The Activity Increase of Blowdown System in Non-Leaking Steam Generators during Tube Leak in the Steam Generator

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1. Introduction

Primary to secondary leak monitoring for Steam Generators (SG) provides a defense-in-depth approach to minimize the potential for a tube rupture.

Domestic pressurized water reactor (PWR) plants have never experienced steam generator's tube rupture during power operations because they have been implementing steam generator leak management using diverse online monitoring devices and radiochemistry analysis program since commercial operations.

The blowdown radiation monitor of a steam generator typically monitors the concentration of total radioactivity (activity) of liquid effluents that are released from primary water during tube leak in the steam generator.

Domestic PWR plants use ion exchangers in the blowdown system to remove all liquid radioactivity. Therefore, non-leaking steam generators should not show an increasing trend in activity. However, small increases in activity were identified in non-leaking steam generators.

Activity increase trends in a non-leaking steam generator blowdown were investigated in this study.

2. Methods and Results

To identify the causes of increase in liquid radioactivity in non-leaking steam generators during an SG tube leak event, the indications of the SG blowdown radiation monitor and the results of grab sample analyses were analyzed.

2.1. Activity balance of steam generator bulk water

Since liquid radionuclides released due to an SG tube leak are theoretically removed through the ion exchanger, it is difficult for liquid radionuclides to enter the other non-leaking steam generators.

Activity balance of a leaking steam generator can be described as below [1].

$$M_{SG}\frac{dA_{SG}}{dt} = [(F_{FW}A_{FW}) + (F_{Leak}A_{RCS})] - [(F_{Steam}A_{Steam}) + (F_{BD}A_{BD}) + (M_{SG}\lambda A_{SG})] \quad (1)$$

A small fraction of liquid radionuclides may be transported to non-leaking steam generators from a leaking steam generator due to moisture carryover of liquid radionuclides.

Domestic PWR plants verified the leakage through grab sample analyses for all of steam generators during a SG tube leak events. However, activity in non-leaking steam generator could not be measured by grab samples.

It is thought that the amount of radionuclides in non-leaking steam generators is very small compared to those in leaking steam generators. This is because the moisture carryover fraction is less than 0.25%, and liquid radionuclides present in the main steam are evenly entered to all of the steam generators.

If we were to measure the activity of isotopes in the non-leaking steam generator, we could evaluate the effect on the activity increase trend in the non-leaking steam generator caused by a leaking generator. However, it is also not easy to establish an activity balance because the accuracy of the activity balance depends on plant operation conditions, such as the flow rate of the ion exchanger, and site-specific factors.

2.2. A potential radionuclide contributing to activity increase in non-leaking steam generator

F-18 is a positron emitter produced through irradiation of O-18 by high energy positron in the reactor coolant. Oxygen-18 is a naturally occurring isotope of oxygen with a natural abundance of 0.2% [2].

$$^{18}O + p \rightarrow {}^{18}F + n + \gamma \quad (2)$$

Half-life of F-18 is 107.8 minutes. F-18 activity of reactor coolant in a domestic PWR unit is about 0.1 μCi/cc which is almost the same as those of overseas PWR plants.

It is believed that F-18 is a most important radionuclide for SG leak monitoring, in case of PWR plants having little activation product in reactor coolant system.

Fluorine is known to be soluble in coolants, however it may be volatile and forms complexes with boron or amines. In addition, it can also exist in other forms such as gaseous hydrogen fluoride (HF).

According to a previous research, steam to total fluoride concentration ratio of a US PWR unit was about 0.08 [2]. Even though it may vary depending on plant conditions such as amine chemistry and plant design, it is thought that F-18 in steam can be present in greater abundance than other liquid radionuclides.

When an SG tube leak occurred, a peak of F-18 energy in the gamma isotopic analysis of grab sample from non-leaking steam generator was identified, but peaks of the other radionuclides were not found.

Even though F-18 activity of non-leaking steam generator was not calculated due to lower limit of detection (LLD) of gamma spectrometer, it has been believed that F-18 radionuclide that was entered through steam cycle from the leaking steam generator to non-leaking steam generator triggered SG blowdown radiation monitor.

3. Conclusion

Domestic PWR nuclear plants operate diverse primary to secondary leak monitoring devices in the secondary system such as N-16 radiation monitor, condenser off gas radiation monitor, and SG blowdown radiation monitor to maintain steam generator integrity.

Activity increase in non-leaking steam generators does not affect steam generator integrity and plant operation. However, it is necessary for plant personnel to understand the radionuclide behaviors released from the reactor coolant into the secondary water as a result of a SG tube leak, in order to properly and promptly implement SG leak management.

It is estimated that the increase in radioactivity of the non-leaking steam generators of domestic PWR plants was mainly caused by F-18 radionuclide.

REFERENCES

[1] B. Capell, EPRI PWR Primary to Secondary Leak Guidelines, Rev. 5, pp. 5-7, 2020.
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