Diesel Generator Room Air Flow Rate Measurements using Tracer Gas Techniques

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ABSTRACT

The air flow rate through a Diesel Generator Room at a commercial nuclear power facility is commonly a Tech Spec or Design Basis item due to the critical need to maintain adequate heat removal capability of an operating Diesel Generator. Traditionally the factory specified fan curves are used to calculate the heat removal capacity versus ambient temperature at an appropriate installation. Measurement of the actual operating air flow rate through a Diesel Generator Room is generally not possible using conventional velocity traverse type measurements. Accordingly heat removal capacities often are based solely on manufacturer fan curves.

In order to enhance plant confidence in the design air flow through the Diesel Generator Rooms at Palo Verde Nuclear Generating Station, several tracer gas flow rate measurements were undertaken in the spring of 2006.

This paper presents the results of measurements on the 2MHDBJ01 fan contained in the Unit 2 Diesel Generator Room. In normal operation a bird screen is emplaced over the discharge of the vane axial fan. With this screen in place the tracer measured values were 6.5 % higher than the design basis flow. With the bird screen removed, the flow through the vane axial fan was 11.3 % higher than the design basis.

For both measured values the 95% confidence interval is 2.7%.

1.0 INTRODUCTION

The air flow rate through a Diesel Generator Room at a commercial nuclear power facility is commonly a Tech Spec or Design Basis item due to the critical need to maintain adequate heat removal capability for an operating Diesel Generator.

Conventionally, air flows often are created by large vane axial fans that are installed in walls or floors of the Diesel Generator Building. Usually there is no air supply or exhaust duct work associated with this installation. Hence, the measurement of actual operating air flow rate through these fans is generally not possible using conventional velocity traverse type measurements.

Traditionally the factory specified fan curves are used to calculate the heat removal capacity versus ambient temperature at an appropriate installation without any supporting measured fan performance data. Accordingly heat removal capacities often are based solely on manufacturer fan curves.

Prior unpublished measurements at a different nuclear facility suggested that tracer gas techniques could be used to measure the actual flow rates through the vane axial fan and hence through a Diesel Generator Room.

At the Palo Verde Nuclear Generating Station (PVNGS), exhaust air from a Diesel Generator Room is discharged into a self contained muffler room above the diesel generator and is then routed up a rectangular concrete stack to the out of doors. This stack represented the only location where it might have been possible to undertake traverse measurement of air flow rate. However, due to the nature of the construction (poured concrete walls) and the relatively short stack length compared to the stack width it was not possible to perform a classical point traverse measurement to obtain air flow velocities. In addition, the diesel's exhaust pipe and its structural supports further perturbing any possible traverse measurements. Figures 1 and 2 provide views looking "up" the exhaust stack from two sides.

In order to enhance plant confidence in the design air flow through the Diesel Generator Rooms at PVNGS and to demonstrate the viability of the technique, several tracer gas flow rate measurements were undertaken through one of the six Diesel Generator Rooms in the spring of 2006.

2.0 MEASURING AIR FLOW RATE USING TRACER GAS DILUTION

Within the nuclear power generation industry, flow rates are commonly measured using point measurements of air velocity combined with a knowledge of duct area to provide an air flow rate. However, there are physical configurations in which a conventional traverse type flow measurement is not feasible.

Fortunately a method to measure duct or stack flow rates exists that does not require Pitot tube or hot wire anemometer traverses. This method entails the use of a tracer gas dilution method. This method is a *volumetric* as opposed to a point measurement. This technique has been used in the mine engineering, industrial hygiene and energy conservation communities, but has been largely ignored in the ventilation engineering community.[1,2,3] Several examples of the use of tracer flow rate measurements within the nuclear power industry have been described in earlier papers.[4,5]

To undertake a tracer gas flow rate measurement, a gaseous tracer 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 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 as follows:

$$Q = IC \times IF / (C_{av} - C_{us}) \qquad (1)$$

where

Q = Stack (or duct) Flow Rate
IC = Tracer Injection Gas Concentration
IF = Tracer Gas Injection Flow Rate
C_{us} = Tracer gas concentration upstream of injection location
C_{av} = Mean tracer gas concentration in stack downstream of injection location

An individual flow rate test is performed by injecting a tracer gas at a known rate into a stack or a section of duct upstream of a point and then measuring the equilibrium tracer gas concentration downstream of that point. One or more measurements of the tracer concentration (if any) upstream of the injection point are also obtained.

This equilibrium concentration in the stack or duct is inversely proportional to the flow rate through the duct (as given by equation (1)). 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.

