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RELIABILITY EVALUATION OF THE SAVANNAH RIVER REACTOR LEAK DETECTION SYSTEM (U)

by

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Abstract

The Savannah River Reactors have been in operation since the mid-1950's. The primary degradation mode for the primary coolant loop piping is intergranular stress corrosion cracking. The leak-before-break (LBB) capability of the primary system piping has been demonstrated as part of an overall structural integrity evaluation. One element of the LBB analyses is a reliability evaluation of the leak detection system.

The most sensitive element of the leak detection system is the airborne tritium monitors. The presence of small amounts of tritium in the heavy water coolant provide the basis for a very sensitive system of leak detection. The reliability of the tritium monitors to properly identify a crack leaking at a rate of either 50 or 300 lb/day (0.004 or 0.023 gpm, respectively) has been characterized. These leak rates correspond to action points for which specific operator actions are required. High reliability has been demonstrated using standard fault tree techniques. The probability of not detecting a leak within an assumed mission time of 24 hours is estimated to be approximately 5 x 10^{-5} per demand. This result is obtained for both leak rates considered. The methodology and assumptions used to obtain this result are described in this paper.

Introduction

The primary coolant piping of the Savannah River Site (SRS) reactors is Type 304 stainless steel and, like BWR piping, has a history of occasional leaks due to intergranular stress corrosion cracking (IGSCC). However, unlike BWRs which have a high energy primary coolant system, the SRS reactors operate at a low temperature and pressure. The low pressure leads to relatively low leakage rates for a given size crack; but on the other hand it also provides a high tolerance for very long cracks with corresponding high leak rates without leading to pipe rupture. The presence of small amounts of tritium in the D_2O coolant (in the form of DTO) is the basis for a very sensitive leak detection system.

As part of the structural integrity demonstration of the primary coolant system, the piping failure frequency has been estimated [1]. Since the primary degradation mechanism for the piping is IGSCC, and such cracks preferentially grow throughwall, the reliability of the leak detection system is a key element of the failure frequency estimate. Once a crack has grown throughwall, the ensuing leakage serves as a warning to its presence. The ability to detect small amounts of leakage with high reliability greatly enhances confidence in identifying the presence of cracks before they grow further to the point of threatening a sudden rupture.

Additionally, the performance of the leak detection system is relied upon in demonstrating the leak-before-break capability of the primary coolant system. This demonstration includes the calculation of safety margins for postulated flaws of a size that assures detection so as to lead to a safe and orderly reactor shutdown. In this regard, key leakage response levels are an instantaneous leakage rate of 50 lb/day (0.004 gpm), and a cumulative leakage of 96 lb in a 24 hour period. The first response level requires various actions to locate the source of leakage and requires reactor shutdown only if the source is confirmed as an abnormal breach of the pressure boundary. The second response level requires reactor shutdown regardless of leakage source.

System Description

Two types of tritium monitors are used in each of the SRS reactors. The Stack Tritium Monitors (STMs) consist of two gas flow-through ionization chambers. Both chambers sample the exhaust stream air; however, the stream going to one of the chambers is dried with silica gel. Both chambers therefore respond to elemental tritium, while the wet stream also measures tritiated water vapor. By taking the difference in the outputs of the two chambers, the amount of tritiated water vapor (and hence the amount of leakage) is determined.

The second type of monitor, the Berthold Tritium Monitor (BTM) employs a pulse rise time discriminator with a gas flow-through proportional counter to identify tritium activity. The BTM can therefore identify gaseous tritium as well as tritiated water vapor.

Both the STMs and BTMs are extremely sensitive, being able to identify coolant losses as low as 12 lb/day and 1 lb/day (0.001 and 0.00008 gpm), respectively. Normal operating losses from the system are on the order of 20 lb/day. Hence, the tritium monitors are easily capable of identifying leakage losses of 50 lb/day or more against the background of normal operating losses.

