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Techniques for Primary-to-Secondary Leak Monitoring in PWR Plants

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1. Introduction

Historically, corrosion and mechanical damage have made steam generator tubes in PWR plants see various types of degradation from both the primary and secondary sides of the tubes. Since the tube degradation can lead to through-wall failure, the plant personnel should make efforts to prevent the failure. One of such preventive efforts is to monitor primary-to-secondary leakage (PSL) that usually precedes the tube rupture. Thus the objective of PSL monitoring is to make operators to determine when to shutdown the plant in order to minimize the likelihood of propagation of leaks to tube rupture under normal and faulted conditions This paper addresses briefly the status of techniques for PSL monitoring used in PWR plants.

2. PSL Monitoring Techniques in PWR Pants [1]

The PSL monitoring techniques that PWR plants are commonly using detect the activities of radionuclides such as activation products (e.g., N-16, Na-24, etc.) and fission products (e.g., Xe-133, Xe-135, etc.) in a coolant of the secondary system. As produced solely in the primary system and subsequently transported into the secondary system with leaks, these radionuclides can serve as an indicator of the occurrence and rate of PSL. Fig. 1 shows the schematic for layout of some typical PSL monitoring techniques in PWR plants.

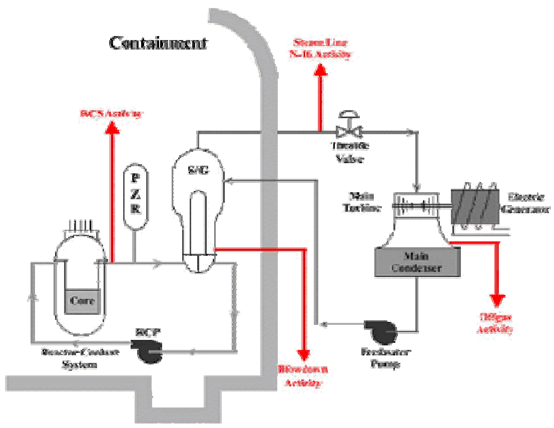

Figure 1. A Schematic for layout of some typical PSL monitoring techniques in PWR plants.

2.1 Steam Generator Blowdown Radiation Monitors

For detecting soluble gamma emitters in each steam generator blowdown, liquid monitors with a sodium iodide (NaI) detector in an off-line sampling configuration are commonly used. The radionuclides detected include I-131 (with a half-life of 8 d), I-132 (2.3 hr), I-133 (21 hr), I-134 (53 min), I-135 (6.6 hr), Na-24 (15 hr) and Cs-138 (32 min). This technique can determine which steam generator is leaking through the measurement of activity of soluble radionuclide in blowdown of respective steam generator. In addition, due to their sensitivity, they are responsive to small changes in activity. The drawbacks of this technique are 1) it's detection can be highly affected by hideout phenomenon of radionuclides in steam generator, 2) the monitor response depends on the specific radionuclide mix of the sampled stream due to its gross counting mode, and 3) the response times is long due to relatively low sample flows through long sample line.

2.2 Condenser Air Removal Radiation Monitors

The radionuclides detected by this technique are non-condensable radioactive gases such as Xe-133 (5.25 d), Xe-135 (9.1 hr), Kr-85m (4.5 hr), Kr-88 (2.84 hr), Kr-87 (1.3 hr) and Xe-135m (15.6 min) discharged from the condenser as offgas. There are several sampling configurations available: off-line, in-line and adjacent to line. Geiger-Muller (GM) detectors or organic (beta) scintillation detectors in a gross counting mode are commonly used and thus, the monitor response depends on the radionuclide mix of the sampled stream. The monitors may function as both a process monitor and effluent radiation monitor. The benefits of these monitors are 1) they provide an accurate estimate of PSL for many leak scenarios and 2) they offer rapid leak rate determinations due to the needlessness to consider equilibrium. One of limitations of this technique is that it can provide only a total PSL rates without being able to identify the leaking steam generator(s).