4.0 EXPERIMENTAL TECHNIQUES AND MEASURED DATA

Tracer gas flow rate tests were performed on the Unit 2 Diesel Generator (D/G) Room Essential Exhaust Fan 2MHDBJ01 at the PVNGS on March 23, 2006 by a team of test engineers from NCS Corporation (NCS) and Lagus Applied Technology, Inc. (LAT). A section view of the Diesel Generator Building is provided in Figure 4.

Tracer gas flow rate measurements of airflow rates were performed using a procedure is based on the methodology described in ASTM Standard E2029-99 “Standard Test Method for Volumetric and Mass Flow Rate Measurement using Tracer Gas Dilution”. Two tests were undertaken: one with the "bird screen" in place over the fan exhaust throat and one with the "bird screen" removed.

The electronegative gas, sulfur hexafluoride (SF6), was used as a tracer in the flow rate tests. This gas is generally recognized as non-toxic and non-reactive. Since it is easily detectable in minute quantities by means of electron capture gas chromatography, SF6 is an ideal tracer gas for ventilation system performance investigations.

In the testing at PVNGS, all SF6 tracer gas measurements were performed by means of chromatographic instrumentation manufactured for field use by LAT. On site calibration using certified calibration standards was performed prior to initiation of the testing to ensure that instrument drift and any sensitivity variations would be minimized. Calibration was performed using an approved procedure. Analytical sensitivity to SF6 ranged from 500 parts per trillion to approximately 35 parts per billion.

Air samples were obtained using disposable polypropylene syringes. Air samples were obtained using a number of pump/manifold sampling systems. Each pump/manifold sampling system consisted of a pump connected to a multi-position sampling valve. A Swagelok™ tee and septum fitting was affixed to the sample pump exhaust. This allowed remotely located air samples (such as those taken from within Exhaust Stack or various rooms within the Diesel Generator Building) to be obtained using polypropylene syringes. Lengths of polyethylene tubing were connected to the multi-position valve and were routed to the appropriate locations for sampling.

A Matheson Model 8270 Mass Flow Controller controlled tracer gas injection rates. Tracer gas injection rates were measured using a Sierra Model 821 Top Trak Thermal Mass Flowmeter. The tracer gas injection source was a high-pressure cylinder containing a dilute mixture of SF6 in nitrogen. The SF6 tracer gas injection concentration was analyzed and certified to +/- 1% (traceable to NIST) of the measured concentration by an independent laboratory. The procedures and test equipment of this laboratory are periodically audited as part of an ANSI NQA-1 QA program.

Tracer gas was injected into the Diesel Generator Room Intake Structure using a Palo Verde-fabricated injection manifold. The Diesel Generator Room Intake Structure is 190" wide by 83" high. The tracer injection manifold utilizes a left and a right manifold section to cover the cross sectional area of the intake. A schematic drawing of the injection manifold is provided in Figure 5.

Each manifold is 90" wide by 79" high and consists of an upper and lower header connecting ten manifold tubes. Holes (0.055 inch in diameter) are drilled on 10" centers on each vertical tube.

The manifold, in turn, is connected to a 1-CFM diaphragm pump that provides increased air flow to the manifold. Tracer gas was delivered to the suction side of the diaphragm pump and supplied tracer gas to each manifold through the upper and lower headers.

4.1 TEST 1: FLOW RATE WITH BIRD SCREEN IN PLACE

From approximately 09:45 to approximately 11:00 on March 23, 2006 a flow rate test was performed on the Unit 2 Diesel Generator Room Essential Exhaust Fan 2MHDBJ01. For this test, the “bird screen” above the exhaust throat remained in place.

An SF6 in nitrogen mixture possessing a concentration of 10030 ppm was injected at an actual flow rate of 4.75 SLPM for the duration of the test. Tracer gas injection occurred through the previously described injection manifold located in the Outside Air Intake on the Diesel Generator Building.

All tracer gas samples were obtained using pump/manifold systems that were attached to lengths of polyethylene tubing. The tubing was routed to appropriate locations within the stack and to four additional locations within the Diesel Generator Building. Samples were drawn by these pump/manifold systems to individual polypropylene syringes for subsequent analysis.

Tracer gas samples for makeup flow rate were obtained from twenty locations in the Exhaust Stack approximately 30 feet above the floor of the Fan Room. These locations are shown schematically in Figure 6. Five suites of samples were obtained at each location at ten minute intervals. This resulted in 100 duct concentration samples.

Mean tracer concentration data from each of these five suites are provided in Table 1 and are denoted as Test 1F1 through 1F5. From these data it is clear that the tracer concentration within the Exhaust Stack was well mixed. The standard deviation of tracer measurements expressed as a percentage of the mean is also shown for each sample suite.

