High Equilibrium Time CREEVS Inleakage Measurements

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ABSTRACT

U.S. nuclear power plants that have adopted TSTF 448 are committed to tracer gas inleakage testing. Regulatory Guide 1.197 provides guidance on testing using the tracer gas techniques documented in ASTM Standard E741 "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Dilution".

Neither the ASTM Standard nor the Regulatory Guide addresses the question of the repeatability of tracer gas inleakage test results. Previous papers have discussed the issue of repeatability for both Pressurization and Recirculation CREEVS. The present effort explores the repeatability of inleakage measurements undertaken in high equilibrium time CREEVS.

For plants that pressurize the Control Room Envelope during emergency operation, the so-called Concentration Buildup/Steady State technique is often used. However for those Control Room Envelopes with a very low makeup flow rate and a correspondingly low air exchange rate, the time to concentration equilibrium can be unreasonably long. This presents a severe experimental challenge to undertaking an air inleakage test. Proper use of the equations in ASTM Standard E741 requires that tracer gas concentration be in equilibrium for valid inleakage results.

Measured inleakage data using the Makeup Flowrate/Concentration decay test from three high equilibrium time plants operating in the pressurization mode are provided and discussed. The technique is based on the use of ASTM Standard E741 in conjunction with ASTM Standard E2029 “Standard Test Method for Volumetric and Mass Flow Rate Measurement in a Duct Using Tracer Gas Dilution” and has been described in a previous technical paper.

The mean value of inleakage from six data sets over three measurement cycles for Plant 1 was 1.47 m^3/min (52 SCFM) with a standard deviation of 8.8%. The mean value of inleakage from four data sets over two measurement cycles for Plant 2 was 20.14 m^3/min (711 SCFM) with a standard deviation 9%. The mean value of inleakage from three data sets over two measurement cycles for Plant 3 was 1.72 m^3/min (61 SCFM) with a standard deviation 15%.

The standard deviations of these inleakage measurements compare favorably with those obtained for both Pressurization and Recirculation CREEVS.

INTRODUCTION

U.S. nuclear power plants that have adopted TSTF 448 [1] are committed to tracer gas inleakage testing of the Control Room Envelope Emergency Ventilations System (CREEVS). Regulatory Guide 1.197 [2] provides guidance on testing using the tracer gas techniques documented in ASTM Standard E741 "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Dilution" [3].

For plants that pressurize the Control Room Envelope (CRE) during emergency operation, the so-called Concentration Buildup/Steady State technique is often used. However for those CREs with a very low makeup flow rate and a correspondingly low air exchange rate, the time to concentration equilibrium can be unreasonably long.

A previous technical paper described a measurement technique utilizing pressurization flowrate data combined with concentration decay data to measure inleakage in high equilibrium time CREs [4]. This technique was called the Makeup Flowrate/Concentration Decay test.

Neither the ASTM Standard nor the Regulatory Guide addresses the question of the repeatability of tracer gas inleakage test results. The repeatability of tracer gas inleakage tests for CREEVS that pressurize and attain an equilibrium concentration (Concentration Buildup/Steady State Tests) as well as those that isolate and re-circulate (Concentration Decay Tests) under emergency conditions has been discussed in previous technical papers [5, 6]. No such discussion has been published regarding the repeatability of tracer gas inleakage tests for the Makeup Flowrate/Concentration Decay tests which can be used when the CREEVS exhibits a long equilibrium time.

Tracer gas inleakage data for high equilibrium time CREEVS have been collected for four nuclear power plants denoted Plant A, Plant 1, Plant 2, and Plant 3. The Plant A data are used to demonstrate the importance of attaining the proper equilibrium concentration in a Constant Injection test. Plant 1, Plant 2, and Plant 3 data are used to examine the repeatability of the Makeup Flowrate/Concentration Decay test method. These data are presented and described in a later section.

MEASURING BUILING AIR FLOWS USING TRACER GAS

There are three principal tracer gas techniques for quantifying airflow rates within a structure; namely, the tracer concentration decay method, the constant injection method, and the constant concentration method. All three of these techniques are incorporated in the most recent revision of ASTM Standard E741. At the present time the constant concentration method is primarily used by researchers in the building physics community and will not be discussed further in this paper.

In all three methods, a gaseous or vapor tracer is introduced into a test volume and the resulting concentration of tracer is measured as a function of time. Conservation of mass equations then allow one to deduce mass flow properties within the test volume.

To interpret data resulting from a tracer gas test, one employs a mass balance of a tracer gas released within the volume under test. Assuming that the tracer gas mixes thoroughly within the structure, the mass balance equation is,

$$V\ dC(t)/dt = S(t) - q(t)C(t) \qquad (1)$$

where V is the test volume, C(t) is the tracer gas concentration (dimensionless), dC(t)/dt is the time derivative of concentration, q(t) is the volumetric airflow rate out of the test volume, S(t) is the volumetric tracer gas injection rate, and t is time.

