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Some Insights from Containment Integrated Leakage-Rate Test Experience

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1. Introduction

The sole purpose of the reactor containment system is to mitigate the consequences of potential accidents (e.g., design basis accidents) by minimizing the release of radionuclides to the environment. Therefore, regulatory requirements require containment to maintain its integrity under design basis accident (DBA) conditions. Containment leakage-rate tests are intended to assure the leak-tight integrity of the containment boundaries under all DBA conditions. Containment leakage-rate tests include the integrated leakage-rate test (ILRT) and the local leakage-rate test (LLRT). The ILRT is conducted to verify the integrity of the containment such that the release of fission products to the environment under DBA conditions does not exceed the limits established in 10CFR 100. The LLRTs verify that the leakage rate of an individual containment penetration component is acceptable. The LLRT subjects include containment air-locks, equipment hatch, electrical penetration assemblies, containment isolation valves, etc.

The ILRT and the LLRT shall be performed in accordance with NSSC Notice 2012-16 and ANSI/ANS-56.8-1994, which provide the leakage-rate test method and the in-service test intervals.

Korea currently has 23 nuclear power plants (NPPs) in operation and more than 80 in-service ILRTs have been performed at these NPPs. In this paper, based on these ILRT experience, provided are some insights on the level of containment leakage rates and the relationship between the integrated leakage-rate and the local leakage rate for domestic NPPs.

2. Methodology

2.1 Integrated Leakage Rate Calculation Method

The ILRT is performed by pressurizing the containment to the calculated peak containment internal pressure derived from the leakage design basis accident, e.g., loss of coolant accident (LOCA), and specified in the unit technical specifications. The containment integrated leakage-rate can be computed by the "Absolute Method of Mass Point Analysis" described in ANSI/ANS-56.8-1994. This method consists of calculating the air mass within the containment, over the test period using pressure, temperature, and dew-point temperature observations made during the ILRT. The air mass is computed using the ideal gas law as follows:

$$M = 144\ V(P - P_v)/RT \quad (1)$$

where:

M = air mass, lbm
P = total pressure, psia
P_v = average vapor pressure, psia
R = 53.35 ft-lbf/lbm ^{o}R(for air)
T = average containment temperature, ^{o}R
V = containment free volume, ft^3

The leakage rate is then determined by plotting the air mass as a function of time, using least-squares fit to determine the slope, A = dM/dT. The leakage rate is expressed as a percentage of the air mass lost in 24 hours or symbolically:

$$\text{Leakage Rate} = -2400\ (A/B) \quad (2)$$

where A is the slope of the least-squares curve and B is the y-intercept. The sign convention is such that the leakage out of the containment is positive, and the units are in percent/day.

A confidence interval is calculated using a Student's T distribution. The sum of the leakage-rate and confidence interval is the Upper Confidence Limit (UCL). According to the NSSC Notice 2012-16, the ILRT leakage-rate, UCL, shall not exceed 0.75 La. The term of "L_a" means the maximum allowable containment leakage-rate specified in the final safety analysis report (FSAR) of NPP.

2.2 Data for the Study

The data of integrated leakage-rates and the local leakage-rates were derived from the periodic inspection reports written by KINS staff between 1982 and 2013. Of specific interest were 84 ILRT inspection reports including 67 for PWRs and 17 for CANDU reactors.

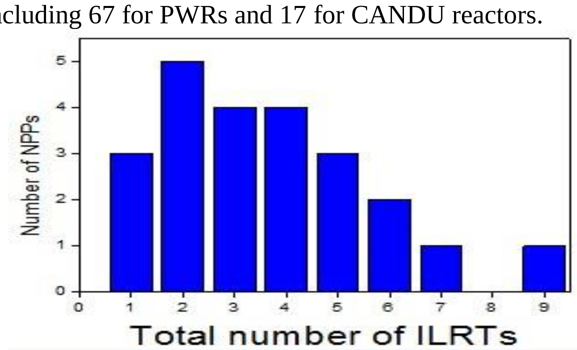

Fig. 1. Distribution of the total number of ILRTs

Figure 1 shows the distribution of the total number of ILRTs performed at each of 23 operating NPPs. The average number of ILRTs is 3.7 and Kori 1 has conducted the most ILRTs, 9, since its commercial operation in 1978.