The standard deviation is a statistical measure of how much a collection of measurements differs from the mean of the collection. The smaller the standard deviation, the closer individual values in the collection are to the mean. Inspection of the concentration data in Table 1 discloses that the standard deviation of the mean concentration for the five sample suites ranged from approximately 1.3 % to approximately 2 % thereby confirming that tracer concentration was well mixed throughout the Exhaust Stack.

In addition, samples were obtained from the Tank Room, the Compressor Room, the Diesel Generator Control Room and from a point approximately 2.5 feet in front of the Outside Air Intake at the same intervals as the stack sampling resulting in 20 additional samples.

Non-stack concentration data are provided in Table 2. Note that no detectable tracer gas concentration was measured at the Outside Air Intake. These concentration values are below the detection limit of the analyzers (approximately 0.05 ppb). This low value demonstrated that no re-entrainment from the Exhaust Stack occurred during Test 1.

A small amount of tracer gas was measured within the Diesel Generator Control Room. This implies that some inleakage occurred to the Diesel Generator Control Room from a common internal hallway in the Diesel Building or that some re-entrainment occurred from the Exhaust Stack to the Diesel Generator Control Room.

The concentrations in the Diesel Generator Control Room are more likely from internal building recirculation. The control room supply air fan draws air from the Diesel Generator combustion air intake. Internal building air flows can then provide tracer to the hallway via the combustion air intake and thence into the Diesel Generator Control Room.

Since the outside air flow provided by the Diesel Generator Supply fan is 12,900 CFM, the measured Diesel Generator Control Room tracer gas concentration results in a potential error in the Exhaust Flow rate of approximately 0.4%. Hence the contribution of exhaust re-entrainment or internal recirculation to the measured Exhaust Flow rate is negligible and may be safely ignored.

The non-zero values for concentration measured in the Tank Room and the Compressor Room demonstrate that air flow occurred into these rooms during operation of the Exhaust Fan which was expected. Since there is no source of outside air (i.e. air not containing tracer gas) into these rooms there is no effect of these concentrations on the measured Exhaust Flow Rate.

The exhaust flow rate for Test 1 measured using the tracer gas technique is given in Table 3. Equation (1) was used to calculate the flow rate. An estimate of the measurement uncertainty is also provided in this table. For the purposes of the uncertainty analysis, equation (1) is used to explicitly include all measured quantities for the tests in which tracer gas flow rate measurements could be used.

In this paper, the uncertainty of each flow rate measurement is calculated using the prescription provided in ANSI/ASME Standard PTC 19.1-1985 (Reaffirmed 1990) “Measurement Uncertainty” [6] and represents 95% confidence limits. Uncertainties for all derived and measured quantities are incorporated into the analysis.

4.2 TEST 2: FLOW RATE WITH BIRD SCREEN REMOVED

From approximately 15:30 to approximately 16:55 on March 23, 2006 a flow rate test was performed on the Unit 2 Diesel Generator Room Essential Exhaust Fan 2MHDBJ01. For this test, the “bird screen” above the exhaust throat was removed.

An SF6 in nitrogen mixture possessing a concentration of 10030 ppm was injected at a flow rate of 4.76 SLPM for the duration of the test. Tracer gas injection occurred through the previously described injection manifold located in the Outside Air Intake on the Diesel Generator Building

All tracer gas samples were obtained using pump/manifold systems that were attached to lengths of polyethylene tubing. The tubing was routed to appropriate locations within the stack and to four additional locations within the Diesel Generator Building. Samples were drawn by these pump/manifold systems to individual polypropylene syringes for subsequent analysis.

Tracer gas samples for makeup flow rate were obtained from twenty locations in the Exhaust Stack approximately 30 feet above the floor of the Fan Room. These locations are shown schematically in Figure 6. Five suites of samples were obtained at each location at ten minute intervals. This resulted in 100 duct concentration samples.

Mean tracer concentration data are provided in Table 3 and are denoted as Test 2F1 through 2F5. From these data it is clear that the tracer concentration within the Exhaust Stack was well mixed. The standard deviation of tracer measurements expressed as a percentage of the mean is also shown for each sample suite.

The standard deviation is a statistical measure of how much a collection of measurements differs from the mean of the collection. The smaller the standard deviation, the closer individual values in the collection are to the mean. Inspection of the concentration data in Table 1 discloses that the standard deviation of the mean concentration for the five sample suites ranged from approximately 0.9 % to approximately 1.2 % thereby confirming that tracer concentration was extremely well mixed throughout the Exhaust Stack.