The air exchange or infiltration rate, A, is given by A(t) = q(t)/V. The units of A are air changes per hour (h^{-1} or ACH). The value of A represents the volume-normalized flow rate of "dilution air" entering the volume during the test interval.

CONCENTRATION DECAY TECHNIQUE

The simplest tracer gas technique is the tracer concentration decay method. After an initial tracer injection into the test volume, there is no source of tracer gas, hence S(t) = 0 and assuming A is constant, a solution to equation (1) is;

$$C = C_0 \exp(-A \cdot t) \qquad (2)$$

where C_0 is the concentration at time t=0.

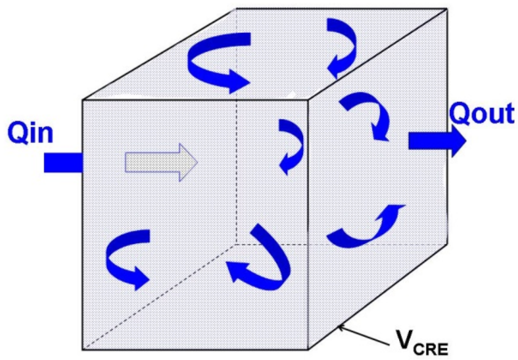
This method requires only the measurement of relative tracer gas concentrations, as opposed to absolute concentrations, and the analysis required to determine A is straightforward. In use, equation (2) is often recast to the following form:

$$\ln C = 1n\ C_0 - A \cdot t \qquad (3)$$

In practice one obtains a series of concentration versus time points and then performs regression analysis on the logarithm of concentration versus time to find the best straight line fit to the form of the equation given by equation (3). The slope of this straight line is A, the air exchange rate. A schematic representation of this technique is provided in Figure 1.

AIR INLEAKAGE BY CONCENTRATION DECAY – ASTM E741

1) Inject tracer and thoroughly mix in the volume



2) Measure mean concentration as function of time

Time (Hrs)	Mean Concentration
0.0	C0
0.5	C1
1.0	C2
1.5	C3
2.0	C4

3) Plot concentration vs time and calculate slope by regression

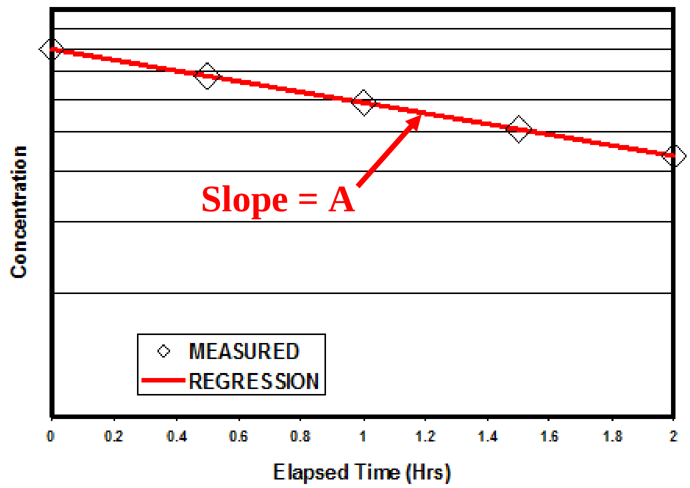


Figure 1. Concentration Decay Inleakage Test

As depicted in Figure 1, the natural logarithm of the tracer concentration decreases linearly with time. The slope of this line is A, the air exchange rate. To calculate the air inleakage rate, one must have independent knowledge of the test room volume from which,

$$q = A \cdot V \qquad (4)$$

Note that volume value required for use in equation (4) is the ***free*** volume of the actual CRE i.e. that portion of the CRE which is capable of exchanging air within the test volume excluding solid objects such as cabinets, desks, structural members and non-ventilated electrical enclosures. In practice one uses the CRE volume utilized in the plant dose analysis and incorporates a volume uncertainty of 5% to 10% into the overall uncertainty analysis. The actual geometric CRE volume value is always larger than the actual free volume.

The results obtained with this technique are exact only for a well-mixed volume, (i.e. concentration at a given time is the same throughout the test volume). Otherwise, the results will be subject to errors, with the magnitude of these errors depending on the extent of the departure from homogeneity. Thus, the experimental challenge is to assure that good mixing of the tracer gas is achieved.

