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Component Leakage Testing using Tracer Gas Techniques

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With the publication of Draft Regulatory Guides 1114 and 1115, the proposed Generic Letter On Control Room Habitability, and NEI Document 99-03 on the habitability of the Control Room Envelope (CRE), the ability to reliably and accurately characterize the leakage characteristics of installed components in critical Nuclear HVAC applications has assumed increased importance and significance. Several plants have used the methodology described in NEI 99-03 to assess Control Room Emergency Ventilation System (CREVS) component leakage using pressure decay techniques that are commonly used in the ventilation testing industry. These results have been reported elsewhere.

It is also possible to undertake CREVS component testing using tracer gas techniques, and in fact, a number of plants have used these techniques in the course of performing integrated tracer gas inleakage tests. This paper will present the theory and practical difficulties of utilizing tracer gas techniques to measure component inleakage rates such as are required for CRE habitability analyses. Examples of the various component inleakage measurement techniques using actual data obtained during the course of various integrated CRE inleakage testing programs will be provided. Results from these tests will be used to illustrate the types of data and the potential sources of error that may arise during the use of tracer gas techniques.

1.0 Introduction

Integrated inleakage testing using tracer gas techniques as described in ASTM Standard E741 [1] has been performed in the nuclear power generating industry in the United States for approximately 12 years. During that time roughly 1/3 of the existing stock of Control Room Emergency Ventilation Systems (CREVS) and Control Room Envelopes (CRE's) have been tested to determine actual air inleakage rates for use in GDC 19-type habitability analyses.

The question often arises in the course of integrated inleakage testing as to where actual inleakage is occurring. This information aids in any subsequent sealing efforts that may be required and also allows segregation of filtered and unfiltered inleakage contributions to the total inleakage measured in an integrated test.

With the publication of the NEI 99-03 document [2] there has been industry-wide interest in the feasibility and efficacy of component testing to determine inleakage-at least for a limited class of Control Room Envelopes and Control Room Emergency Ventilation Systems-in lieu of integrated inleakage testing.

In the course of integrated testing undertaken by this investigator, the majority of programs also incorporated some type of component testing using tracer gas techniques. As is the case with the integrated test, all tracer gas component testing is based on the application of conservation of mass techniques. In the following sections, the mathematical basis for the various types of component tests will be described and measured data from actual tests will be provided as an aid in understanding the magnitude of inleakage values that can be determined by these techniques.

Common testing techniques as described in ANSI Standard N510 are the pressure decay and the constant-pressure flow test [3]. In a pressure decay test a component undergoing test is pressurized to some nominal overpressure. The decay is pressure is then measured as a function of time. The rate of decay coupled with a knowledge of the actual volume of the component and the temperature of the pressurizing gas allows calculation of actual leakage flow.

In a constant pressure flow test, the flow of air (or nitrogen) required to maintain a certain differential pressure across a component is measured. This flowrate is then considered to be the leakage flow that is characteristic of the component.

While the pressure decay and constant-pressure flow test techniques enjoy wide acceptance in the ventilation testing industry, there are several disadvantages to their use in the nuclear power plant control room inleakage assessment context.

In many cases components to be tested are required to be blanked off with impermeable plates in order to measure pressure decay in a section of ductwork, an air handling unit housing, or similar component. This requires that the ventilation system be made inoperable prior to, during, and for some time after the actual testing since the system must be opened to allow placement of the blank-off plate and then reconstituted to its original configuration.

Sometimes testing may be undertaken across a component that can be isolated by ''zero leak'' dampers. In this case the question naturally arises as to whether any measured leakage is characteristic of the component or is caused by leakage across the dampers.

Testing of component leakage using any type of pressure test, by its very nature, does not accurately replicate the actual pressure distribution that a component may experience when it is operated in a plant context. Pressure tests are inherently one-dimensional, i.e. the component is subjected to a hydrostatic differential pressure that is positive and is everywhere the same magnitude along the entire component. Yet in actual operation, a component such as an air-handling unit housing is subject to both positive and negative differential pressures at the same time along different sections of the housing. In some cases, a component, such as a run of return air ducting, may even be subjected to a differential pressure gradient in actual operation.

A more perplexing difficulty is that a pressure test assumes that the leakage measured from the component being tested under a positive differential pressure will be the same as that when the component experiences a negative differential pressure. This may not be the case and represents both a major assumption of any pressure test and a major source of uncertainty in the interpretation of the results. We should note here that inleakage is commonly associated with a negative differential pressure on a component of interest.

Finally, use of the pressure and flow techniques solely to determine overall inleakage requires the assumption that all leakage sites can be identified by inspection. While this assumption may be valid for systems that exhibit a small number of potential inleakage sites, it is unlikely that simple inspection will divulge the location of all possible inleakage sites for systems exhibiting even a moderate degree of complexity.

2.0 Tracer Gas Component Testing

In all tracer gas component tests, a concentration of tracer gas is established either within a component that is to undergo testing or within a control volume surrounding the component. Then the magnitude of, or the change in, tracer gas concentration within the component or the control volume is measured. Judicious use of conservation of mass equations allows one to deduce the leakage that would cause an observed value of the measured tracer gas concentration.

In the following sections we shall discuss the following test types. These tests should realistically encompass the types of components encountered in actual field testing situations.

1. Inleakage into a CREVS component using the concentration decrease method.
2. Inleakage into a CREVS component using the control volume method.
3. Inleakage into several joined CREVS components using the concentration decrease method.
4. By-pass leakage across isolation dampers by a constant flow technique.
5. By-pass leakage across isolation dampers by a tracer buildup technique
6. By-pass leakage across isolation dampers by a tracer decay technique.
7. Outleakage from a CREVS component using the control volume method.
8. Outleakage from a non- CREVS component that traverses a CRE.
9. Inleakage across a CRE structural component.

All of the techniques that are described below rely on the use of conservation of mass concepts. In addition, tracer gas within the component or the control volume must be well mixed. Often the uncertainty associated with a given measurement is directly proportional to the degree to which good mixing has been achieved.

Note that all of the methods described below used sulfur hexafluoride, SF6, as a tracer gas. Tracer gas analysis was accomplished by means of one or more electron capture chromatographs that were specifically configured for the detection of SF6.

3.0 Inleakage into a CREVS component using the concentration decrease method

It is possible to quantify the amount of inleakage into a section of ductwork (or, for that matter, any component that is topologically similar to a duct such as an air handling unit housing, or an entire room) during a tracer gas injection through the duct section. Applying the conservation of mass to airflow in a section of duct (see Figure 1), we arrive at

$$C_D \bullet (Q_{Duct} + I) = C_U \bullet Q_{Duct} \tag{1}$$

From which

$$I = Q_{Duct} \bullet \left[(C_U / C_D) - 1 \right] \tag{2}$$

where;

I = Inleakage Rate
Q_{Duct} = Duct Flowrate
C_U = Concentration Upstream of (entering) Duct Section
and, C_D = Concentration Downstream of (leaving) Duct Section

Note that in order to apply equation (2) the flowrate of air entering the section of duct must be known or measured. In practice one often uses a hot wire anemometer or Pitot tube traverse to measure this flowrate.

In Table 1 we provide actual measured duct inleakage data from an operating CREVS. Note that for the analyzers used in this testing the minimum ratio that could be reliably and repeatably detected was on the order of 1.01

Thus by making only a small number of tracer gas measurements, it is possible to reliably measure the inleakage into a section of ductwork under actual operating conditions. Note that the derivation of equation (2) assumes that the tracer gas in well mixed. In practice one can measure the tracer concentration contemporaneously at a number of locations along a plane perpendicular to the axis of the duct and thereby obtain an average value for concentration and hence duct inleakage. A similar experimental approach can be used for air handling unit housings or any other component with a similar geometric shape.