In addition, samples were obtained from the Tank Room, the Compressor Room, the Diesel Generator Control Room and from a point approximately 2.5 feet in front of the Outside Air Intake at the same intervals as the stack sampling resulting in 20 additional samples.

Non-stack concentration data are provided in Table 4. Note that no detectable tracer gas concentration was measured at the Outside Air Intake. These concentration values are below the detection limit of the analyzers (approximately 0.05 ppb). This low value demonstrated that no re-entrainment from the Exhaust Stack occurred during Test 2.

A small amount of tracer gas was measured within the Diesel Generator Control Room. This implies that some inleakage occurred to the Diesel Generator Control Room from a common internal hallway in the Diesel Building or that some re-entrainment occurred from the Exhaust Stack to the Diesel Generator Control Room.

The concentrations in the Diesel Generator Control Room are more likely from internal building recirculation. The control room supply air fan draws air from the Diesel Generator combustion air intake. Internal building air flows can then provide tracer to the hallway via the combustion air intake and thence into the Diesel Generator Control Room.

Since the outside air flow provided by the Diesel Generator Supply fan is 12,900 CFM, the measured Diesel Generator Control Room tracer gas concentration results in a potential error in the Exhaust Flow rate of approximately 0.4%. Hence the contribution of exhaust re-entrainment or internal recirculation to the measured Exhaust Flow rate is negligible and may be safely ignored.

The non-zero values for concentration measured in the Tank Room and the Compressor Room demonstrate that air flow occurred into these rooms during operation of the Exhaust Fan which was expected. Since there is no source of outside air (i.e. air not containing tracer gas) into these rooms there is no effect of these concentrations on the measured Exhaust Flow Rate.

The exhaust flow rate for Test 2 measured using the tracer gas technique is given in Table 5. Equation (1) was used to calculate the flow rate. An estimate of the measurement uncertainty is also provided in this table. For the purposes of the uncertainty analysis, equation (1) is used to explicitly include all measured quantities for the tests in which tracer gas flow rate measurements could be used.

In this paper, the uncertainty of each flow rate measurement is calculated using the prescription provided in ANSI/ASME Standard PTC 19.1-1985 (Reaffirmed 1990) “Measurement Uncertainty” [6] and represents 95% confidence limits. Uncertainties for all derived and measured quantities are incorporated into the analysis.

5.0 DISCUSSION

The original design calculation for this unit was equivalent to 113,140 SCFM at 70 Deg F. For the system tested, the measured flow rates exceeded the design flow by approximately 6.5 % with the bird screen in place and by approximately 11.3% with the bird screen removed. Based on the increased margin afforded by removal of the bird screen, it was decided that the bird screens on all six systems at PVNGS would be removed permanently.

6.0 CONCLUSIONS

Tracer gas flow rate measurements demonstrated that the flow through the Diesel Generator Room with Essential Exhaust Fan 2MHDBJ01 operating exceeded the design basis value.

Two tests were undertaken over the course of a single day. Thus the tracer gas technique affords a simple way to quantitatively evaluate the flow performance of a Diesel Generator exhaust fan. The tracer gas technique is ideally suited for this type of measurement since it is a volumetric technique. The measurement is independent of the area of the exhaust volume used to obtain tracer gas measurement points

Traverse methods are incapable of providing this data since there is no supply or exhaust ductwork associated with the diesel exhaust fans at PVNGS. Thus, point measurements of air velocity cannot be reasonably interpreted to provide a measure of flow through an operating vane axial fan that possess neither supply nor exhaust ductwork.

The remaining five Diesel Exhaust fans are scheduled to be evaluated using the same technique at a future date.

7.0 REFERENCES

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3. Lagus, P.L., Flanagan, B.S., Peterson, M.E., and Clowney, S.L., "Compressor Flow Measurement Using a Tracer Technique", Paper 90-DT-18 in 1990 Operating Section Proceedings, American Gas Association, Arlington, Virginia, 1990

4. Adams, D.G., Lagus, P.L., and Fleming, K.M., “Unit Vent Airflow Measurements Using A Tracer Gas Technique", in Proceedings of the 24th NRC/DOE Air Cleaning Conference, Portland, 1996

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

TABLE 1

Mean Concentration Data-Test 1
(Each datum is the mean of 20 measurement points)

Test	Mean Concentration (ppb)	Relative Standard Deviation (%)
1F1	13.99	2.0%
1F2	13.97	1.8%
1F3	14.00	1.5%
1F4	13.99	1.2%
1F5	13.97	1.5%