CONCENTRATION BUILDUP/STEADY STATE TECHNIQUE

With the CREEVS operating in a Pressurization Mode, air inleakage testing is often performed using the Constant Injection Method, also known as the Concentration Buildup/Steady State technique. This method measures the equilibrium tracer concentration within a ventilated volume. This equilibrium concentration can be related to the airflow rate into the test volume if the tracer release rate is known. It is possible to solve equation (1) assuming a constant tracer gas injection.

For the constant injection technique S(t) = constant. If A is also assumed to be constant, a solution to equation (1) is,

$$C(t) = (S/q)[1 - \exp(-A \cdot t)] + (C_0 \exp(-A \cdot t) \qquad (5)$$

A schematic representation of this technique is provided in Figure 2.

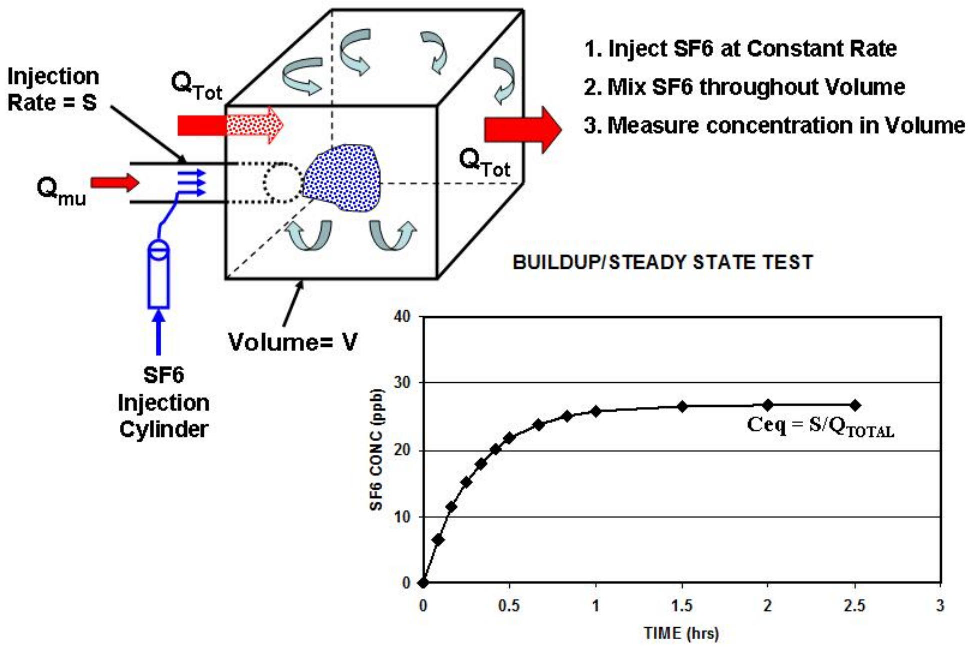


Figure 2. Concentration Buildup/Steady State Inleakage Test.

As depicted in Figure 2, the tracer concentration initially increases with time but eventually reaches a plateau. After waiting a sufficient time (according to ASTM Standard E741 at least equal to approximately 3/A), the transient dies out and concentration equilibrium occurs. Equation (5) then becomes the simple constant injection equation,

$$C = S/q \qquad (6)$$

The reason that this technique is preferred for the measurement of inleakage is that the result is ***independent*** of the volume of the CRE when the concentration value is at equilibrium. Often in the nuclear power plant context there is uncertainty as to the exact value for the volume of the CRE.

Inspection of equation (6) in light of equation (5) discloses that equilibrium is attained when the exponential term exp(-A*t) is negligible (ideally equal to zero) so that the term [1-exp(-A*t)] is approximately equal to one. ASTM Standard E741 states that this occurs at a time of 3/A for 95% equilibrium.

Table 1 provides values of the term [1-exp(-A*t)] expressed as a percentage for the four plants described in this paper. When the percentage equals 100%, equation (5) becomes equation (6).

As can be seen, rather than for time 3/A, but rather for times between 4/A and 5/A, equilibrium has been attained for all practical purposes.

Table 1

Equilibrium Times for Four Plants

Wait Time	Equilibrium %	Plant A (Hr)	Plant 1 (Hr)	Plant 2 (Hr)	Plant 3 (Hr)
3/A	95.0	9.5	10.0	13.3	16.6
4/A	98.2	12.6	14.9	19.8	24.8
5/A	99.3	15.8	20.7	27.6	34.5

Referring to Table 1 it is apparent that significant time must elapse for these low A value plants to achieve equilibrium. Hence tracer sampling to determine inleakage must wait for this period of time to elapse. In an inleakage measurement using the Concentration Buildup/Steady State Technique it is important to attain concentration equilibrium because if one uses concentration measurements to calculate inleakage *before* equilibrium is achieved, *the value of inleakage will always be **larger** than the true value attained at equilibrium.*

Waiting for such an extended period of time (as shown in Table 1) is not practical within the context of the plants described in his paper. If a test requires limiting access to the CRE for more than the duration of one shift (usually the back shift) this is difficult if not impossible to implement.