In addition to the tritium monitors, two other systems are available which have sufficient sensitivity to detect leakage of 50 lb/day. The Kanne vacuum system consists of several radiation detector units, each of which is available to sample airstreams drawn from the reactor areas. Since the Kanne chambers respond to any radioactive gas and do not draw a quantified air stream from a known volume, they are of limited use in quantifying the leakage rate. Therefore, the Kanne chambers serve primarily for leak location, since they can sample from very localized areas. Also used for leak location are a number of closed circuit television cameras located throughout the reactor areas. While the cameras cannot view all the primary coolant piping, leakage from those areas they can access can be identified visually.

Reliability Study

For this reliability study, a mission time of 24 hours was assumed for the following two cases:

1) A leakage rate of 50 lb/day, and

2) A leakage rate of 300 lb/day.

These two cases describe cases of leakage less than and greater than the response level of 96 lb leakage in a 24 hour period. For the first case, both leak detection and leak location are required for success. The second case requires only leak detection for success. The 24 hour mission time also is sufficiently short as to provide high confidence that no significant crack growth will occur during this period.

Figure 1 provides a simplified flow diagram of the key elements of the leak detection system that were reviewed. Exhaust streams from four operating areas (-40', 0' near side, 0' far side and purification) combine to form the 148' exhaust stream which exits the building. Leaks in the primary coolant boundary can enter the -40' and 0' exhaust streams. Therefore, heavy water losses known to come from purification are not attributable to leakage of the primary pressure boundary. Technical Specifications require one BTM dedicated to the 148' exhaust, while at least 2 of the remaining 5 tritium monitors must be on-line during operation. One of these additional two monitors must also monitor the 148' exhaust.

As one can see in Figure 1, a number of potential failure sources exists. For example, if the ventilation system failed to draw air from the reactor areas, leakage could not be detected. This could result from failure of the exhaust fans or failure of the exhaust ductwork in the form of inadvertent damper closure. Additionally, failure of the sample lines, sample pumps or associated isolation valves could prevent the air sample from reaching the tritium monitors.

More tritium monitors are installed in each reactor building than needed for operation, and any of the extra monitors can be used to sample any of the reactor areas. Monitor failure can result from the individual failure of each monitor or from common mode failure of all monitors. For example, loss of the P-10 counting gas can fail all three BTMs. Loss of electric power will fail all six tritium monitors. Additional details used in developing the fault tree for each case are as follows:

1) Since the BTMs are newer than the STMs, they are considered more reliable.

2) The data processing system for the BTMs consists of the LB 1001 computer and the count rate meter / recorder. Failure of both of these components fails the three BTMs.

3) The data recording system for the STMs consists of an electrometer (amplifier), a recorder and an integrator. Failure of both the recorder and integrator, or the electrometer alone, fails the three STMs.

4) The leak location equipment consists of the CCTV electronics, the CCTV cameras and Kanne monitors. Failure of these components constitutes a failure to locate leakage in a particular area. Although there are several cameras in the system, no credit is taken for overlap in the viewing areas.

5) Failure of the ductwork in the vicinity of a small leak also constitutes a failure to locate the leak. The purification area is excluded since a leak in that area does not reflect on the primary coolant system structural integrity.

6) BTMs, STMs, pumps, fans and instrumentation are powered by common power supplies. The BTMs are also powered by a separate high voltage power supply, as are the Kanne chambers.

7) Operator error can fail the leak detection system, even with all equipment properly functioning. Three shifts are on duty over a given 24 hour period. The second and third shift operators are partially dependent on the previous shifts and are therefore assumed to be less reliable. Similarly, day supervision is partially dependent on shift operator actions.

8) All equipment is assumed to be properly calibrated and operational.

