LEAKAGE TESTING OF INSTALLED DAMPERS USING A CONSTANT INJECTION TRACER GAS TECHNIQUE

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ABSTRACT

Testing the leakage of installed dampers in critical Nuclear HVAC applications represents a technical challenge. A test described in a previous paper utilized the accumulation or dilution of tracer gas within fabricated volumes to infer leakage rate through a damper. While the technique was capable of providing an accurate measurement of the leakage through an installed damper, it required the installation of additional test volumes to allow use of conservation of mass equations along with tracer gas concentration measurements. Recently, a tracer gas technique based on a continuous flow injection has been developed. The technique does not require the fabrication of test volumes in the ductwork. It requires only that test ports be provided in the existing ductwork. The only assumption is that the tracer gas is well mixed within the duct. Measurement of tracer gas concentrations coupled with an accurately known injection of a constant flow of tracer gas allows leakage flowrate to be easily measured in the majority of installed dampers. Damper leakage rates ranging from 4 CFM to 274 CFM were measured for eight installed dampers at Prairie Island using this technique.

1.0 INTRODUCTION

After installation, the quantification of leakage through isolation dampers using conventional methods has been both costly and time consuming. The pressure decay and constant pressure methods used for acceptance testing often require the installation of leak tight, temporary blank-off plates which may be impractical once duct connections have been completed. The soap bubble method used by the manufacturer as a quality control measure is not quantitative and requires access to the damper seat--often not possible in the field.

Lack of a suitable surveillance method for installed, in-service dampers has led to estimates of leakage ranging from 0 to 100 CFM. Such estimates are not useful in evaluating damper leakage unless acceptance criteria are also approximate. This is unlikely since such loose criteria contradict the design intent of isolation dampers. In light of the current regulatory climate and the interest in Control Room Habitability issues, imprecise estimates of critical air boundary leakage rates across these dampers are not acceptable.

In a previous paper, the successful application of tracer gas techniques to the problem of measuring the leakage across an installed isolation damper was described (1). In this paper, a small amount of easily detectable tracer gas was injected upstream of a damper to be tested and the region downstream of the damper was sampled for the presence or absence of this tracer. The existence of measurable tracer downstream of the damper was evidence that the damper allowed leakage. Application of conservation of mass equations to the measured tracer concentration data allowed inference of actual flowrate values for leakage through the dampers tested.

A drawback of this previously described technique is that physical test (control) volumes had to be established either upstream or downstream of each damper. In some cases, installation of such control volumes can be prohibitively expensive or physically impossible.

The constant injection tracer gas method 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 performed by injecting a tracer gas at a known rate into a section of duct upstream of each 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. This concentration is inversely proportional to the leakage flowrate through the damper. For this test only a few access holes need to be drilled in a particular duct section.

2.0 TRACER GAS TESTING

The use of a tracer gas(es) to investigate the flow, migration and dispersion of potentially harmful, noxious, or toxic gases and vapors is well established within the industrial hygiene, indoor air quality, and ventilation engineering communities (2,3). During the last few years tracer testing results specific to concerns within the nuclear industry have appeared in the literature (4,5,6). In simplest terms, tracer gas testing provides a means to document the actual performance of an operating ventilation system by tagging and unambiguously tracing one or more ventilation induced flows. This is done by introducing easily measurable, inert, non-toxic, non-reactive gases that are not part of the common industrial background.

The theoretical interpretation and experimental detail necessary to undertake tracer gas testing of complex ventilation systems is provided in the six prior references and will not be discussed further. Application of the principles of mass conservation to tracer injection and tracer measurement conditions allows quantitative information to be obtained on the performance of actual operating ventilation systems.

3.0 DAMPER LEAKAGE TESTING

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. 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, this direct measurement is not always practical due to the inability of the flow velocity measurement technique to exhibit suitable accuracy and resolution at low flow velocities.