Section 9 of ASTM E741 deals with the Constant Injection Method. There is some ambiguity in the wording regarding a short injection of tracer gas at a higher rate or higher concentration - also known as a "boost" - in order to achieve concentration equilibrium more rapidly than without the boost. Unfortunately, the standard does not point out that some time must still elapse after the boost injection of tracer gas before approximate equilibrium is attained. Attaining the proper equilibrium concentration is critical when utilizing the Constant Injection Method, with or without the boost, which is described later.

An alternative method for measuring inleakage in high equilibrium time plants is to use the Makeup Flowrate/Concentration Decay technique that is described below.

TRACER GAS FLOW RATE MEASUREMENT

For many years it has been known that a method to measure duct flow rates exists other than Pitot tube or hot wire anemometer traverses. This other method entails the use of a tracer gas dilution method. This method is a *volumetric* as opposed to a point measurement and does not require knowledge of the duct area.

To undertake such a measurement, a tracer gas is continuously metered into a flowing duct at a known rate. After allowing for mixing, air samples are collected across a plane downstream of the injection point and the mean concentration of tracer gas is measured. Assuming that the tracer gas is well mixed within the duct, the rate of flow is readily calculated from the ratio of the tracer injection flow rate to the diluted concentration, C_{av}--in symbols:

$$q = S / C_{av} \qquad (7)$$

This mean concentration in the duct is inversely proportional to the flow rate through the duct (as given by equation (7)). Thus, the measured concentration allows calculation of the flow rate since the injection flow rate is known. The basic test setup is shown in Figure 3.

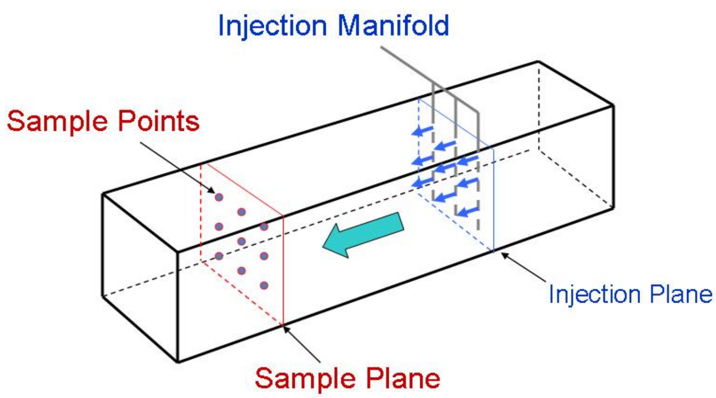


Figure 3. Tracer Gas Flowrate Test

One can rewrite equation (7) to explicitly reflect this measurement as equation (8),

$$q_{m/u} = S / C_{m/u} \qquad (8)$$

where, $q_{m/u}$, is now the fresh air makeup flow rate.

MAKEUP FLOWRATE/CONCENTRATION DECAY TEST

In a Makeup Flowrate/Concentration Decay Test, tracer gas is continuously injected into the makeup air stream of the CREEVS at a constant rate while the makeup flowrate is measured using the method described in ASTM Standard E2029 "Standard Test Method for Volumetric and Mass Flow Rate Measurement using Tracer Gas Dilution" [7]. Tracer gas is then injected into the CRE for an additional period of time in order to achieve a robustly measurable concentration after which injection is stopped and the tracer gas is allowed to disperse throughout the CRE.

After waiting for adequate mixing to occur, timed sampling for tracer gas is initiated. From these samples one obtains a series of concentration versus time points and performs regression analysis on the logarithm of concentration versus time to find the best straight-line fit to the data. The slope of this straight line is the volume normalized air inleakage rate in air changes per hour (ACH). Knowledge of the CRE volume allows calculation of the Total Air Inflow rate in CFM. Note that this Concentration Decay Test is the first test type described in ASTM Standard E741.

Makeup flowrates are measured before and after measurement of the Total Air Inflow. The values are averaged to obtain the mean makeup flowrate extant during the testing. Knowledge of the makeup flowrate in combination with a measured Total Air Inflow value allows calculation of the amount of air inleakage to the CRE that is not provided by makeup flow by differencing these two measured values.

CONTROL ROOM ENVELOPE INLEAKAGE

In an air inleakage testing program using the Makeup Flowrate/Concentration Decay technique, the Total Air Inflow rate into the CRE is measured using equation (4). Tracer gas is injected into the CRE ventilation system and, after waiting for concentration mixing to occur, a number of measurements of the resulting concentration within the CRE are obtained. Rewriting equation (4) yields the following:

$$q_{tot} = A*V \tag{9}$$

Where q_{tot} now represents the Total Air Inflow rate into the CRE. q_{tot} is made up of two components, namely, the amount of makeup air, $q_{m/u}$ and the amount of air inleakage, q_{inleak} .