Note that this technique is not usable for very small inleakage values since, at some concentration value difference, it becomes impossible for the tracer gas analyzer to distinguish between the “upstream” and the “downstream” tracer gas concentrations. This technique does require the use of an analyzer with excellent repeatability and minimal drift.

4.0 Inleakage into a CREVS component using the control volume method.

As alluded to above, at very small inleakage values, it becomes impossible to distinguish between the “upstream” and “downstream” concentration values. In such a situation a companion technique has proven useful.

It is possible to quantify the amount of inleakage into a section of ductwork by creating a concentration of tracer in a control volume surrounding the duct section. Applying the conservation of mass to inleakage and airflow in a section of duct (see Figure 2), we arrive at the following expression:

$$C_{CV} \bullet I + C_U \bullet Q_{Duct} = C_D \bullet (Q_{Duct} + I) \qquad (3)$$

from which

$$(C_{CV} - C_D) \bullet I = (C_D - C_U) \bullet Q_{Duct} \qquad (4)$$

In all practical situations C_{CV} is >> C_D, hence

$$I = (C_D - C_U) \bullet Q_{Duct} / C_{CV} \qquad (5)$$

where;

I = Duct Inleakage Rate
Q_{Duct} = Duct Flowrate
C_U = Concentration Upstream of Duct Section
C_D = Concentration Downstream of Duct Section
C_{CV} = Concentration in Control Volume

Note that in order to apply equation (5) the flowrate of air entering the section of duct must be known or measured. For maximum sensitivity to inleakage, equation (5) requires that there exist no tracer gas in the air entering the duct (i.e. upstream concentration is zero).

Measured inleakage data using this technique are provided in Table 2.

5.0 Inleakage into several CREVS components using the concentration decrease method.

In the case of two ducts merging into a third it is also possible to quantify leakage at the junction of the ductwork.

Applying conservation of mass concepts to the duct flowrates and duct concentrations illustrated in Figure 3, it is possible to derive the following equation:

$$Q_1 \bullet C_1 + Q_2 \bullet C_2 = Q_T \bullet C_T \qquad (6)$$

and

$$Q_T = Q_1 + Q_2 + I \qquad (7)$$

from which

$$I = (Q_1 \bullet C_1 + Q_2 \bullet C_2 - (Q_1 + Q_2) \bullet C_T) / C_T \qquad (8)$$

where

I = Inleakage at junction
Q_T = Flow in downstream duct
Q_1 = Flow in first upstream duct
Q_2 = Flow in second upstream duct
C_T = Tracer Concentration in downstream duct
C_1 = Tracer Concentration in first upstream duct
C_2 = Tracer Concentration in second upstream duct

It should be apparent that equation (8) could be extended to any number of components that join a common header by incorporating the flowrate and tracer concentration contribution of each into equation (6).

Tracer gas concentration data obtained in two separate measurements of leakage at the triple junction are provided in Table 3.

The ductwork involved in this measurement was heavily insulated. Thus, there was considerable reluctance on the part of the plant to remove the insulation. However since the measured inleakage at this junction was substantial and gave a similar result for two different operating ventilation trains, the insulation was eventually removed. It was discovered that an approximately 36 inch long tear in a duct seam at the triple junction had occurred.

6.0 Inleakage across isolation dampers by a constant flow technique.

A direct way to measure by-pass leakage across a damper is to measure the air flowrate through a section of duct containing a damper. Recall that it is possible to use a constant tracer gas injection technique to measure the flow in a duct. The relevant equation is

$$Q_{Duct} = S / C_{av} \qquad \textbf{(7)}$$

where,

Q_{Duct} = Duct flowrate
S = Tracer gas injection rate
C_{av} = Average Concentration measured across the duct

If there is no leakage through the damper, there will be no flow through the duct. If the leakage is large enough, this flowrate can be measured by conventional means, i.e. Pitot tube traverse or hot wire anemometer traverse. However, for low leakage rates, with correspondingly low duct flow velocities, such a direct measurement is not always practical due to the inability of the flow velocity measurement technique to exhibit suitable accuracy and resolution at low velocity.

Using a constant injection rate tracer gas test it is possible to measure very low duct flowrates. The tracer gas method for measuring by-pass leakage across dampers relies on the use of a continuous injection of tracer gas to infer flowrate through a section of duct containing a damper.

An individual damper by-pass leakage rate test is normally performed by injecting a tracer gas at a known rate into a section of duct immediately upstream or downstream of a damper, waiting for tracer equilibrium to occur, and then measuring the equilibrium tracer gas concentration either immediately upstream or downstream of the damper while the tracer gas injection continues. Samples are taken at spatially distinct locations within a fixed plane perpendicular to the duct axis. These are then analyzed for tracer concentration values.

This equilibrium concentration in the duct is inversely proportional to the flowrate through the damper and hence is inversely proportional to the amount of by-pass leakage. Thus, the measured concentration allows calculation of the amount of by-pass leakage through an individual damper. The basic test configuration is illustrated in Figure 4.

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

$$Q_{bypass} = S / C_{av} \qquad (8)$$

where, Q_{bypass} , is now the by-pass leakage across the particular damper. Measurement of tracer samples from the duct yield values of tracer concentration that are used in equation (8) to calculate by-pass flowrate or by-pass leakage.

In essence, the technique uses a tracer gas measurement of flowrate *through* a damper to allow evaluation of potential by-pass leakage. The measurement technique is identical to that used to measure flowrate in a duct. The tracer gas flow rate measurement technique is described in ASTM Standard E 2029. [4]

Dampers CD 34203 and CD 34204 were individual dampers in their respective duct runs and as such could be tested in with a straightforward application of the above described technique. A schematic layout of these dampers is illustrated in Figure 5. For each of these dampers injection occurred at location A immediately downstream of the damper as shown on Figure 5, while tracer gas sampling occurred at sampling location A located approximately 10 to 20 feet downstream of the damper. Tracer was injected for five minutes prior to the onset of sampling for each of these dampers.

Duct air samples were obtained using disposable polypropylene syringes in conjunction with a pump/manifold sampling system. Each sampling system consisted of a pump connected to a multi-position sampling valve. A Swage tee and septum fitting was affixed to the sample pump exhaust. A probe consisting of a 36-inch section of stainless steel tubing was connected to a length of polyethylene tubing, which was itself connected to the multi-position valve. The probe was moved to various locations within the duct in a plane at right angles to the duct after which individual samples were drawn by the pump/manifold system into individual polypropylene syringes for subsequent analysis.

For duct air samples taken in round duct replicate samples were taken from 0.25, 0.5 and 0.75 of the diameter of the duct along two perpendicular diameters. Duct air samples in rectangular ducts were taken at grid points corresponding to 0.25, 0.5, and 0.75 of the width and of the length of each duct.

For these tests, tracer gas injection flowrate was controlled by an electronic mass flow controller in conjunction with an electronic mass flow meter. The injection gas source was a cylinder of 9.82 ppm SF6 in nitrogen. The injection flowrate for the tests was 2.0 SLPM. Tracer concentration data and resulting flowrates are provided in Tables 4a and 4b for these two dampers.

7.0 Inleakage across isolation damper by a tracer buildup technique.

An interesting experimental challenge was presented by the damper configuration illustrated in Figure 6. Damper 54C isolated the Control Room Supply duct from the A System Air Handling Unit Cooling Coil Housing. This unit, in turn, was connected by a short length of duct to an Air Handling Unit Fan housing. The technique described above was inappropriate for testing potential by-pass flow across this damper since in its normal configuration there is no physical location that allows tracer gas injection across the 54C damper.

Accordingly a concentration buildup test was proposed. A sheet of builder's plastic was spread over the duct connection between the Cooling Coil Housing and the Fan Housing. Several 12-inch long slits were cut in this sheet to minimize backpressure buildup within the volume.