For many years it has been known that a method to measure duct flowrates exists other than pitot tube or hot wire anemometer traverses. It entails the use of a tracer gas dilution method. This method is a *volumetric* as opposed to a point measurement (7,8). 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 at a location downstream of the injection point and the concentration of tracer gas at this location is measured. The flowrate is readily calculated from the ratio of the tracer injection flowrate to the diluted concentration--in symbols:

$$Q = S / C_{av} \qquad (1)$$

This same concept can be applied to the measurement of by-pass leakage across dampers. The basic test set-up is illustrated in Figure 1.

An individual damper by-pass leakage rate test is performed by injecting a tracer gas at a known rate into a section of duct upstream (or, in some cases downstream) of each 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. Gas samples are taken at spatially distinct locations within a fixed plane perpendicular to the duct axis. These are then analyzed for tracer concentration values.

The equilibrium concentration in the duct is inversely proportional to the flowrate through the damper (as given by equation (1)) 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.

One can rewrite equation (1) to explicitly reflect this measurement as equation (2),

$$Q_{bypass} = S / C_{av} \qquad (2)$$

where, Q_{bypass} , is now the by-pass leakage across a particular damper. Measurement of tracer samples from the duct yield values of tracer concentration that are used in equation (2) to calculate by-pass flowrate or by-pass leakage.

In the following, the electronegative gas, sulfur hexafluoride (SF6), was used as a tracer. This gas is generally recognized as non-toxic, non-reactive, and inert. Since it is easily detectable in minute quantities by means of electron capture gas chromatography, SF6 is an ideal tracer gas for isolation damper leakage investigations. Analytical sensitivity to this gas ranged from 10 parts per million to approximately 50 parts per trillion, although this sensitivity level is not generally required for damper leakage testing.

All tracer gas measurements were performed on-site by means of gas chromatographic instrumentation manufactured for field use. The response of a chromatographic monitor to SF6 is not affected by the presence of other gases in the plant background such as Freons and halogenated solvents. In addition, since SF6 possesses a zero ozone depletion factor, it will not harm the ozone layer.

Differential pressure across each damper was measured using two commercially available digital barometers capable of accurately measuring absolute pressures to within +/-0.02 in. w.c. These were used to simultaneously read the absolute pressure upstream and downstream of the damper after which the readings were differenced to provide a measurement of differential pressure.

In all of the tests described in this paper, the 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 all tests was 2.0 SLPM.

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.

Dampers CD 34203 and CD 34204 were individual dampers in their respective duct runs and as such could be tested in with a straight forward application of the above described technique. A schematic layout of the installation of these dampers is illustrated in Figure 2. For each of these dampers injection occurred at location A immediately downstream of the damper as shown on Figure 2, 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.

The layout for four of the remaining six dampers was more complex. The damper layouts are shown schematically in Figures 3 and 4. For all dampers in these two figures, tracer was injected for ten minutes prior to the onset of sampling. Dampers CD 34178 and CD 34180 were configured such that an injection upstream of the damper was possible. For each of these tracer injection occurred at injection location A as shown on Figures 3 and 4, while tracer gas sampling occurred at sampling location A immediately upstream of the respective dampers.

Dampers CD 34176 and CD 34177 were configured such that an injection upstream of the damper was possible. For each of these tracer injection occurred at injection location B as shown on Figures 3 and 4, while tracer gas sampling occurred at sampling location B immediately upstream of the respective dampers.

Due to the close spacing of dampers CD 34142 and CD 34176 in Room 121 and dampers CD 34145 and CD 34177 in Room 122, it was necessary to provide tracer gas injection at injection location B while tracer gas sampling occurred at sampling location C. Thus these tests measured the leakage of *both* CD 34142 and CD 34178 or *both* CD 34145 and CD 34180. To obtain the individual leakage through CD 34145 and CD 34142, it was necessary to subtract the individual contribution of either CD 34178 or CD 34180 from the measured combined leakage values.