Making use of these quantities, one can write an expression for the Total Air Inflow rate to the CRE as;

$$q_{tot} = q_{m/u} + q_{inleak} \tag{10}$$

Rearranging equation (10) to put the known quantities on the same side of the equation results in;

$$q_{inleak} = q_{tot} - q_{m/u} \qquad (11)$$

Since $q_{m/u}$ can be measured independently by using a tracer flow measurement technique, it is possible to calculate the Air Inleakage into the CRE using equation (11).

UNCERTAINTY CALCULATIONS

For the measured data provided below, the uncertainty of each CRE air inleakage measurement or duct flow rate measurement is calculated using the prescription provided in ANSI/ASME Standard PTC 19.1-1985 (Reaffirmed 1990) "Measurement Uncertainty" [8] and represent 95% confidence limits. This analysis is based upon equation (11) for the makeup flowrate/concentration decay tests, equation (8) for flow rates, and equation (4) for concentration decay tests. Uncertainties for all derived and measured quantities are incorporated into the analysis.

THE IMPORTANCE OF EQUILIBRIUM IN CONSTANT INJECTION TESTS

Reg Guide 1.197 mandates that tracer gas inleakage testing be undertaken using ASTM Standard E741. Unfortunately, the standard does not explicitly refer to the fact the equations found in the standard rely on solutions to the first order differential equation [equation (1) in this paper] describing conservation of mass in a control volume. To properly apply the equations found in ASTM E741, the tester must confirm that first order conditions are satisfied prior to using these equations.

The solution to equation (1) for a Concentration Decay Test is given by equation (2). In practice performing this test is straightforward and has been discussed extensively in the technical literature.

For a Constant Injection Method (also known as a Concentration Buildup/Steady State test), the solution to equation (1) is given by equation (5). The equations provided in ASTM E741 for a Constant Injection Test are satisfied when the exponential term has gone to zero, i.e. the system is in concentration equilibrium. Even when utilizing the boost technique to attain concentration equilibrium more rapidly some time must still elapse after the boost injection of tracer gas before approximate equilibrium is attained.

As an example of this phenomenon, for the CREEVS concentration history shown in Figure 4, the 4/A equilibrium time was more than 12 hours and the 5/A time was in excess of 15 hours. The initial tracer gas injection rate for this test was 4.75 SLPM for 90 minutes. The boost for this test used a 24 minute injection at 24.2 SLPM to expedite the approach to equilibrium, after which the tracer injection rate was returned to 4.75 SLPM for the remainder of the test. Note that even so, it required almost 10 hours to attain 99% equilibrium. The ultimate inleakage value was determined to be 85 +/- 38 SCFM. Based on Reg Guide 1.197 the inleakage would be taken as 85 SCFM. The plant Dose Analysis allowed 100 SCFM of inleakage.

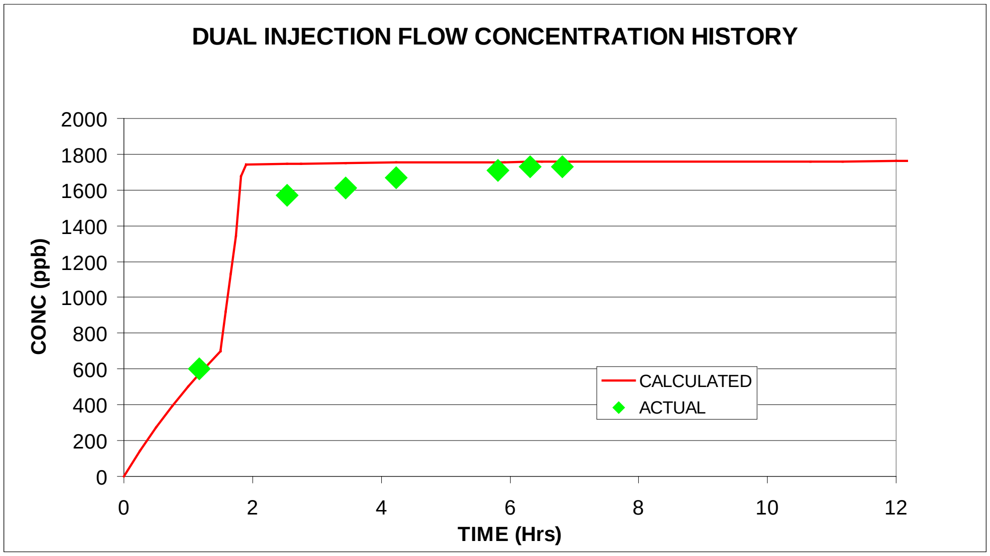


Figure 4. A Train calculated versus measured concentration at Plant A

ASTM E741 suggests taking 3/A as an approximate equilibrium value. For this same plant data, using the CRE concentration attained at 95 % of equilibrium, would have resulted in a calculated inleakage value of 105 +/- 38 SCFM. Based on Reg Guide 1.197 this inleakage would be taken as 143 SCFM and the plant would not have satisfied its Dose Analysis allowable inleakage.