For this case, concentration buildup data are can be analyzed by considering the definition of concentration within a control volume:

Concentration = Volume of Tracer Gas/Volume of Control Volume

Since we have postulated a leak into a fixed volume, the concentration in the volume will increase with time.

It can be shown that if tracer gas in injected into the Control Room Supply duct, any tracer concentration within the Cooling Coil Housing volume is given by the following equation:

$$C_H = C_{CRS} \bullet Q_{bypass} \bullet t / V_H \tag{9}$$

This can be re-arranged to provide a value for Q_{bypass}

$$Q_{bypass} = C_H \bullet V_H / (C_{CRS} \bullet t) \tag{10}$$

where,

Q_{bypass} = Damper by-pass leakage
C_H = Tracer Concentration in Coil Housing
V_H = Volume of Coil Housing
C_{CRS} = Tracer Concentration in Control Room Supply Duct

Since at the beginning of the test it was not clear how well tracer would penetrate the coils, tracer gas samples were taken at timed interval from both side of the coil. Large circulating fans were placed on each side of the coil in order to enhance mixing. During the actual testing the concentration values differed by less than 2%, hence the assumption that the tracer was well mixed was satisfied.

A mixture of approximately 1% SF6 in nitrogen was injected into the Control Room Supply Duct at a rate of 0.97 SLM. The resulting concentration was 26.4 ppb. Measured tracer data are provided in Table 5 along with the measured value of Q_{bypass}.

8.0 By-pass leakage across isolation damper by a tracer decay technique.

The damper configuration for this test is shown in Figure 7. For this particular test, it was known that the leakage was higher than could be used with the buildup test described above. Accordingly a tracer concentration decay test was initiated. Tracer gas was injected into the DS side of the damper enclosure. A builders plastic sheet was installed slightly downstream of the damper to create a control volume. Several slits were made in the sheet to allow pressure equilibrium and flow to occur across the damper. Gas samples were taken from the geometric center of the volume by means of a sampling pump system connected to length of polypropylene tubing. A large circulating fan was emplaced within the volume to ensure that adequate mixing of the tracer gas occurred.

Recall that the simplest tracer gas technique is the tracer concentration decay test. After an initial tracer injection into a test volume, and assuming A is constant, the concentration as a function of time is given by: [5]

$$C = C_0 \exp(-A \cdot t) \qquad (11)$$

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 (11) is often recast to the following form;

$$\ln C = \ln C_0 - A \cdot t \qquad (12)$$

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 (12). The slope of this straight line is A, the air exchange rate.

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

To calculate the air inleakage rate, one must have independent knowledge of the test volume from which,

$$L = A \cdot V \qquad (13)$$

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.

Resulting data from this test are provided in Table 6

Regression of the natural logarithm of the concentration data versus time yields an air exchange rate of 0.781 Air Changes per Minute (ACM). The volume of the control volume was 28.65 cubic feet resulting in a by-pass leakage rate of 22.5 CFM.

9.0 Outleakage from a CREVS component using the control volume method.

To perform an outleakage test on a run of duct, it is necessary to create a test volume around it. At this plant outleakage from the positive differential pressure makeup duct constituted *inleakage* into the CRE since the section of ductwork lay within the CRE.

For this particular run of duct, the control volume was a tent erected using metal framing and builder's plastic sheeting. By applying the conservation of mass to airflow in a section of duct (see Figure 8), equation (14) below can be derived.

A concentration of tracer gas was established in the duct, and the resulting tracer concentration history within the control volume surrounding the duct was measured. So long as the outleakage rate remains approximately constant, the outleakage rate can be calculated by using equation (15) below.

Duct outleakage data can be analyzed by considering the definition of concentration within a control volume:

Concentration = Volume of Tracer Gas/Volume of Control Volume

Since we have postulated an outleak into a fixed volume, the concentration in the volume will increase with time. In symbols, for an outleak from a duct section into a control volume

$$C_{CV}(t) = O \bullet C_{Duct} \bullet t / V_{CV} \qquad (14)$$

where O = Duct Outleakage Rate
C_{CV} = Concentration in Control Volume
t= Time
C_{Duct} = Duct Concentration
V_{CV} = Volume of Control Volume

If we now difference equation (14) for two times t_2 and t_1, we arrive at equation (15)

$$O = m \bullet V_{CV} / C_{Duct} \qquad (15)$$

where:

$$m = (C_2 - C_1)/(t_2 - t_1)$$

Equation (15) is valid for early times or low leakage rates. When the numerator of equation (14) becomes large compared to the denominator, the definition of concentration must be modified to include the additional volume of gas provided by the outleakage. Note also that for this test, the flow rate through the duct must be constant, however it is not necessary to measure the duct flowrate in order to determine duct outleakage.

Actual data are provided in Table 7. The measured tracer concentration values were regressed against time in minutes to arrive at a slope of 0.817. The third column in Table 7 provides the expected control volume concentration using the regression equation. As can be seen the agreement is excellent. The tracer concentration in the duct was measured as 146 ppb. The control volume enclosed 210 cubic feet.

Using equation (15), the outleakage from this run of ductwork was found to be 1.17 CFM.

10.0 Outleakage from a non- CREVS component that traverses a CRE.

The basic configuration required to undertake this test is illustrated in Figure 9. In general, this test seeks to quantify the leakage out of a duct (or other such component) into the Control Room Envelope. Generally these ducts are parts of an ancillary ventilation system that is not associated with the Control Room Emergency Ventilation System. Ducts such as these are often routed through the CRE for ease of installation and directness of routing. To represent a potential source of leakage into a CRE, the duct must be operated at a static pressure that is higher than that within the CRE.

In order to evaluate duct outleakage into a CRE, recall that for a constant tracer gas injection source, the resulting concentration in a ventilated, well-mixed zone is given by the following equation; [6]

$$C(t) = (S/Q) \bullet (1 - \exp(-A \bullet t)) \qquad (16)$$

where,

C = Concentration at time t
t = Time
S = Tracer injection rate
Q = Fresh air supply rate
A= Air exchange rate

If we now inject tracer gas into the duct traversing the CRE and consider the outleakage from the duct as the source of tracer, we can define S as equal to the product of the actual outleakage rate O, and the concentration of tracer in the duct, C_{Duct}. In symbols,

$$S = O \bullet C_{Duct} \qquad (17)$$

Rearranging equation [16] in light of equation [17] yields;

$$O = [C(t)/C_{Duct}] \bullet Q/[1 - \exp(-A \bullet t)] \qquad (18)$$

By measuring the tracer gas concentration within the CRE at several different times, one can use equation (18) to arrive at values for O.

Mixing fans may be required to ensure that the CRE is well mixed. However, experience in the majority of nuclear power plant Control Room Envelopes has shown that the air flow into well-ventilated rooms is sufficient to mix tracer over a reasonable time interval prior to initiation of sampling. Mixing, of course, should be confirmed by measurement. If sufficient mixing cannot be achieved then additional fans should be emplaced with the CRE.

Note that to undertake this calculation an independent estimate of the air exchange rate, A, is required. This can be calculated from makeup flowrates if the inleakage is a small fraction of the makeup flowrate, or it can be measured directly by means of a concentration decay test.

11.0 Inleakage across a CRE structural component.

At this particular plant, the Cable Spread Room lay directly beneath the Main Control Room and comprised part of the Control Room Envelope. An extensive sealing program had been undertaken on the south and east walls of the Cable Spread Room as prior testing with smoke pencils had disclosed the existence of substantial inleakage through the myriad cable penetrations in these two walls.

Accordingly control volumes were erected abutting these two walls at locations that encompassed the cable penetration locations. Each control volume was a tent erected using metal framing and builder's plastic sheeting. Tracer gas decay tests were initiated in both control volumes. In each volume a large circulating fan was emplaced to assist in mixing the tracer gas.