Failure rate estimates are obtained from several sources. For the various electrical and mechanical components, industry compilations were used [2,3]. Such components include radiation detectors, amplifiers, recorders, control computer, sample pumps and valves, fans and ductwork. The rate for the loss of site power was derived from SRS site-specific experience. The loss of power scenario includes both the initial loss of power and the failure to restore power within 24 hours through corrective actions. The human error frequencies are based on screening values developed as part of the SRS probabilistic risk assessment (PRA). These frequencies were derived using the THERP (Technique for Human Error Rate Prediction) methodology, with site-specific judgment used for the dependencies between operators and between operators and day supervision. A summary of the failure probabilities, as input to the fault tree, is provided in Table 1.

The system logic described above was translated into two fault trees - one for each case. Both cases include the same elements for leak detection. The 50 lb/day case adds an additional branch dealing with leak location. Separate runs to quantify the random and common cause failure unavailabilities were made and the results added to obtain the total system unavailability.

For the 300 lb/day case, the total system unavailability is 5.05×10^{-5} per event. This means that for each leak that might develop, the probability of not detecting that leak and correctly identifying its magnitude, is 5.05×10^{-5}. This failure frequency is dominated by a common cause failure of the exhaust fans and by the random failure of the ductwork in the vicinity of the leak. All common cause failures contribute about 5 per cent of the total failure frequency.

The results for the 50 lb/day case are similar, due to the same contributors being dominant. The total system unavailability for this case is 5.25×10^{-5} per event. In addition to the dominant contributors identified for the 300 lb/day case, the slight increase in failure frequency is due primarily to the failure of CCTV cameras and the Kanne chamber recorders. For the 50 lb/day case, common cause failures contribute about 10 per cent of the total.

Conclusions

The reliability of the tritium monitors to properly identify a crack leaking at a rate corresponding to key response levels has been shown to be very high. Standard fault tree techniques were applied in this study, considering all plausible failure mechanisms. The probability of not detecting a leak within an assumed mission time of 24 hours is estimated to be approximately 5×10^{-5} per demand for each of the two cases considered. This high reliability supports an evaluation of the pipe break frequency as well as the demonstration of leak-before-break for the primary coolant piping.

References

1. "Failure Probability Estimate of Type 304 Stainless Steel Piping", W. L. Daugherty, N. G. Awadalla, R. L. Sindelar (Westinghouse Savannah River Company), and H. S. Mehta (General Electric Company), Proceedings for ANS Topical Meeting on The Safety, Status and Future of Non-commercial Reactors and Irradiation Facilities, September 31-October 4, 1990, Boise Idaho.

2. "IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear Power Generation Stations", IEEE Std 500-1984.

3. "Offshore Reliability Data Handbook", 1st Edition, OREDA-84.

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Table 1. Summary of Failure Probabilities

Source of Failure	Failure Probability	Source of Failure	Failure Probability
CCTV Electronics	2.40 E-5	Independent Operator Error	1.00 E-3
CCTV Camera	3.36 E-3	Dependent Operator Error	1.00 E-2
Kanne Monitor	1.19 E-4	Supervisor Error	1.00 E-1
Electrometer	9.12 E-6	Electric Power (Init.)	1.92 E-3
High Voltage	1.18 E-5	Electric Power (Rest.)	1.40 E-2
Recorder	4.13 E-4	Backup Power (FD)	1.90 E-2
Exhaust Fan (FTR)	3.67 E-4	Backup Power (Rest.)	1.80 E-1
Exhaust Fan (FTS)	1.30 E-3	Ductwork	2.40 E-6
Exhaust Fan (CC)	4.77 E-5	Count Rate Meter	2.76 E-5
BTM Monitor	5.57 E-5	Integrator	2.76 E-5
BTM Monitors (CC)	5.57 E-6	Control Computer	2.76 E-5
STM Monitor	9.29 E-5	Exhaust Pump	2.78 E-4
STM Monitors (CC)	9.29 E-6	Sample Pump	2.78 E-4
Sample Line	2.40 E-6	Pumps (CC)	3.06 E-5
Sample Lines (CC)	2.40 E-7		

Key:
FTR - Fails to run (normally running)
FTS - Fails to start (normally not running)
CC - Common mode failure
Init. - Initial loss of power
Rest. - Failure to restore power
FD - Failure on demand

