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REACTOR COOLANT PRESSURE BOUNDARY LEAKAGE DETECTION SYSTEMS

A. INTRODUCTION

General Design Criterion 30, "Quality of Reactor Coolant Pressure Boundary," of Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," requires that means be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage. This guide describes acceptable methods of implementing this requirement with regard to the selection of leakage detection systems for the reactor coolant pressure boundary. This guide applies to light-water-cooled reactors. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

The safety significance of leaks from the reactor coolant pressure boundary (RCPB) can vary widely depending on the source of the leak as well as the leakage rate and duration. Therefore, the detection and monitoring of leakage of reactor coolant into the containment area is necessary. In most cases, methods for separating the leakage from an identified source from the leakage from an unidentified source are necessary to provide prompt and quantitative information to the operators to permit them to take immediate corrective action should a leak be detrimental to the safety of the facility. Identified leakage is: (1) leakage into closed systems, such as pump seal or valve packing leaks that are captured, flow metered, and conducted to a sump or collecting tank, or (2) leakage into the containment atmosphere from sources that are both specifically located and known either not to interfere with the operation of unidentified leakage monitoring systems or not to be from a flaw in the RCPB. Unidentified leakage is all other leakage.

Leakage Separation

A limited amount of leakage is expected from the RCPB and from auxiliary systems within the containment such as from valve stem packing glands, circulating pump shaft seals, and other equipment that cannot practically be made 100% leaktight. The reactor vessel closure seals and safety and relief valves should not leak significantly; however, if leakage occurs via these paths or via pump and valve seals, it should be detectable and collectable and, to the extent practical, isolated from the containment atmosphere so as not to mask any potentially serious leak should it occur. These leakages are known as "identified leakage" and should be piped to tanks or sumps so that the flow rate can be established and monitored during plant operation.

Uncollected leakage to the containment atmosphere from sources such as valve stem packing glands and other sources that are not collected 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 where the flow rate can be established and monitored during plant operation. A small amount of unidentified leakage may be impractical to eliminate, but it should be reduced to a small flow rate, preferably less than one gallon per minute (gpm), to permit the leakage detection systems to detect positively and rapidly a small increase in flow rate. Thus a small unidentified leakage rate that is of concern will not be masked by a larger acceptable identified leakage rate.

Substantial intersystem leakage from the RCPB to other systems across passive barriers or valves is not expected. However, should such leakage occur, it may not be detectable through the above-mentioned detection systems, and other alarm and detection methods should be employed. For example, steam generator leakage in pressurized water reactors (PWR's) should be monitored to detect tube or tube sheet leaks.

Acceptable Detection Methods

Although monitoring of both identified and unidentified leakage is important, effective systems for detecting and locating unidentified leakage are also needed. The following paragraphs describe some acceptable detection methods.

In addition to monitoring flow rate changes to tanks and sumps for liquid collection, other methods should be included to indicate when and where coolant is released to the containment atmosphere. For example, these additional detection methods would indicate and/or monitor changes in:

a. airborne particulate radioactivity,
b. airborne gaseous radioactivity,
c. containment atmosphere humidity,
d. containment atmosphere pressure and temperature,
e. condensate flow rate from air coolers.

Since intersystem leakage does not release reactor coolant to the containment atmosphere, detection methods should include monitoring of water radioactivity in the connected systems where the systems flows through the containment boundary, and monitoring of airborne radioactivity where such systems are vented outside the containment boundary. Another important method of obtaining indications of uncontrolled or undesirable intersystem flow would be the use of a water inventory balance, designed to provide appropriate information such as abnormal water levels in tanks and abnormal water flow rates.

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

While the above-mentioned leakage detection systems reflect the present state of technology, it is recognized that other detection methods may be developed and used in order to obtain operating experience with them. Among such methods are sonic indicators and moisture sensitive tapes applied to RCPB component parts. Because of the potential importance of early leak detection in the prevention of accidents, continued improvements in leakage detection and locating techniques should be sought.

It is not necessary that all of the above-mentioned leakage detection methods or systems be employed in a specific nuclear power plant. However, since the methods differ in sensitivity and response time, prudent selection of detection methods should include sufficient systems to assure effective monitoring during periods when some detection systems may be ineffective or inoperable. Some of these systems should serve as early alarm systems signaling the operators that closer examination of other detection systems is necessary to determine the extent of any corrective action that may be required.

Detector Sensitivity

It is essential that leakage detection systems have the capability to detect significant RCPB degradation as soon after occurrence as practical to minimize the potential for a gross boundary failure. It is possible that some cracks might develop and penetrate the RCPB wall, exhibit very slow growth, and afford ample time for a safe and orderly plant shutdown after a leak is detected. On the other hand, leakage such as that resulting from stress-assisted corrosion in stainless steel or from a flaw at a high fatigue point in the RCPB would demand rapid detection and probable plant shutdown. Therefore, an early warning signal is necessary to permit proper evaluation of all unidentified leakage.

Industry practice has shown that water flow rate changes of from 0.5 to 1.0 gpm can readily be detected in containment sumps by monitoring changes in sump water level, in flow rate, or in the operating frequency of pumps. Sumps and tanks used to collect unidentified leakage and air cooler condensate should be instrumented to alarm for increases of from 0.5 to 1.0 gpm in the normal flow rates. This sensitivity would provide an acceptable performance for detecting increases in unidentified liquid leakage by this method.

An increase in humidity of the containment atmosphere would indicate release of water vapor to the containment. Dew point temperature measurements can be used to monitor humidity levels of the containment atmosphere. A 1° increase in dew point is well within the sensitivity range capability 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 to 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.