A typical control volume installation is shown on Figure 10. Measured tracer concentration data for both the south and east control volumes are provided in Table 9.

In Table 10 we provide the air exchange rate and resulting inleakage rates for both of the volumes. Note that due to the low concentration values achieved in the south volume the regression fit was not as statistically good as in the case of the east volume.

12.0 Conclusions

It must be explicitly pointed out that all of the techniques described previously require that the tracer gas be well mixed within the test volume of interest. Often mixing can be enhanced by the use of inexpensive oscillating fans. In order to use the equations presented with any confidence, however, the degree of mixing should be experimentally verified by means of tracer concentration measurements at a number of spatially separated locations within the test volume.

No attempt has been made in this paper to undertake a systematic evaluation of the measurement uncertainties attendant to each method. This can be most usefully accomplished during actual data analysis using accepted statistical methods such as those provided in ANSI/ASME PTC 19.1. [7]

Because of the fact that the attainment of good mixing of tracer gas may not always be achievable within a given component, a quantitative estimate of the leakage into a particular component may not be possible. However, even for these components the techniques presented can provide a qualitative measure of leakage that often can be used to rank potential leakage locations for the purposes of remediation and retrofit.

It should be noted that the tracer gas component testing method shares a common difficulty with the pressure and flow test methods, namely that the likely leakage component must be identified prior to undergoing actual testing. In some CREVS this may be a difficult task. Accordingly care must be exercised in the use of this method in lieu of integrated testing techniques.

Two major advantages of using a tracer gas technique as opposed to a pressure or flow technique, are that 1) the CREVS need not be rendered inoperable during the testing, and 2) that the pressure distribution that the component experiences during testing is the same as the component would experience during actual emergency operation of the CREVS.

The most efficacious use of the techniques presented in the previous sections is as an adjunct to an integrated test. If unacceptable CRE inleakage values are detected, likely leakage sites may be ranked thereby allowing remedial actions such as retrofitting, replacement or redesign to be accomplished first on the actual components providing the largest contribution to overall inleakage.

In addition, for those CREVS that provide both filtered and unfiltered inleakage, these techniques must be used to distinguish between the two types of inleakage as they represent vastly different inleakage contributions in any habitability calculation.

13.0 References

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[2] NEI Document 99-03, "Control Room Habitability Assessment Guidance", Nuclear Energy Institute, Washington DC, 2001

[3] ASME Standard N510-1989, "Testing of Nuclear Air Treatment Systems", American Society of Mechanical Engineers, New York, NY, 1989

[4] ASTM Standard E2029-00, "Standard Test Method for Volumetric and Mass Flow Rate Measurement using Tracer Gas Dilution", ASTM, Philadelphia. PA, 2000

[5] Lagus, P.L., Adams, D.G., Grot, R.A, Pearson, J.R., and Fleming, K.M., "Control Room Air Inleakage Testing at Two Nuclear Power Plants" in Proceedings of the 25th NRC/DOE Air Cleaning Conference, Minneapolis, 1998

[6] Lagus, P.L., and Grot, R.A., "Control Room Envelope Unfiltered Air Inleakage Test Protocols" in Proceedings of the 24th NRC/DOE Air Cleaning Conference, Portland, 1996

[7] 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

Table 1

Measured Ductwork Inleakage Values

Duct Run	Ratio	Flowrate (CFM)	Duct Inleakage (CFM)
R2 to R3	1.0869	9200	799
R3 to R7	1.0244	7200	176
R3 to R4	1.0182	1080	20
R5 to R6	1.0351	2000	70

Table 2

Duct Inleakage using the Control Volume Method

Time (min)	Control Vol Conc (ppb)	US Conc (ppb)	DS Conc (ppb)	Inleakage (CFM)*
0	750	1.395	2.153	10.2
2	630	1.429	2.033	9.6
4	510	1.414	1.807	7.7
6	440	1.435	1.854	9.6
8	370	1.416	1.713	8.1
10	300	1.408	1.757	11.7
			MEAN	9

* Measured duct flowrate was 10,145 CFM

Table 3

Inleakage at Triple Junction

Train	C1 (ppb)	C2 (ppb)	CT (ppb)	Q1 (CFM)	Q2 (CFM)	**I (CFM)**
A	10.72	10.90	10.22	6291	5481	**675**
B	27.80	28.22	26.48	6173	6184	**714**

Table 4a

By-pass Leakage Damper CD 3420

TIME (MIN)	CONCENTRATION (PPB)
5	22.6
5.5	23.1
6	23.4
6.5	18.0
7	7.8**
7.5	26.8
12	23.6
12.5	22.9
13	23.1
13.5	15.7
Mean Conc.	22.13
Std Dev (%)	10.4
By-pass Leakage	31 +/- 9

**Eliminated as outlier using ASTM E 178-80 "Standard Practice for Dealing with Outlying Observations"

Table 4b

By-pass leakage damper CD34203

TIME (MIN)	CONCENTRATION (PPB)
5	39.2
5.5	39.3
6	38.0
6.5	38.7
7	40.2
7.5	40.8
8.5	39.0
9	35.0
9.5	37.8
10	39.9
Mean Conc.	38.67
Std Dev (%)	4.3
By-Pass Leakage	18 +/- 2

Table 5

By-pass Leakage for Damper 54C

Elapsed Time (min)	Mean Conc (ppb)	By-pass Leakage (SCFM)
20	33.95	32.1
25	43.1	32.6
30	55	34.67
40	74.5	35.22
50	84.45	31.94
	Mean Value	33.3
	Std Dev	+/- 1.5

Table 6

Tracer Concentration Decay Data Damper OFCV-PV44

Elapsed Time (min)	Conc (ppb)
1	41.3
2	19.77
3	7.75
4	3.10
5	1.45
6	0.72
7	0.45
A	0.781 ACH
By-pass leakage	22.5 CFM

Table 7

Duct Outleakage into Control Volume

Time (min)	Cmeas(ppb)	Ccalc(ppb)
6	1.77	1.78
7	2.63	2.60
8	3.34	3.41
9	4.24	4.23
10	5.14	5.04
11	5.80	5.86

Table 8

Duct Outleakage into the CRE

Time [min]	CRE Conc [ppb]	Duct Conc [ppm]	Outleakage [CFM]
15	38.0	3.0	115
20	56.3	3.0	134
		MEAN	

Table 9

Tracer Concentration in Wall Test Control Volumes

Elapsed Time (min)	East Control Volume Concentration (ppm)	South Control Volume Concentration (ppm)
0	2.67	0.95
10	1.82	0.52
20	1.31	0.42
30	1.01	0.40
40	0.79	0.42

Table 10

Air exchange and inleakage rate across Cable Spread Room walls

	East	South
Volume (CuFt)	2754	861
Air Exchange Rate (ACH)	1.81	1.13
Inleakage (CFM)	83.3	16.3