Testing of the eight dampers required approximately 20 hours spread over three evening work shifts.

In Table 1 we summarize by-pass flowrates and measured differential pressures for each damper. In the appendix, we provide the measured tracer concentration data for each test.

Except for dampers CD 34145 and CD 34142, measurement uncertainties provided in Table 1 were calculated using ANSI Standard PTC 19.1 "Measurement Uncertainty" and represent 95% confidence limits. Uncertainties for the above mentioned two dampers were taken as the greater of the measurement uncertainties for the two measurements that were differenced to obtain the leakage rate for the particular damper.

4.0 CONCLUSIONS

Actual damper leakage through installed isolation dampers has been measured in the range of 4 to 274 CFM using a constant injection tracer gas technique. To the authors' knowledge only one other limited data set on the measured leakage of installed isolation dampers has been published

A significant advantage of using a constant injection tracer gas technique to leak test isolation dampers is that quantitative leakage data are obtained under actual operating differential pressure conditions. Another advantage is that leakage data can be obtained without the need for control (test) volumes that may require fabrication within the installed ductwork

In light of the current regulatory climate and the interest in Control Room Habitability issues, imprecise estimates of critical air boundary leakage rates are not acceptable. Such imprecise estimates can skew radioactive dose assessments as well as chemical contaminant exposure calculations. Using a constant injection tracer gas technique, the *actual* leakage rate is obtained which can then be used in these evaluations thereby eliminating a significant source of uncertainty. The technique also can provide an accurate field evaluation of the performance of isolation dampers on a periodic basis.

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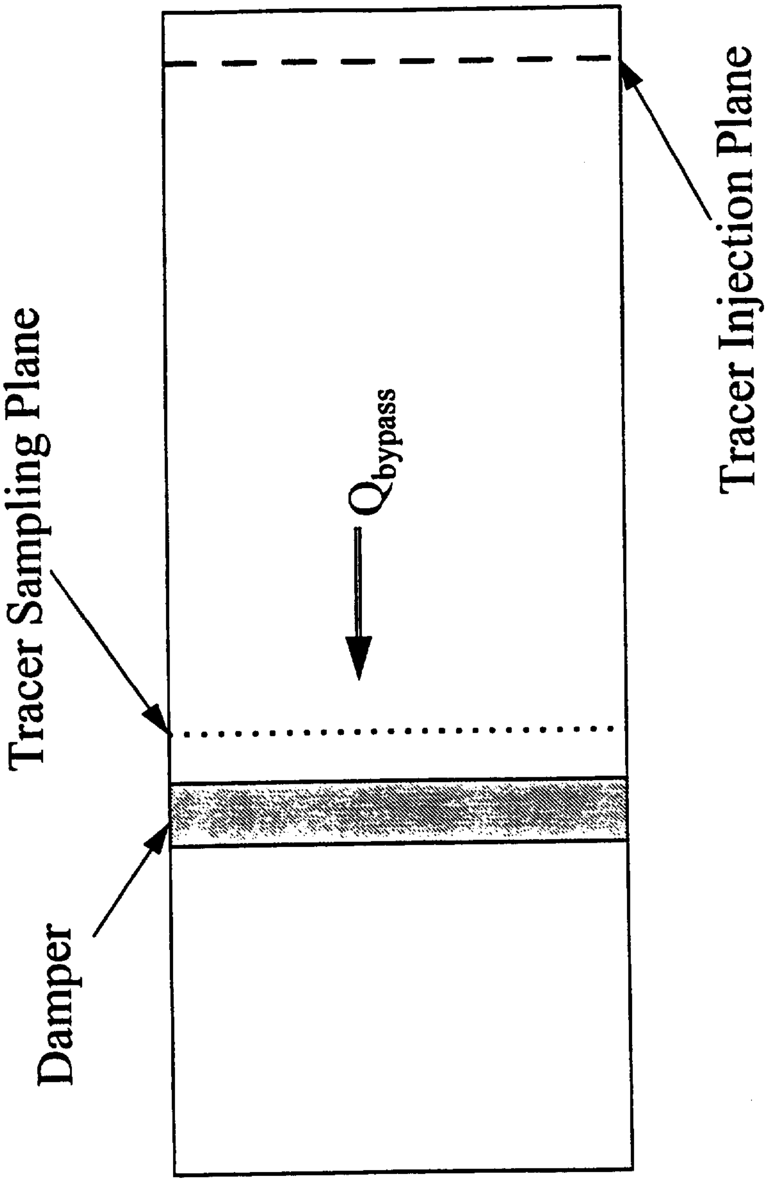