By using the 95% versus the 99% equilibrium concentration value, the difference in reported inleakage value for the dose analysis would have been almost 70% greater. It should be emphasized once again that concentration values in a Concentration Buildup/Steady State test that are not true equilibrium values always *overestimate* the inleakage value.

As can be seen from this example, for those plants with low allowable inleakage values, it is important to attain an equilibrium concentration value. For High Equilibrium Time tests, even with the Boost Technique, attaining the proper equilibrium concentration can be especially problematic. It is possible that when using a Constant Injection Method to evaluate inleakage, a plant could fail an inleakage test solely because the CRE concentration had not attained a suitable equilibrium value.

REPEATABILITY OF INLEAKAGE DATA FOR THREE PLANTS

Three separate US nuclear plants were selected to demonstrate the repeatability of the Makeup Flowrate/Concentration Decay Test technique. Testing occurred at two or three different testing intervals depending upon the plant.

Inleakage Data for Plant 1

For the purposes of air inleakage testing at Plant 1, the Control Room Envelope consisted of the Main Control Room (MCR), adjacent Electrical Equipment Rooms, and the associated CREEVS ductwork. The CRE encompassed a volume of approximately 2235 m^3 (78,900 Ft^3). Two Mechanical Equipment Rooms are located outside the CRE.

A summary of the measured inleakage data encompassing six data sets over a 12 year span for Plant 1 is provided in Table 2. The mean inleakage for three tests on the B Train was 1.47 m^3/min (52 SCFM) with a standard deviation of 0.13 m^3/min (4.6 SCFM). A plot of these data with the attendant uncertainties is provided in Figure 5. The mean pressurization flow rates ranged from 7.02 to 8.04 m^3/min (248 to 284 SCFM).

Table 2

Inleakage data in m^3/min for Plant 1

Year	2004		2010		2016	
Train	A	B	A	B	A	B
Inleakage	0.74	1.50	0*	1.59	0*	1.33
Urss (+/-)	0.45	0.25	--	0.59	--	0.88

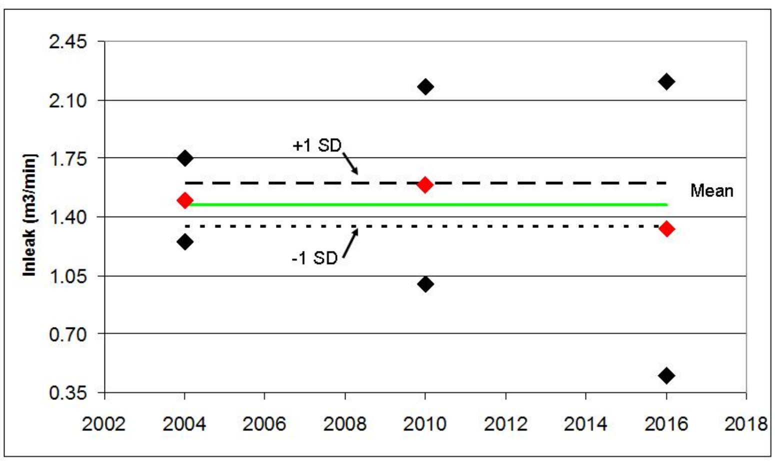


Figure 5. Inleakage data for Plant 1

In this figure, the red diamonds represent the measured inleakage rates, while the black diamonds represent the upper and lower 95% confidence limits for each measurement. The green line is the mean of the three measurements. The dashed black lines represent one standard deviation above and below the mean value for the three measurements.

The inleakage for the A train was initially measured as 0.74 m^3/min (26 SCFM). However the next A Train measurements at six and twelve years later evidenced values which were statistically indistinguishable from a zero value. Zero values were appreciated by the plant engineering staff, but they make a statistical comparison irrelevant.

Inleakage Data for Plant 2

For the purposes of air inleakage testing at Plant 2, the Control Room Envelope consisted of the Main Control Room (MCR), the adjacent Electrical Cabinet Rooms, and the associated CREEVS air handling and filtration units and ductwork. The Mechanical Equipment Room is located outside the CRE. The volume of the CRE is approximately 8350 m^3 (295,000 Ft^3).