Figure 1. Concentration Decrease Method

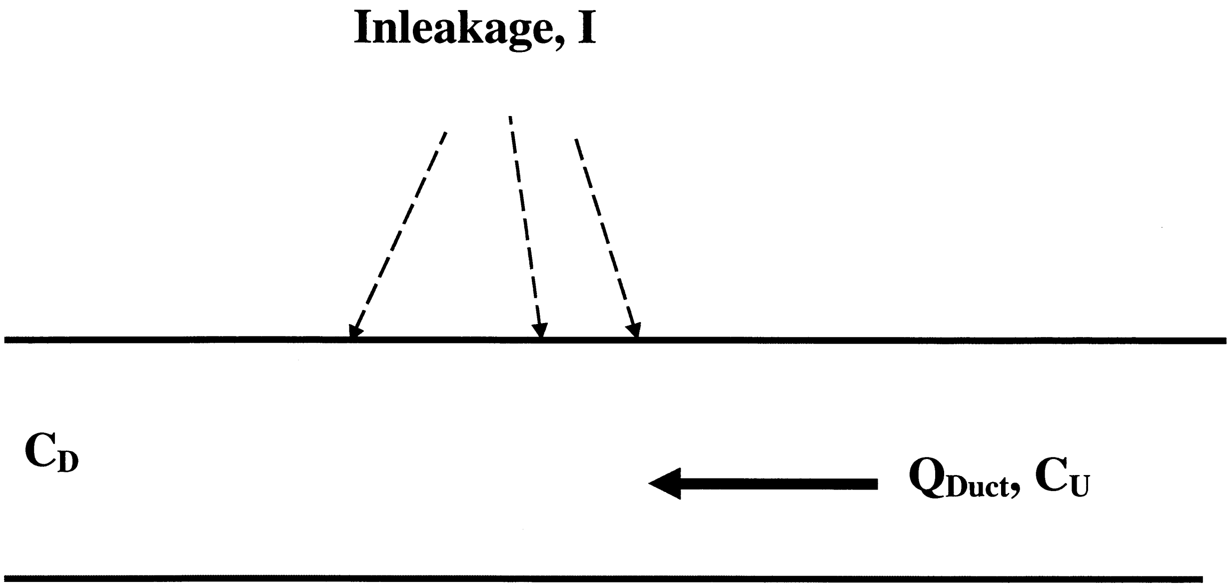

Figure 2. Control Volume Method

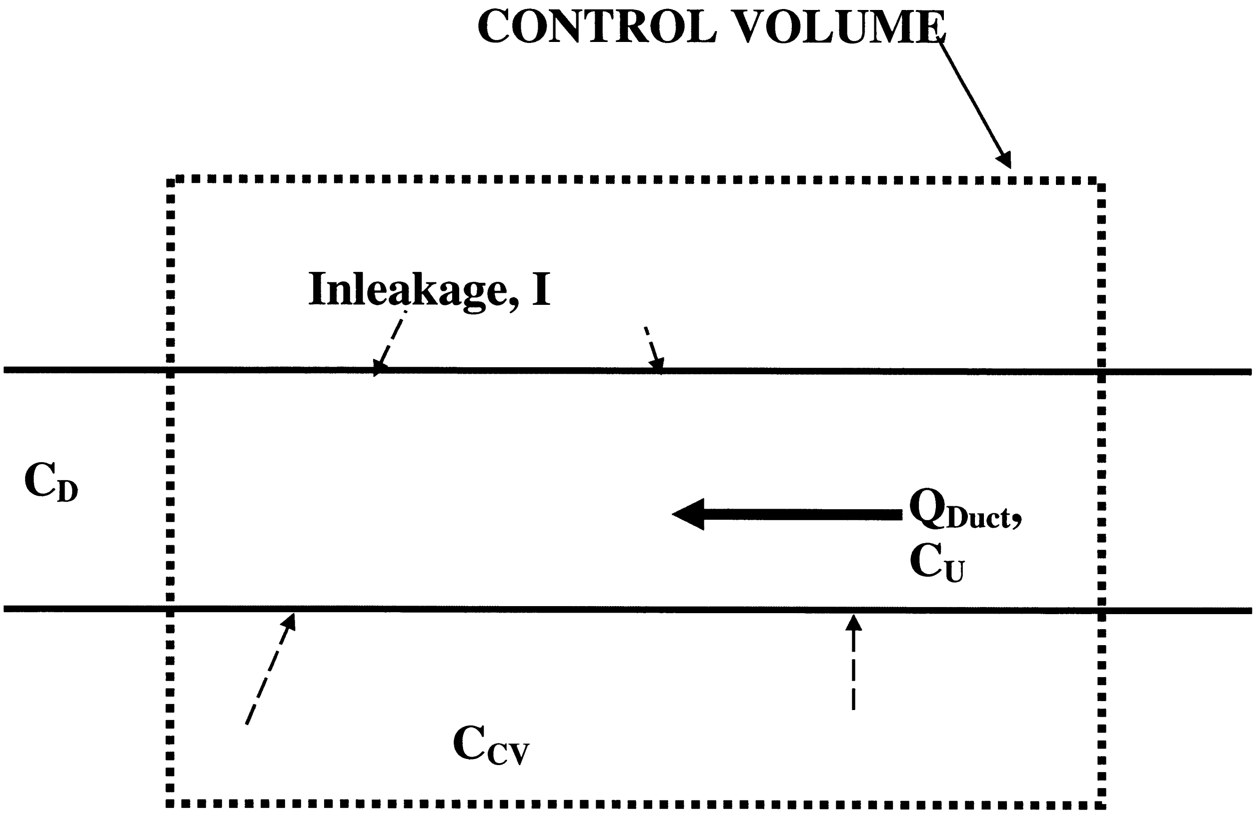

Figure 3. Multiple Branch Concentration Decrease Method