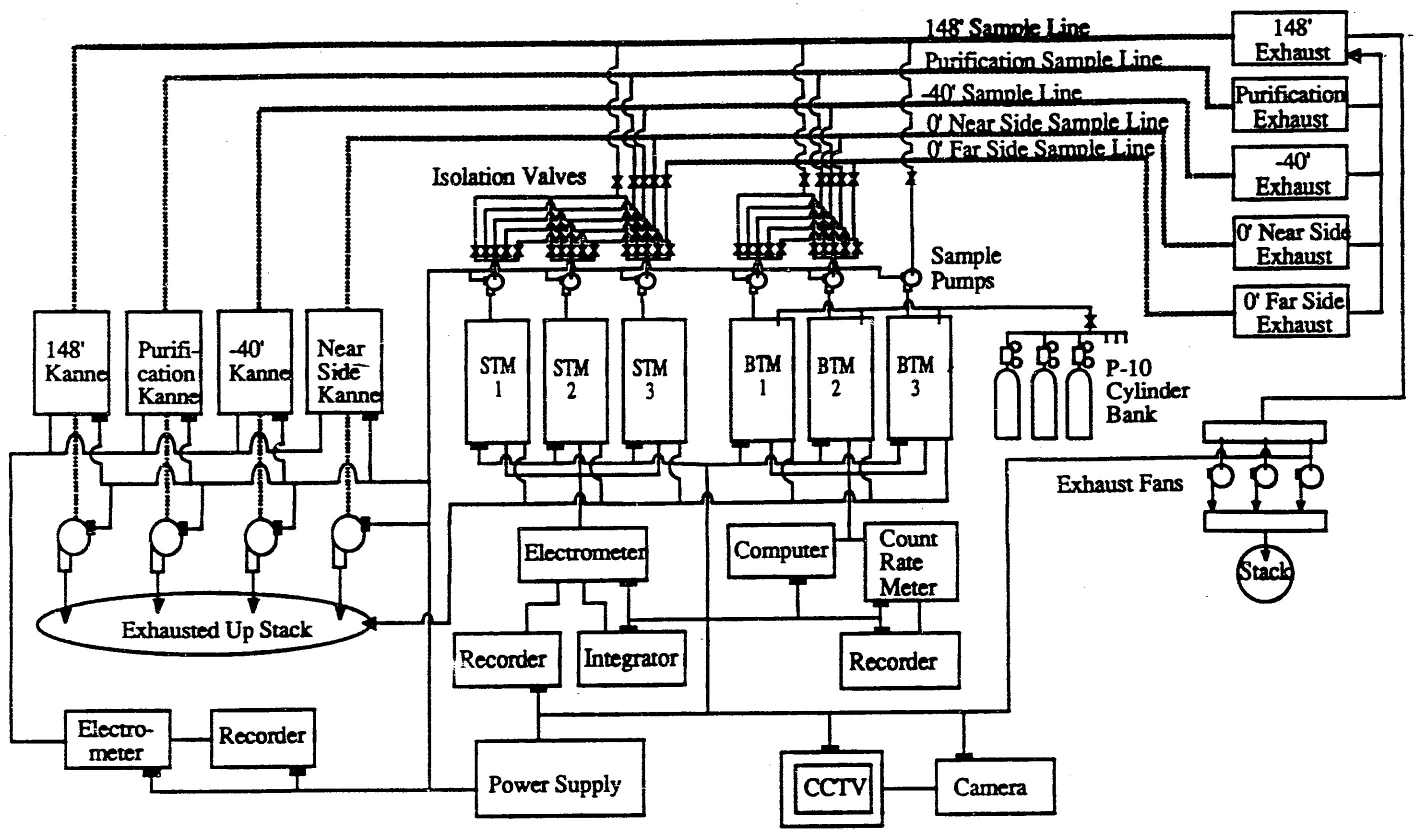

Figure 1. Tritium Monitoring System Simplified Flow Diagram

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