A summary of the measured inleakage data encompassing four data sets over a 6 year span for Plant 2 is provided in Table 3. The mean inleakage for four tests on the CREEVS was 20.14 m^3/min (711 SCFM) with a standard deviation of 1.81 m^3/min (64 SCFM). A plot of these data with the attendant uncertainties is provided in Figure 6. The mean pressurization flow rates ranged from 34.6 to 38.1 m^3/min (1221 to 1347 SCFM).

Table 3

Inleakage data in m^3/min for Plant 2

Year	2004		2010	
Train	**A**	**B**	**A**	**B**
Inleakage	22.65	20.04	18.41	19.45
Urss (+/-)	3.57	3.37	4.39	3.77

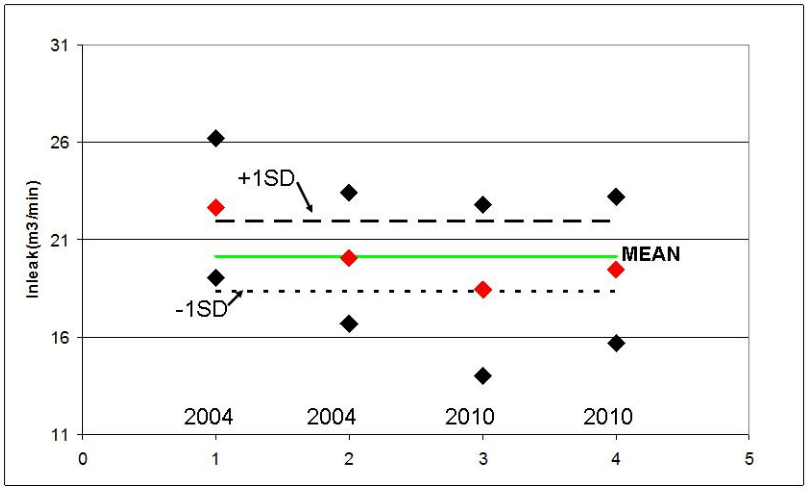


Figure 6. Inleakage data for Plant 2

In this figure, the red diamonds represent the measured inleakage rates, while the black diamonds represent the upper and lower 95% confidence limits for each measurement. The green line is the mean of the four measurements. The dashed black lines represent one standard deviation above and below the mean value for the four measurements.

Note that inleakage testing was repeated in 2017 with resulting inleakage values far in excess of 56 m3/min for each train. This result indicated that significant degradation of the CRE boundary and/or CREEVS had occurred and repair work was subsequently undertaken. Hence, the inleakage values from 2017 were not included in this analysis.

Inleakage Data for Plant 3

For the purposes of air inleakage testing at Plant 3, the Control Room Envelope consisted of the Main Control Room (MCR), the TSC, the Work Control Center, adjacent Support Rooms, as well as two distinct Mechanical Equipment Rooms. The CREEVS air handling and filtration units and ductwork are contained entirely within the CRE. A Train and B Train Computer Cabinet Cooler HVAC systems are located outside the CRE but are ducted to systems within the CRE. The CRE volume is approximately 10,200 m^3 (360,000 Ft^3).

A summary of the measured inleakage data encompassing three data sets over a 6 year span for Plant 3 is provided in Table 4. The mean inleakage for three tests on the CREEVS was 1.72 m^3/min (61 SCFM) with a standard deviation of 0.26 m^3/min (9.1 SCFM). A plot of these data with the attendant uncertainties is provided in Figure 7. The mean pressurization flow rates ranged from 50.6 to 52.3 m^3/min (1786 to 1847 SCFM).

Table 4

Inleakage data in m^3/min for Plant 3

Year	2004		2011	
Train	**A**	**B**	**A**	**B**
Inleakage	1.90	1.84	5.24	1.41
Urss (+/-)	2.69	2.38	4.81	4.30

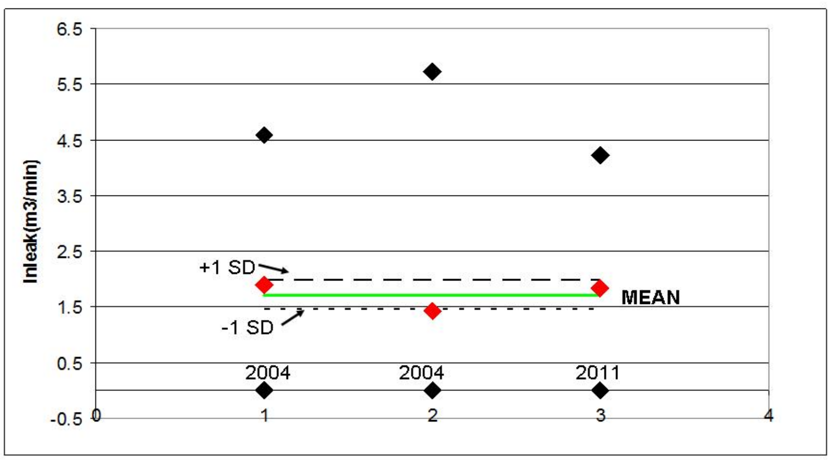


Figure 7. Inleakage data for Plant 3 excluding 2011 A Train outlier.