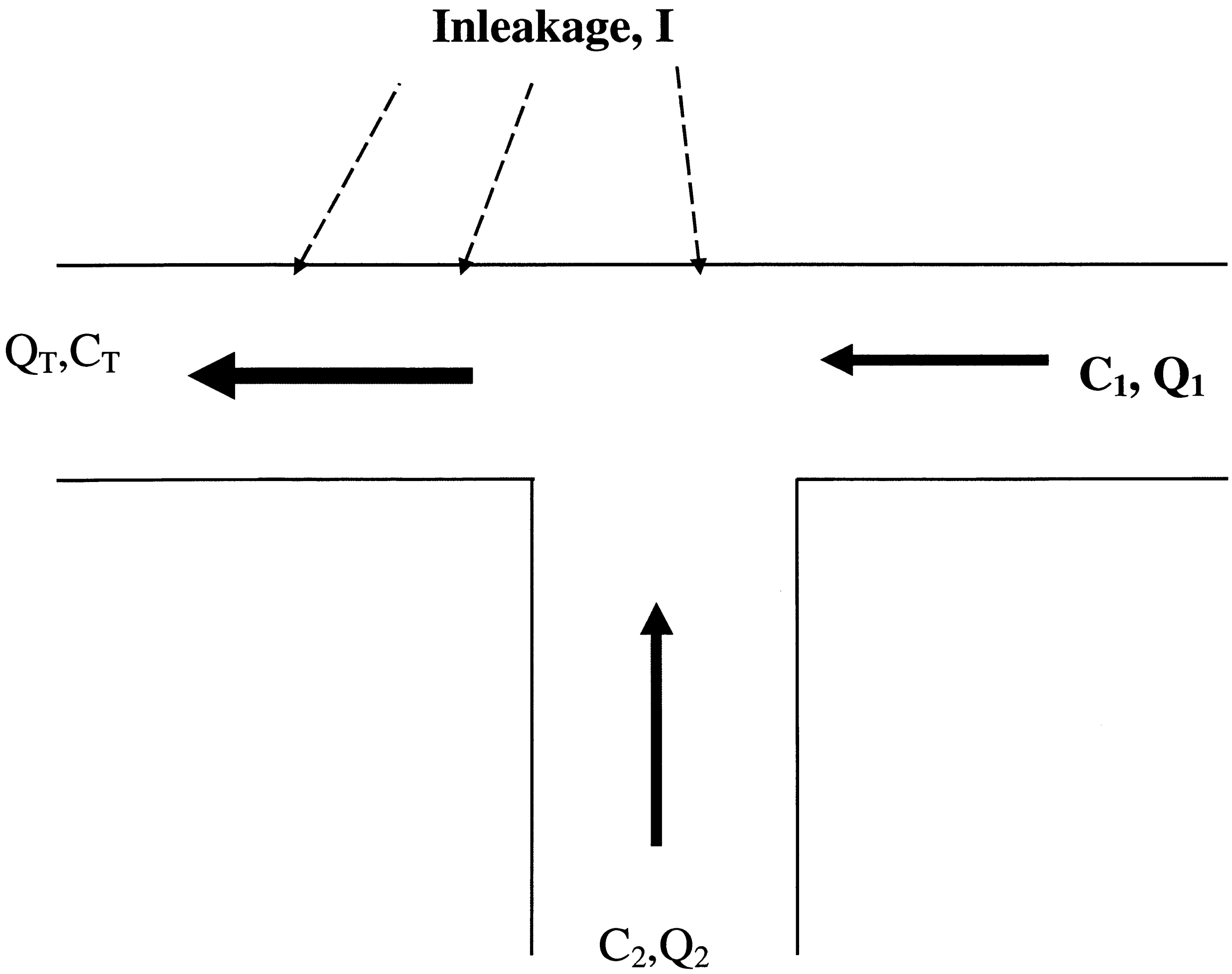

Figure 4. Damper Test Configuration

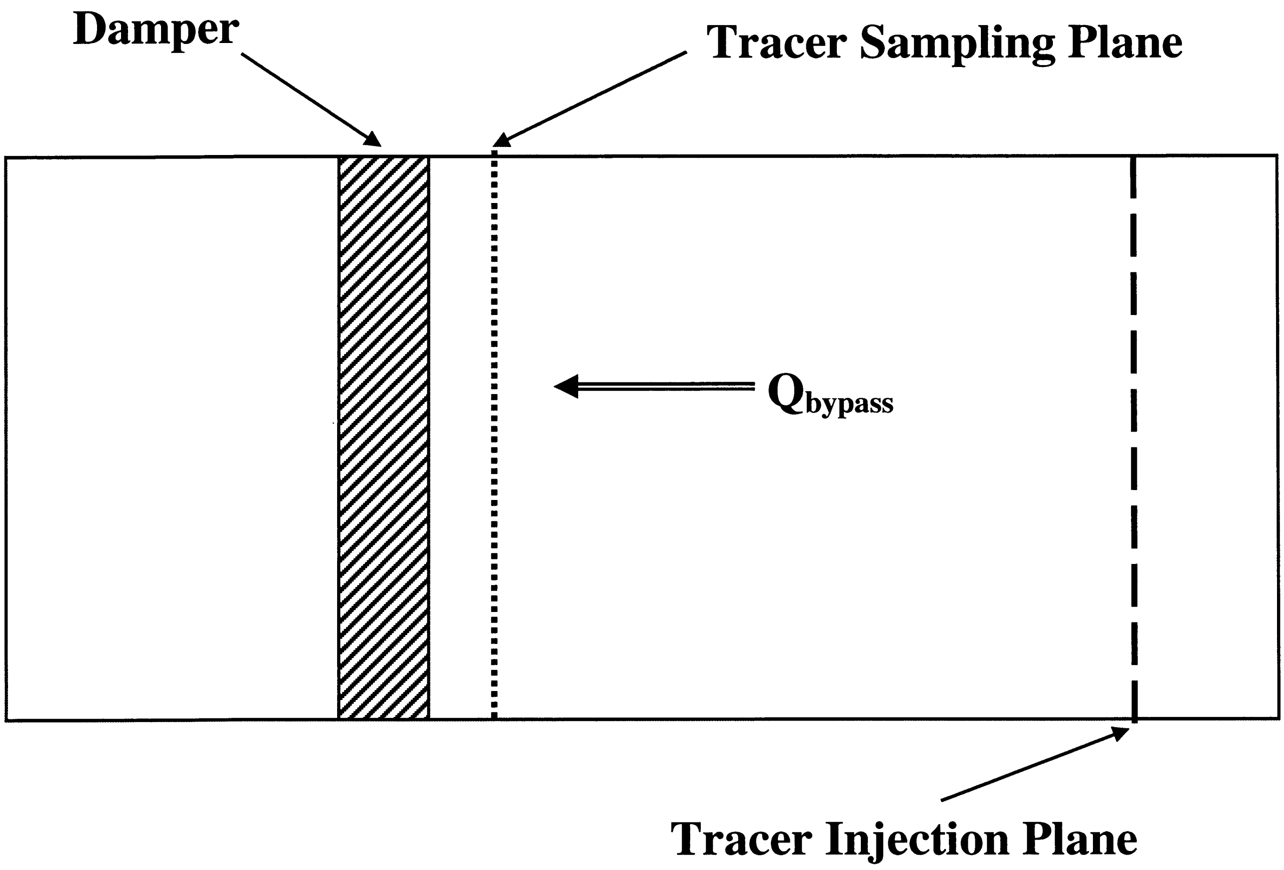

Figure 5. Damper Layout for CD Dampers