2.3 Main Steam Line Radiation Monitors

Typically, these monitors are installed in an adjacent-to-line configuration due to the high pressure and temperatures of the process stream. The detectors used are either Ion Chambers, GM tubes, or in some applications, NaI. GM and Ion Chamber typically detect gamma ray emitted from the radioactive gases and vapor being carried through the steam lines. The radionuclides to be detected are the same as in Condenser Air Removal Radiation Monitors. Since these monitors are installed at the steam line of each steam generator, it is possible to identify the leaking steam generator(s) with these monitors. The major limitation of these monitors is that they are not sensitive to small leak rate changes. These monitors would only respond if there was a significant source term in the reactor cooling system. As a result, these monitors cannot be used for low level leak rate detection and are limited to post-accident of significant releases. Because of the low sensitivity of these monitors under normal failed fuel conditions and low leak rates, they typically do not provide any useful trend information.

2.4 N-16 Monitors

The monitors with a large volume NaI detector are mounted on the main steam lines in an adjacent-to-line configuration. The monitor is usually operated in either a multi-channel analyzer mode with an energy window set to detect the N-16 6.13 MeV photopeak or in a gross counting mode with a lower level discriminator set to detect only high energy gamma radiation. Because N-16 has a 7 second half-life, sample transport time to the monitor becomes significant. Some of the advantages of N-16 monitors are: 1) the source term (oxygen in water in RCS) is stable and is dependent only on reactor power, 2) due to the high flow velocity in the steam lines, the monitors respond almost instantaneously to increase in leak rates, and 3) these monitors can also provide diagnostic information. One of the limitations is that there is a difficulty in using a NaI detector with a fixed window.

2.5 Tritium Monitor

Tritium from the reactor coolant enters the steam generator and the secondary system when PSL exists. All of the tritium can be assumed to be in the form of tritiated water. Followings are the advantages in quantifying leak rates via tritium over other methods: 1) unnecessary to consider ion exchange effects when considering steady state, 2) needlessness to consider hideout and hideout-return effects, 3) needlessness to account for liquid/steam partitioning, 4) needlessness to account for concentration effects in the blowdown for steam generators, 5) the good precision and accuracy of radiochemistry analysis for tritium, and 6) needlessness to consider decay due to its long half-life (12.3 yr). Because of these advantages, the tritium method is recommended for validation of the condenser offgas and steam generator blowdown methods. The major disadvantage of the tritium method is an effect of its long half-life that requires a lengthy time period to reach equilibrium. This reduces the sensitivity of the method with respect to identifying a new leak in the initial states.

2.6 Ar-41 monitors with Ar injection [2,3]

There have been many efforts to develop effective PLS monitoring techniques. One of such developments is Ar-41 monitors with Ar injection. This technique is a special case of Condenser Air Removal Radiation Monitors, where Ar-41 in the offgas is monitored. Ar-41 has a half-life of 1.8 hr with a gamma emission of 1.3 MeV. In order to enhance the monitor response for Ar-41, the concentration of Ar in reactor cooling system is increased by purposely injecting Ar (99.6% Ar-40) into the reactor cooling system via VCT, resulting in the activation of some of Ar-40 to Ar-41. This method was implemented at Diablo Canyon Plant for the first time in 1999, and subsequently at Comanche Peak Plant in 2003. The plant experiences showed that the Ar-41 concentration of 0.1Ci/cc in the reactor cooling system could be maintained by injecting Ar at a rate of 5cc/min, and that this increased concentration enhanced the monitor sensitivity from 2 to 50 cpm/gpd. Due to this enhanced sensitivity, this method made the monitors to better detect small leaks and decreased occurrence of false alarms. An investigation showed that the increased Ar-41 concentration did not significantly effect operation does.

3. Conclusion

In this paper, various PSL monitoring techniques used in PWR plants are briefly described. The benefits and limitations of each technique are attributed to factors such as sampling location and method, the constituent to be detected and the detector used, etc. Thus, it is needed to understand well characteristics of each technique in order to select the technique that fits the tube-rupture preventive purpose at a plan with taking account of the plant-specific conditions. Also, to make up for the limitations of each technique, it is desirable and necessary to employ multiple PSL monitoring techniques as many plants do.

REFERENCES

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