In Figure 7, the red diamonds represent the measured inleakage rates, while the black diamonds represent the upper and lower 95% confidence limits for each measurement. The green line is the mean of three measurements. The dashed black lines represent one standard deviation above and below the mean value for the three measurements.

Note that the A Train test in 2011 evidenced a significantly higher inleakage value than the three other measured values. It was subsequently discovered that there was substantial fan shaft seal leakage in the A Train Computer Cabinet Cooling system air handling unit. Because of this, the A Train test data from 2011 was not included in this analysis.

Additionally, a third test inleakage test program would have been scheduled for 2017. Unfortunately, this plant was shut down prior to its 6-year retest date.

CONCLUSIONS

For the inleakage values from the three plants tested using the Makeup Flowrate/Concentration Decay test, the Urss values for each individual test ranged from approximately 140% for plant 1 to approximately 20 % for plant 3. However, the standard deviations of multi-year set of measured inleakage values at each plant ranged from 8.8% to 15.1%. The measured inleakage values tended to remain within in one standard deviation of the mean of the data set suggesting that the PTC 19.1 uncertainty analysis may be overly conservative when evaluating the uncertainties in an individual inleakage measurement.

A singular advantage of the Makeup Flowrate/Concentration Decay test is that it can be usually performed in less than eight hours making the test attractive for High Equilibrium Time CREEVS. The downside of the test, however, is that knowledge of the actual free volumes of a typical nuclear power plant CRE may not be well determined and thus represents a significant source of uncertainty in the final inleakage result.

Previous analyses on Pressurization CREEVS evidenced standard deviation values that ranged from 17% to 21% of the mean for the multi-year set of inleakage values while the individual test Urss values sometimes approached 200%. Earlier studies on Recirculation CREEVS provided standard deviation values that were less than 2.5% although these tests were run at a single plant over four different days and may not be representative of that which would be measured for different plants that incorporate a Recirculation CREEVS.

In retrospect, based on the present results of the Makeup Flowrate/Concentration Decay test, as well as the results of previously discussed Buildup/Steady State tests, and Concentration Decay tests, it appears that the standard deviation of an individual inleakage measurement can be estimated to be approximately 20% of the measured value, assuming that no significant changes to the CRE or CREEVS have occurred.

However, since the overall uncertainty in any ***single*** measurement is subject to a large number of individual instrumental and measurement uncertainties, PTC 19.1 analysis remains a necessary method to quantitatively examine the measurement uncertainty for a ***single*** measured inleakage value.

REFERENCES

[1] Federal Register, 72, (10), pp. 2022-2033, US Govt. Printing Office, 2007

[2] Regulatory Guide 1.197 "Demonstrating Control Room Envelope Integrity at Nuclear Power Reactors" , US NRC, Washington, DC, 2003

[3] ASTM Standard E741, “Standard Test Method for Determining Air Change Rate in a Single Zone by means of a Tracer Dilution”, ASTM, Philadelphia. PA, 2000

[4] Lagus, P.L., “Air Inleakage Measurements in High Equilibrium Time Control Room Envelopes”, Proceedings of the 28th Nuclear Air Cleaning and Treatment Conference, Albuquerque, NM, 2004.

[5] Lagus, P.L., Udagawa, H.,Yamaji, T., and Grot, R.A. "Neutral Pressure CREEVS Inleakage Measurements", Proceedings of the 31st Nuclear Air Cleaning and Treatment Conference, Charlotte, NC, 2010. Proceedings of the 31st Nuclear Air Cleaning and Treatment Conference, Charlotte, NC, 2010.

[6] Lagus, P.L., Grot, K.R., Carlyle, J.W., and Helly, P.J., “Long Term Repeatability of Pressurization Mode Inleakage Tests”, Proceedings of the 34th Nuclear Air Cleaning and Treatment Conference, San Antonio, TX, 2016.

[7] ASTM Standard E2029, “Standard Test Method for Volumetric and Mass Flow Rate Measurement using Tracer Gas Dilution”, ASTM, Philadelphia. PA, 2000

[8] ANSI/ASME Standard PTC 19.1 1985 (Reaffirmed 1990), Part 1, “Measurement Uncertainty: Instruments and Apparatus”, American Society of Mechanical Engineers, New York, NY, 1990