Figure 1. Tracer Gas Damper By-pass Leakage Test

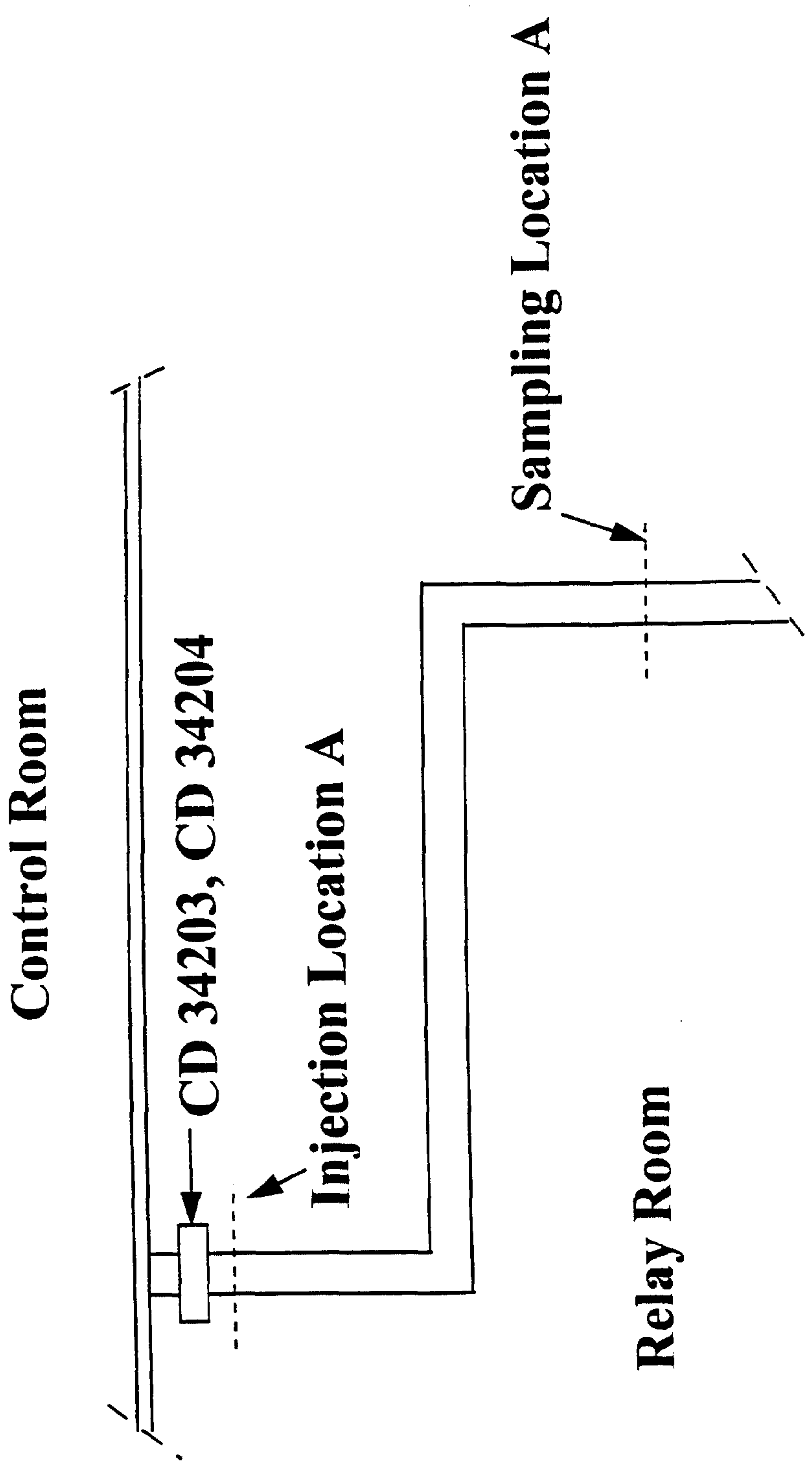

Figure 2. Schematic illustration of dampers CD 34203 & CD 34204.

