, the critical flaw size should consider changes in material properties over time. Ideally, the leakage rate limit would be below the leakage rate from the most limiting critical flaw size.

**identified leakage:** Leakage (1) into closed systems, such as pump seal or valve packing leaks that are captured, flow-metered, and conducted to a sump or collecting tank; (2) into the containment atmosphere from sources that are both specifically located and known either not to interfere with operation of unidentified leakage monitoring systems or not to be from a flaw in the RCPB; or (3) intersystem leakage from the RCPB to other systems across passive barriers or valves [e.g., primary-to-secondary leakage in pressurized water reactors (PWRs)].

**instrument response time:** The amount of time that a detection instrument takes to process the input signal and display or otherwise present the measured leakage rate.

**leak-before-break (LBB):** A component integrity analysis procedure, as described in Section 3.6.3, “Leak-Before-Break Evaluation Procedures,” of NUREG-0800, “Standard Review Plan [SRP] for the Review of Safety Analysis Reports for Nuclear Power Plants” (Ref. 7).

**leakage rate:** The volume of leakage divided by the duration (time) over which the leakage accumulated. Leakage rate is usually expressed as gallons per minute (gpm) or liters per minute (lpm).

**overall response time:** The maximum amount of time from the start of a leak until the leakage detection instrument/method indicates that the specific leakage rate is occurring. The overall response time includes the transport delay time and instrument response time.

**sensitivity:** The ability to measure a specific leakage rate (usually a minimum leakage rate) with a required (or specified) accuracy. The sensitivity of a leakage monitoring instrument indicates how well the instrument is capable of measuring small changes in leakage rate and providing a corresponding output with a specific accuracy. Depending upon the type of instrument (e.g., one that measures the change in radioactivity, humidity, acoustic noise, etc., with respect to the background), the sensitivity may vary, depending on factors such as flow rate. Usually, the sensitivity of a leakage detection instrument is low at very low leakage rates and high at relatively high leakage rates.

**transport delay time:** The period of time required for the leakage to travel from the source to the detection site of the instrument.

**rending:** Recording and documenting the observed leakage rate over a period of time.

**trend analysis:** Any statistical analysis of the leakage rate data over an interval of time to identify the onset and continuation of any trend in leakage rate.

**unidentified leakage:** Leakage into the containment that is not classified as identified leakage.