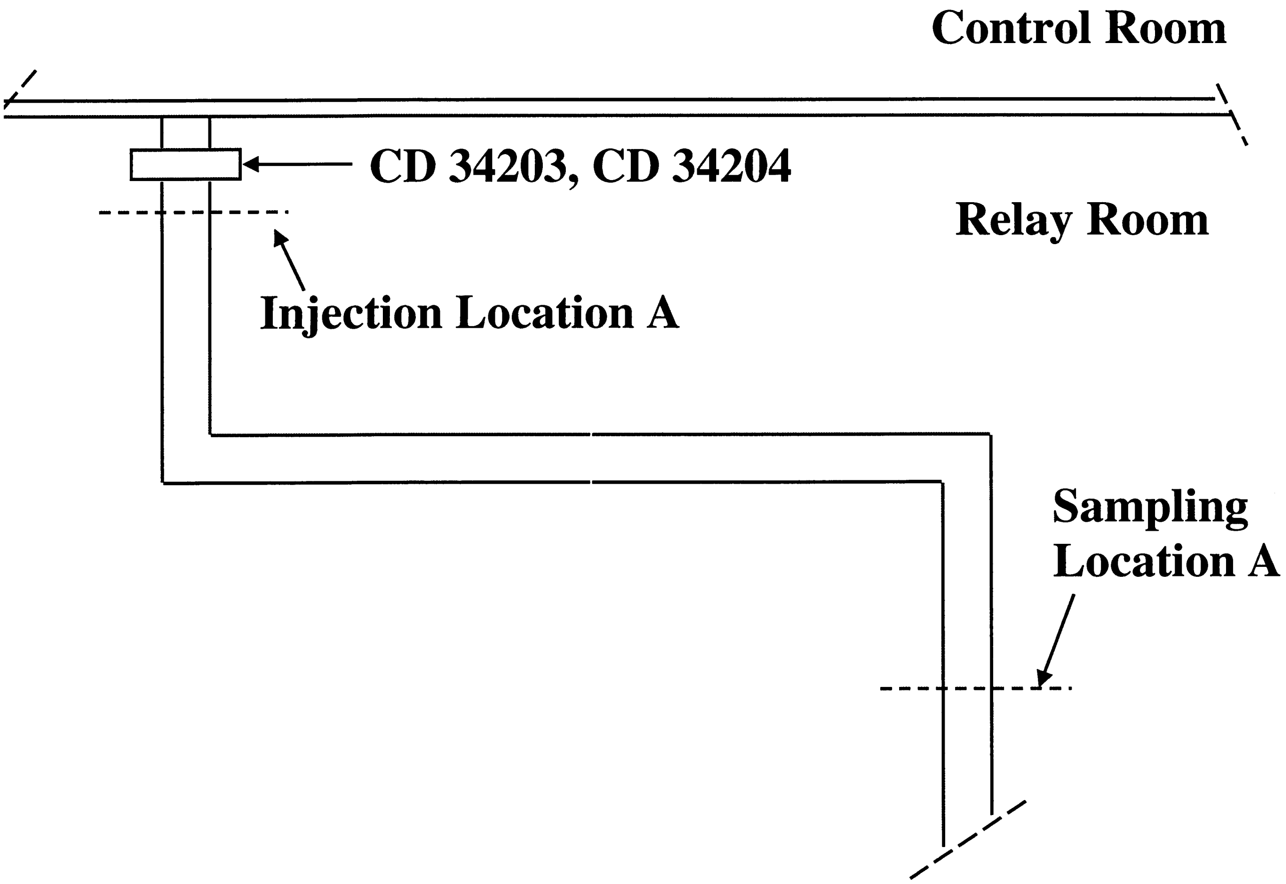

Figure 6. Tracer Buildup Technique

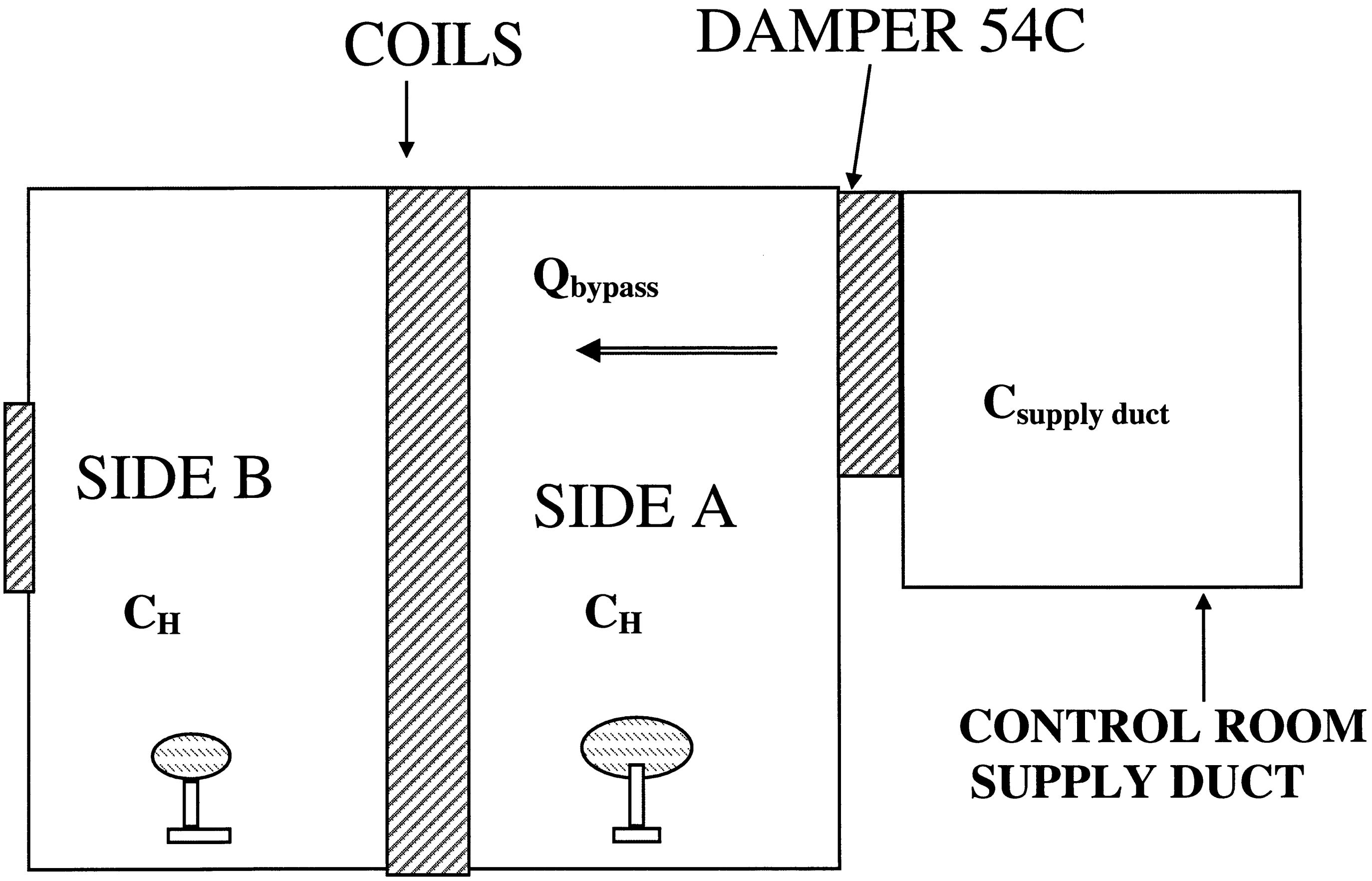

Figure 7. Damper Leakage by Tracer Decay Method

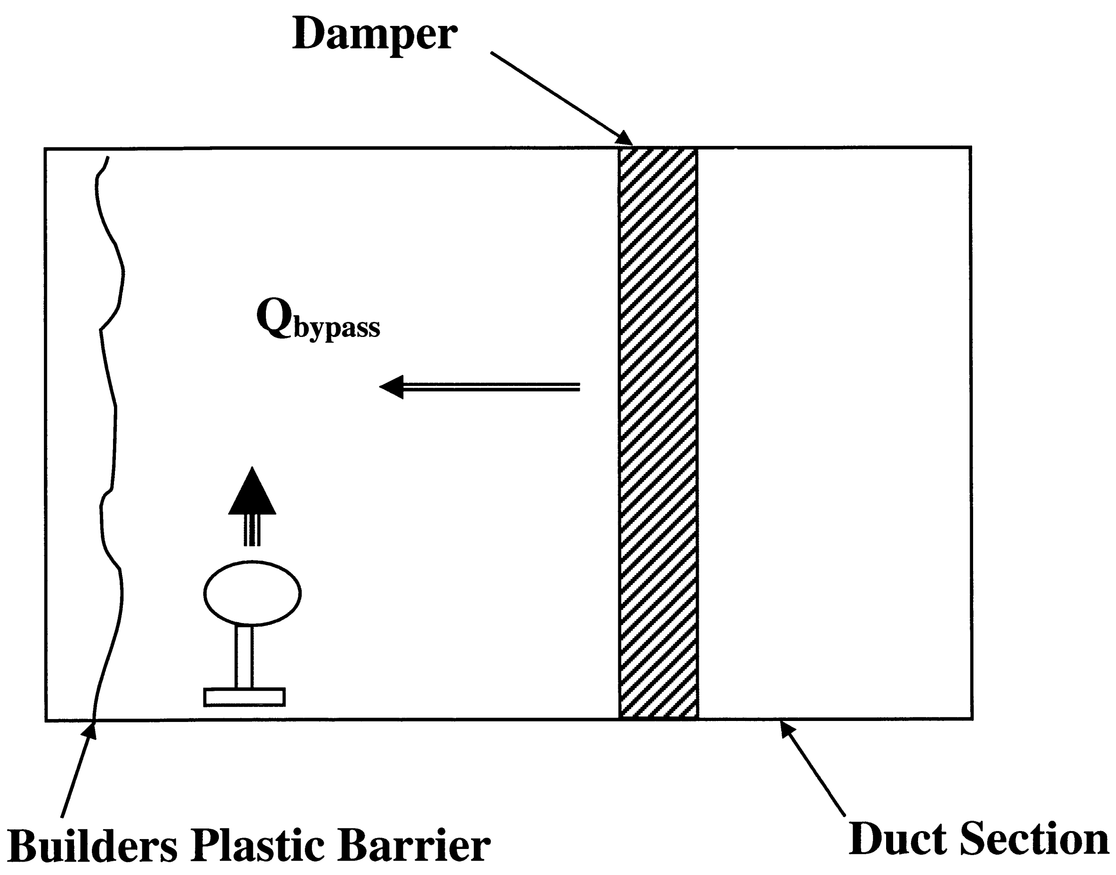

