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Uncertainty Analysis of Inleakage Test for Pressurized Control Room Envelop

J. B. Lee
KHNP Central Research Institute, 70, Yuseong-daero 1312 beon-gil, Yuseong-gu, Daejeon 305-343
Corresponding author: jbdoll@khnp.co.kr

1. Introduction

Inleakage tests for control room envelops(CRE) of newly constructed nuclear power plants are required to prove the control room habitability. Results of the inleakage tests should be analyzed using an uncertainty analysis. Test uncertainty can be an issue if the test results for pressurized CREs show low inleakage. To have a better knowledge of the test uncertainty, a statistical model for the uncertainty analysis is described here and a representative uncertainty analysis of a sample inleakage test is presented.

2. Methods and Results

2.1 Inleakage Test using Tracer Gas

In order to ensure control room habitability, inleakage test methods are used according to E741 and USNRC Reg. Guide 1.197 [1, 2]. The test methods use tracer gas dilution to determine air change within the CRE which is considered as a single zone. Inleakage, the volume rate of incoming air, can be calculated by measuring the concentration of the tracer gas that is injected into the CRE. These techniques are: (1) concentration decay, (2) constant injection, and (3) constant concentration. In choosing a technique for measuring air change, the quantity to be measured, the comparative capabilities of the techniques, and the complexity of the required equipment should be considered. For pressurized control room envelope constant injection method is usually used in inleakage test.

Air inleakage rate can be calculated using the following equation:

$$Q_{in} = Q_{tot} - Q_{m/u} \tag{1}$$

where Q_{in} = inleakage rate,
Q_{tot} = total air flow rate, and
$Q_{m/u}$ = makeup flow rate.

If concentration equilibrium occurs, Q is proportional to 1/C where C is the concentration of the tracer gas. Then the Eq. (1) can be written as

$$Q_{in} = \mathrm{const} \times C_{inj} \times \left[\left(\frac{1}{C_{tot}}\right) - \left(\frac{1}{C_{m/u}}\right)\right] \tag{2}$$

By measuring the concentrations of the tracer gas, it is possible to calculate the total air inleakage into the CRE [3]. But test results usually have some uncertainties such as bias and test itself. Specifically, test uncertainty can be an issue if the resultant inleakage flow is low. That's why uncertainty analysis is needed to evaluate the test results. This uncertainty analysis is based on the statistical method shown below.

2.2 Statistical Method for Analyzing Uncertainty

A statistical hypothesis is a statement about a set of samples of a population distribution. Suppose that sample mean values of the concentrations of tracer gas for total air flow and inleakage are μ_{tot} and $\mu_{m/u}$ respectively. Then, the inleakage rate is 0 if $\mu_{tot} = \mu_{m/u}$, according to Eq. (2).

Since the number of data set is small for most inleakage tests, *t-Test* is selected as a statistical tool for evaluating the hypothesis. *t-Test* is a statistical test used to determine within a specified degree of certainty whether the two means are different, or whether the difference might have occurred by chance [4]. *t-Test* is often performed when samples are less than 30 and the distribution of the underlying population is a normal distribution. In *the t-Test*, a *t-Value* is calculated based on the difference in the means and variances of the two populations. The less the *t-Value*, the more certain that the two means are same. There are many variations of the *t-Test*. But *t-Value* can be described by the following formula:

$$t\text{-}Value = \frac{Difference\ \ between\ \ the\ group\ \ means}{Variability\ \ \ of\ the\ groups}$$

t-Test can be a one-tailed test or a two tailed test. A one-tailed test determines where the means are different in one specific direction. For example, a one-tailed test could be used to determine only if $\mu_{m/u}$ is greater or less than μ_{tot}. A two-tailed test determines whether the two means are merely different. The two-tailed test is more stringent because the mean area in the outer tails outside of the region of required degree of certainty is split into two tails. In the uncertainty analysis of inleakage test, two-tailed *t-Test* is used since the goal of the analysis is to evaluate the null hypothesis that the two means are indistinguishable.

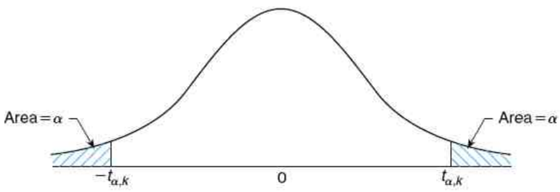

Fig. 1. Density of a t-random variable with k degree of freedom

The *t-Test* consists of three steps: (1) to define the null and alternate hypotheses, (2) to calculate the t_{calc} for the data, and (3) to compare t_{calc} to the tabulated *t-Value*, for the appropriate significance level and degree of freedom.

First, we assume that the null hypothesis is $\mu_{tot} = \mu_{m/u}$ and the alternate hypothesis is $\mu_{tot} \neq \mu_{m/u}$.

The second step is to calculate the t_{calc} and degree of freedom. The formula is given by

$$t_{calc} = \frac{\overline{\mu_{m/u}} - \overline{\mu_{tot}}}{\sqrt{\frac{\sigma_{m/u}^2}{n_{m/u}} + \frac{\sigma_{tot}^2}{n_{tot}}}}$$

where σ = standard deviation, and
n = number of samples in data set.

The *t-Value* depends on the significance level desired and the number of degrees of freedom. The number of degrees of freedom can be calculated by using the following formula

$$d.o.f = \frac{\left(\frac{\sigma_{m/u}^2}{n_{m/u}} + \frac{\sigma_{tot}^2}{n_{tot}}\right)^2}{\frac{\sigma_{m/u}^4}{n_{m/u}^2(n_{m/u} - 1)} + \frac{\sigma_{tot}^4}{n_{tot}^2\,(n_{tot} - 1)}}$$

and the result is rounded to the nearest integer.

Finally, in order to evaluate the null hypothesis t_{calc} is compared to *t-Value* which can be calculated by using a lookup table or by using TINV function in the Microsoft Excel program. If t_{calc} is greater than *t-Value*, we reject the null hypothesis and accept the alternate hypothesis. Otherwise, we accept the null hypothesis.

2.3 Uncertainty Analysis of Inleakage Test Results

Air inleakage tests using SF6 as a tracer gas were performed and the tests results are given in Table 1. Mean concentrations of the makeup and total gas flow are shown with their standard deviations.

The degrees of freedom, t_{calc}, and *t-Value* are calculated based on the statistical method described above. 95% significance level was used.

In this case, since t_{calc} is less than *t-Value* we accept the null hypothesis. That is, we can say with 95% significance level that the two mean values are same and the inleakage flow rate is zero.

Table 1. Uncertainty Analysis of the Test Results

	Makeup	Total
Mean (ppm)	17.5267	17.0938
Std. Deviation	0.1370	0.0484
# of Samples	5	5
d.o.f	7	
t_{calc}	2.2477	
t-Value	2.3646	

3. Conclusions

A statistical method for analyzing the uncertainty of the inleakage test is presented here and a representative uncertainty analysis of a sample inleakage test was performed. By using the statistical method we can evaluate the test result with certain level of significance. This method can be more helpful when the difference of the two mean values of the test result is small.

REFERENCES

[1] ASTM Standard E741-00, "Standard Test Method for Determining Air Change Rate in a Single Zone by means of a Tracer Dilution", ASTM, Philadelphia, PA, 2000.
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