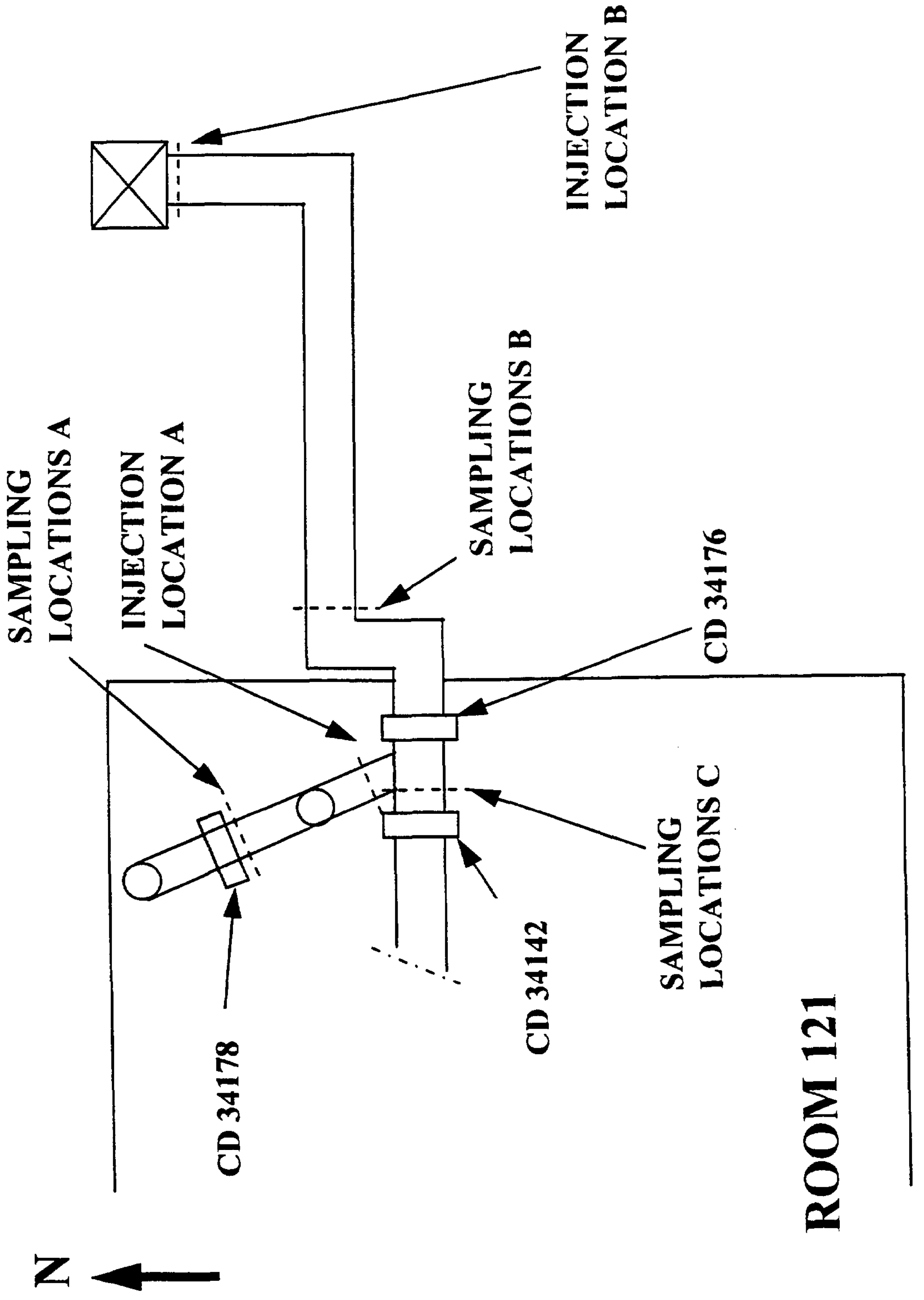

Figure 3. Damper installation in Room 121

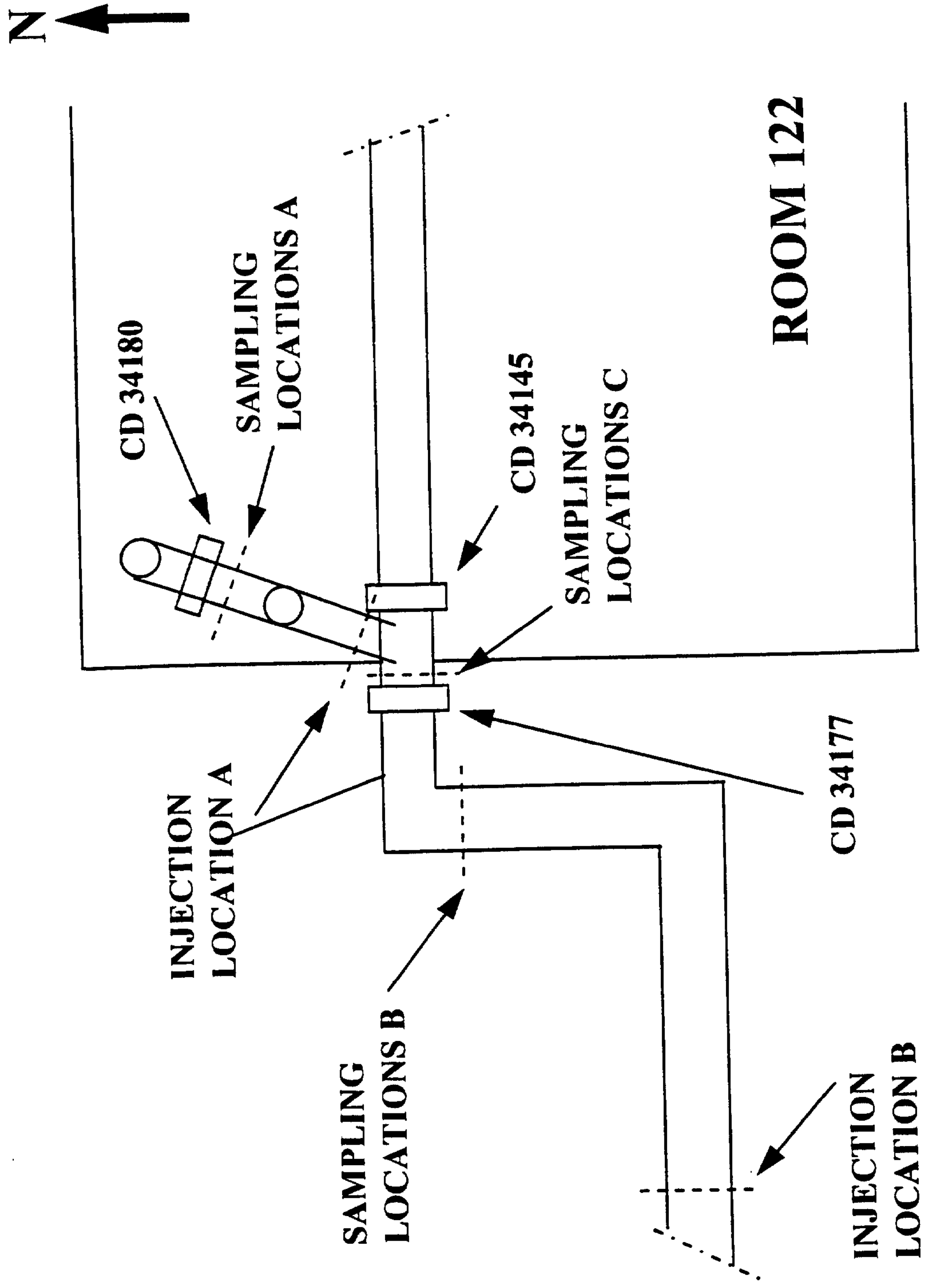

Figure 4. Damper installation in Room 122.

Table 1

Measured Damper By-pass Leakage Data

DAMPER	LEAKAGE (SCFM)	DIFF. PRESSURE (in.w.c.)
CD 34204	31 +/- 9	nm*
CD 34203	18 +/- 2	nm*
CD 34178	12 +/- 8	1.3
CD 34142	4 (+8, -4)	0.8
CD 34176	274 +/- 107	0.7
CD 34180	47 +/- 4	1.0
CD 34145	19 +/- 50	0.6
CD 34177	119 +/- 6	0.6

*nm Not Measured

APPENDIX: TRACER CONCENTRATION DATA

Table A1

Damper CD 34204 Tracer Data

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

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