Figure 8. Duct Outleakage Test

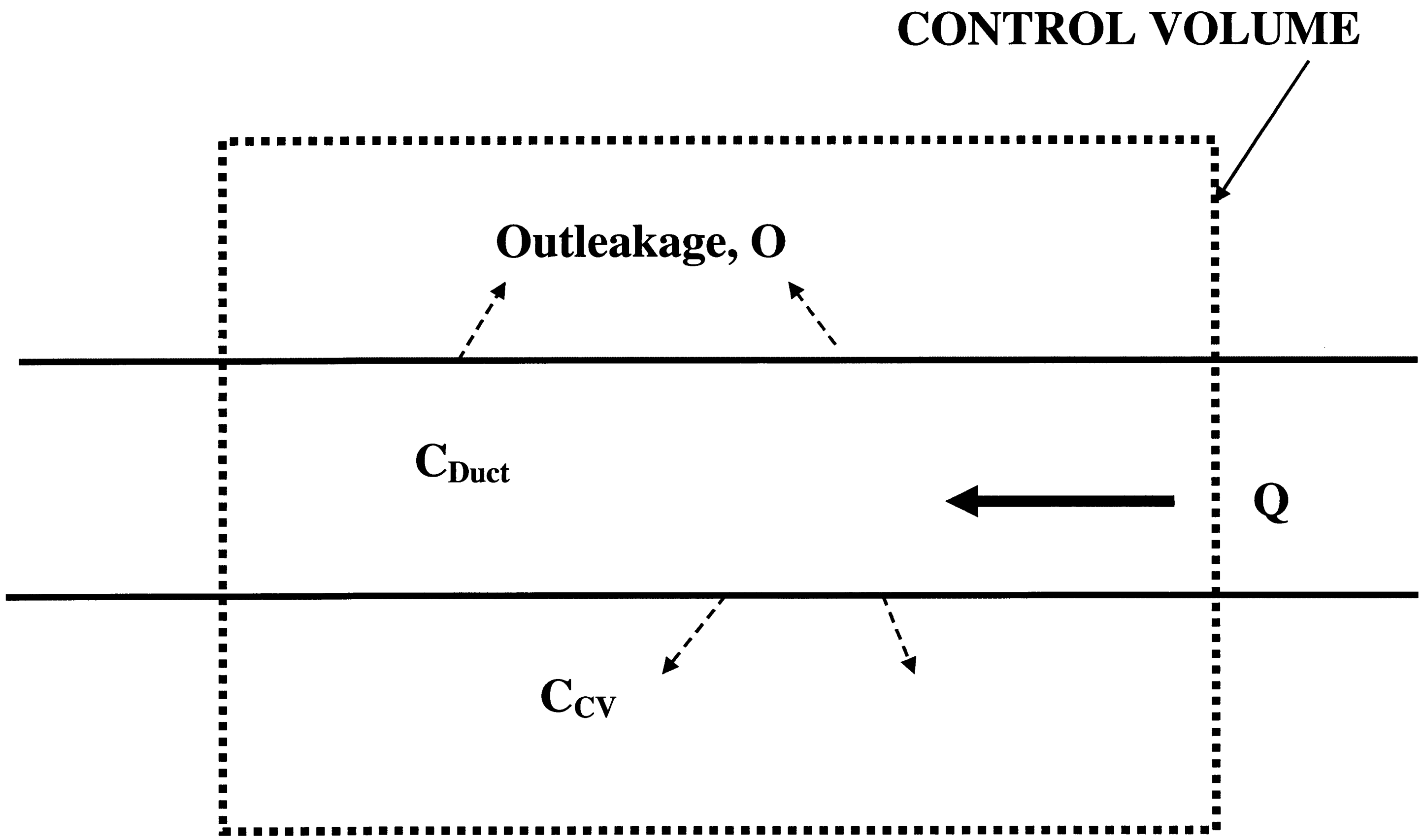

Figure 9. Non-CREVS Component Leakage Test

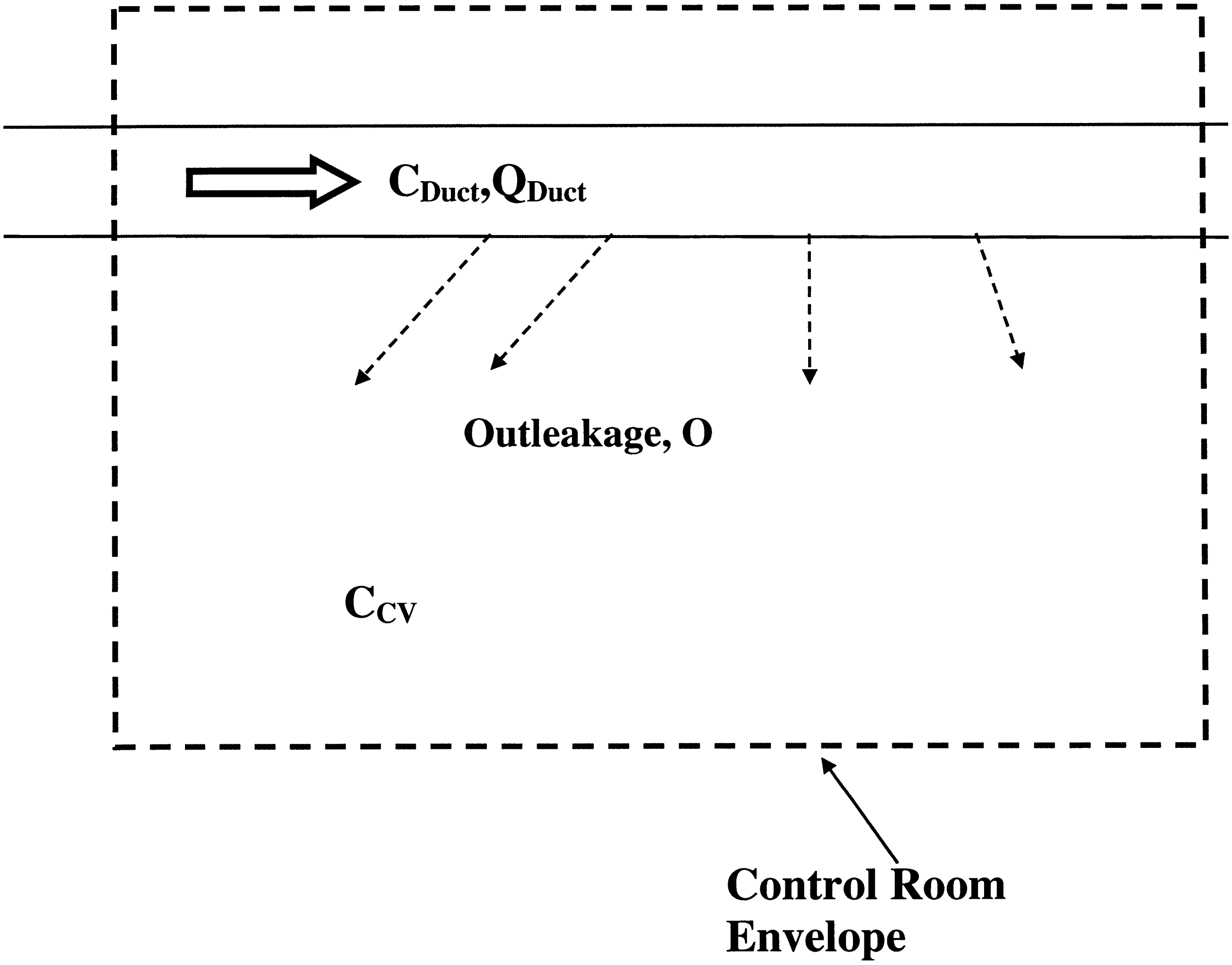

Figure 10. Inleakage Across a Wall