Reactor coolant normally contains sources of radiation which, when released to the containment, can be detected by the monitoring systems. However, reactor coolant radioactivity should be low during initial reactor startup and for a few weeks thereafter until activated corrosion products have been formed and fission products become available from failed fuel elements; during this period, radioactivity monitoring instruments may be of limited value in providing an early warning of very small leaks in the RCPB. Instrument sensitivities of 10^{-9} μCi/cc radioactivity for air particulate monitoring and of 10^{-6} μCi/cc radioactivity for radiogas monitoring are practical for these leakage detection systems. Radioactivity monitoring systems should be included for every plant (especially particulate activity monitoring) because of their sensitivity and rapid response to leaks from the RCPB.

Air temperature and pressure monitoring methods may also be used to infer RCPB leakage to the containment. Containment temperature and pressure fluctuate slightly during plant operation, but a rise above the normally indicated range of values may indicate RCPB leakage into the containment. The accuracy and relevance of temperature and pressure measurements is a function of containment free volume and detector location. Alarm signals from these instruments can be valuable in recognizing rapid and sizable energy releases to the containment.

While the concern about instrument sensitivity applies to the lower range of service for which the instruments are selected, the upper instrument range limits should be established to prevent exceeding the saturation limits of instruments, thus making them useless as indicators of containment conditions.

Detector Response Time

The need to evaluate the severity of an alarm or indication is important to the operators, and the ability to compare with indications from other systems is necessary. The system response time should therefore be included in the functional requirements for leakage detection systems. Except for the limitations during the initial few weeks of plant operation as discussed previously, all detector systems should respond to a one gpm, or its equivalent, leakage increase in one hour or less. Multiple instrument locations in monitored areas should be utilized if necessary to assure that the transport delay time of the leakage effluent from its source to the detector or instrument location will yield an acceptable overall response time. A useful technique in identifying the general location of a leakage area is the placing of several sensors within the containment area and observing differences in response from the sensors, and this technique should be used to satisfy this requirement of General Design Criterion 30.

In analyzing the sensitivity of leak detection systems using airborne particulate or gaseous radioactivity, a realistic primary coolant radioactivity concentration assumption should be used. The expected values used in the plant environmental report would be acceptable.

Signal Correlation and Calibration

It is important to be able to associate a signal or indication of a change in the normal operating conditions with a quantitative leakage flow rate. Except for flow rate or level change measurements from tanks, sumps, or pumps, signals from other leakage detection systems do not provide information readily convertible to a common denominator. Approximate relationships converting these signals to units of water flow should be formulated to assist the operator in interpreting signals. Since operating conditions may influence some of the conversion procedures, the procedures should be revised during such periods. To assure the continued reliability of the leakage detection systems, the equipment should comply with Paragraph 4.10 of IEEE Std. 279-1971, "Criteria for Protection Systems for Nuclear Power Generating Stations,"[1] for tests and calibration.

Seismic Qualification

Since nuclear power plants may be operating at the time an earthquake occurs and may continue to operate after earthquakes, it is prudent to require the leakage detection systems to function under the same conditions. If a seismic event comparable to a safe shutdown earthquake (SSE) occurs, it would be important for the operator to assess the condition within the containment quickly. The proper functioning of at least one leakage detection system would assist in evaluating the seriousness of the condition within the containment in the event leakage has developed in the RCPB. The airborne particulate radioactivity monitoring equipment has the desirable sensitivity to indicate RCPB leakage, and it should be included for all plants. Components for the airborne particulate radioactivity equipment should be qualified to function through the SSE.

C. REGULATORY POSITION

The source of reactor coolant leakage should be identifiable to the extent practical. Reactor coolant pressure boundary leakage detection and collection systems should be selected and designed to include the following:

1. Leakage to the primary reactor containment from identified sources should be collected or otherwise isolated so that:
   a. the flow rates are monitored separately from unidentified leakage, and
   b. the total flow rate can be established and monitored.

2. Leakage to the primary reactor containment from unidentified sources should be collected and the flow

[1] Copies may be obtained from the Institute of Electrical and Electronics Engineers, United Engineering Center, 345 East 47th Street, New York, N.Y. 10017.

rate monitored with an accuracy of one gallon per minute (gpm) or better.

3. At least three separate detection methods should be employed and two of these methods should be (1) sump level and flow monitoring and (2) airborne particulate radioactivity monitoring. The third method may be selected from the following:

a. monitoring of condensate flow rate from air coolers,

b. monitoring of airborne gaseous radioactivity.

Humidity, temperature, or pressure monitoring of the containment atmosphere should be considered as alarms or indirect indication of leakage to the containment.

4. Provisions should be made to monitor systems connected to the RCPB for signs of intersystem leakage. Methods should include radioactivity monitoring and indicators to show abnormal water levels or flow in the affected area.

5. The sensitivity and response time of each leakage detection system in regulatory position 3. above employed for unidentified leakage should be adequate to detect a leakage rate, or its equivalent, of one gpm in less than one hour.

6. The leakage detection systems should be capable of performing their functions following seismic events that do not require plant shutdown. The airborne particulate radioactivity monitoring system should remain functional when subjected to the SSE.

7. Indicators and alarms for each leakage detection system should be provided in the main control room. Procedures for converting various indications to a common leakage equivalent should be available to the operators. The calibration of the indicators should account for needed independent variables.

8. The leakage detection systems should be equipped with provisions to readily permit testing for operability and calibration during plant operation.

9. The technical specifications should include the limiting conditions for identified and unidentified leakage and address the availability of various types of instruments to assure adequate coverage at all times.