3. Results of the Study

3.1 Level of Integrated Leakage-Rates

According to the data considered in this study, the as-left integrated leakage-rates ranged from 0.025 L_a to 0.74 L_a, which were below the NSSC's requirement. There were only three as-found ILRT failures; one failure was caused by the excess leakage at the containment isolation valves and the others were caused by the excess leakage at local penetrations which had not been considered the LLRT subject, e.g., spent fuel discharge room access plugs in CANDU reactor. Three verification test failures have also been reported and it was assumed that those failures were caused by inadvertent operations of plant equipment during the ILRTs. Table 1 provides a summary of the integrated leakage-rates for NPPs with more than three in-service ILRTs conducted until the end of 2013. The averaged integrated leakage-rate and its standard deviation are presented in the table. As shown in the table, Kori unit 4 and Hanbit unit 3 have relatively large integrated leakage-rates.

Table 1: Summary of Integrated Leakage-Rates

Unit	Avg. ILR*	STD*	Unit	Avg. ILR	STD
Kori1	0.41	0.12	Hanul1	0.17	0.09
Kori2	0.44	0.18	Hanul2	0.19	0.11
Kori3	0.52	0.14	Hanul4	0.24	0.20
Kori4	0.68	0.04	Wolsong1	0.30	0.05
Hanbit1	0.52	0.14	Wolsong2	0.31	0.03
Hanbit2	0.52	0.24	Wolsong3	0.27	0.03
Hanbit3	0.69	0.02	Wolsong4	0.28	0.05
Hanbit4	0.52	0.30			

*Unit: L_a, ILR: integrated leakage-rate, STD: standard deviation

3.2 Assessment on the Correlation between Integrated Leakage-Rate and Local Leakage-Rate

In order to assess the association between integrated leakage-rates and local leakage-rates, the correlation coefficients of integrated leakage-rate and local leakage-rate were calculated. Figure 2 shows the scatter diagram for 67 sets of these two leakage-rates for 19 operating PWRs. The local leakage-rates were measured prior to the ILRTs. As we can see in the figure, the local leakage-rates show a uniform distribution on the integrated leakage-rates and there is no apparent correlation between integrated leakage-rate and local leakage-rate. This observation is supported by the correlation coefficients of these two leakage-rates for some NPPs.

Table 2 summarizes the correlation coefficients of integrated leakage-rate and local leakage-rate for 11 PWRs with more than three in-service ILRTs. The closer to 1 the correlation coefficient is, the closer to the linear function the correlation is. As shown in the table, most correlations are not linear functions. This result is different from what we expect intuitively, i.e., the integrated leakage-rate would be proportional to the local leakage-rate. One of the reasons for this unexpected result may be relatively small local leakage-rates compared to integrated leakage-rates. Although having some limitations, this result indicates that the level of integrated leakage-rates cannot be deduced from local leakage-rates.

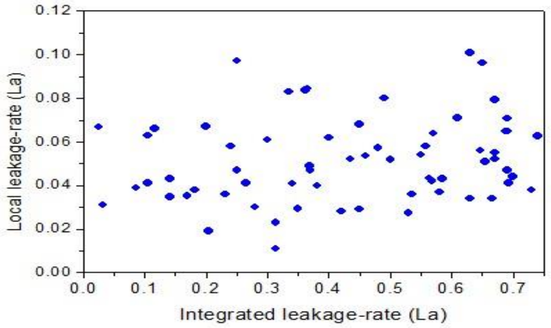

Fig. 2. Scatter diagram of integrated leakage-rates and local leakage-rates

Table 2: Correlation Coefficient of integrated leakage-rate and the local leakage-rate

Unit	Correlation coefficient	Unit	Correlation coefficient
Kori 1	-0.33	Hanbit 3	0.89
Kori 2	-0.06	Hanbit 4	0.49
Kori 3	0.55	Hanul 1	-0.91
Kori 4	0.10	Hanul 2	-0.45
Hanbit 1	0.58	Hanul 4	-0.94
Hanbit 2	-0.21		

4. Conclusions

The level of containment integrated leakage-rates was studied and it was revealed that the integrated leakage-rates ranged from very low to almost regulatory limit. Some NPPs have relatively high leakage levels so that much more concerns should be given to their ILRTs. It was also found that integrated leakage-rates were independent of local leakage-rates measured before the ILRTs.

REFERENCES

[1] 10CFR 100, "Reactor Sites Criteria".
[2] NSSC Notice 2012-16, "Standards for Leakage Rate Tests of Reactor Containment".
[3] ANSI/ANS-56.8-1994, "Containment System Leakage Testing Requirements"