Table A2

Damper CD 34203 Tracer Data

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

Table A3

Damper CD 34178 Tracer Data

TIME (MIN)	CONCENTRATION (PPB)
5	37.4
5.5	45.3
6	47.3
6.5	56.1
7	65.1
7.5	69.0
8.5	78.3
9	85.8
9.5	87.6
10	95.3
MEAN CONC.	63.54
STD DEV (%)	28.7

Table A4

Combined Damper CD 34142 plus CD 34178 Tracer Data

TIME (MIN)	CONCENTRATION (PPB)
5	33.8
5.5	43.0
6	42.1
6.5	43.3
7	45.4
7.5	46.9
8.5	45.4
9	49.0
9.5	47.8
MEAN CONC.	44.08
STD DEV (%)	10.2

Table A5

Damper CD 34176 Tracer Data

TIME (MIN)	CONCENTRATION (PPB)
5	2.73
5.5	2.2
6	2.81
7.0	2.13
7.5	3.49
8.0	2.18
9.0	2.86
9.5	2.18
10.0	2.8
MEAN CONC.	2.60
STD DEV (%)	17.7

Table A6

Damper CD 34180 Tracer Data

TIME (MIN)	CONCENTRATION (PPB)
10	35.0
10.5	35.2
11	35.3
11.5	36.8
12	34.5
12.5	35.2
13.5	33.4
14	37.
14.5	35.7
15	36.2
MEAN CONC.	35.34
STD DEV (%)	3.1

Table A7

Combined Damper CD 34145 and CD 34180 Tracer Data

TIME (MIN)	CONCENTRATION (PPB)
10.0	5.52
10.5	5.31
11.0	4.55
12.0	6.89
12.5	5.87
13.0	4.72
14.0	7.33
14.5	6.72
15.0	7.13
MEAN CONC.	6.00
STD DEV (%)	17.4

Table A8

Damper CD 34177 Tracer Data

TIME (MIN)	CONCENTRATION (PPB)
10.0	5.82
10.5	5.80
11.0	5.86
12.0	5.81
12.3	5.81
13.0	5.75
14.0	6.03
14.5	5.87
15.0	5.74
MEAN CONC.	5.83
STD DEV (%)	1.5