TABLE 2

Non-stack Tracer Concentration Measurements –Test 1
(Concentration Values in ppb)

SAMPLE	D/G CONTROL ROOM	TANK RM	COMP RM	OS AIR
1	0.33	14.2	14.7	ND*
2	0.32	14.9	14.9	ND*
3	0.29	14.7	14.9	ND*
4	0.35	14.9	14.8	ND*
5	0.49	15.1	15.0	ND*

* ND-Concentration less than Lower Detection Limit

TABLE 3

Tracer Gas Flow Rate-Test 1

Test	Operating Condition	Operating Exhaust Fan	Flow Rate (SCFM*)
1	Screen in place	2MHDBJ01	120,429 +/- 3314

* Referenced to 70 Deg F and 14.7 psia

TABLE 4

Non-stack Tracer Concentration Measurements –Test 2
(Concentration Values in ppb)

SAMPLE	D/G CONTROL ROOM	TANK RM	COMP RM	OS AIR
1	0.44	13.6	14.2	ND*
2	0.42	14.3	14.3	ND*
3	0.52	14.4	14.4	ND*
4	0.43	14.6	14.4	ND*
5	0.26	14.7	14.2	ND*

* ND-Concentration less than Lower Detection Limit

TABLE 5

Mean Concentration Data-Test 2
(Each datum is the mean of 20 measurement points)

Test	Mean Concentration (ppb)	Relative Standard Deviation (%)
2F1	13.44	1.0%
2F2	13.40	1.2%
2F3	13.40	0.9%
2F4	13.42	1.0%
2F5	13.39	1.0%

TABLE 6

Tracer Gas Flow Rate-Test 2

Test	Operating Condition	Operating Exhaust Fan	Flow Rate (SCFM*)
2	Screen removed	2MHDBJ01	125,850 +/- 3485

* Referenced to 70 Deg F and 14.7 psia

2MHDBJ01 Exhaust Stack – East Side

Figure 1. East side of exhaust stack looking “up”

2MHDBJ01 Exhaust Stack – West Side

Figure 2. West side of exhaust stack looking “up”

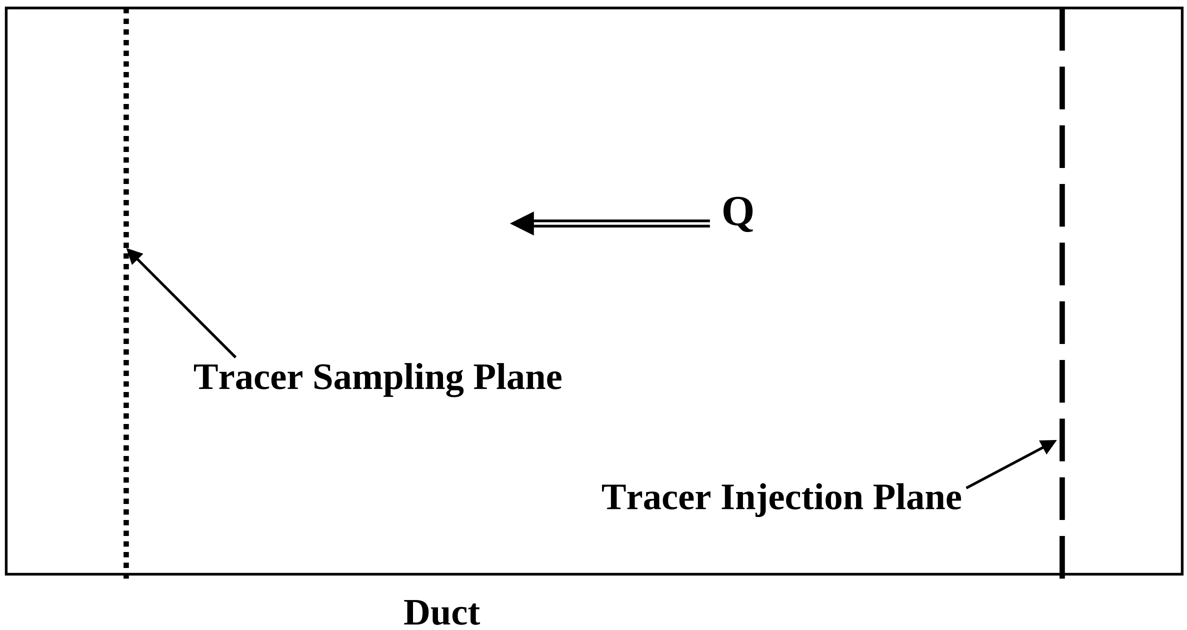

Figure 3. Schematic representation of tracer gas flow rate test.

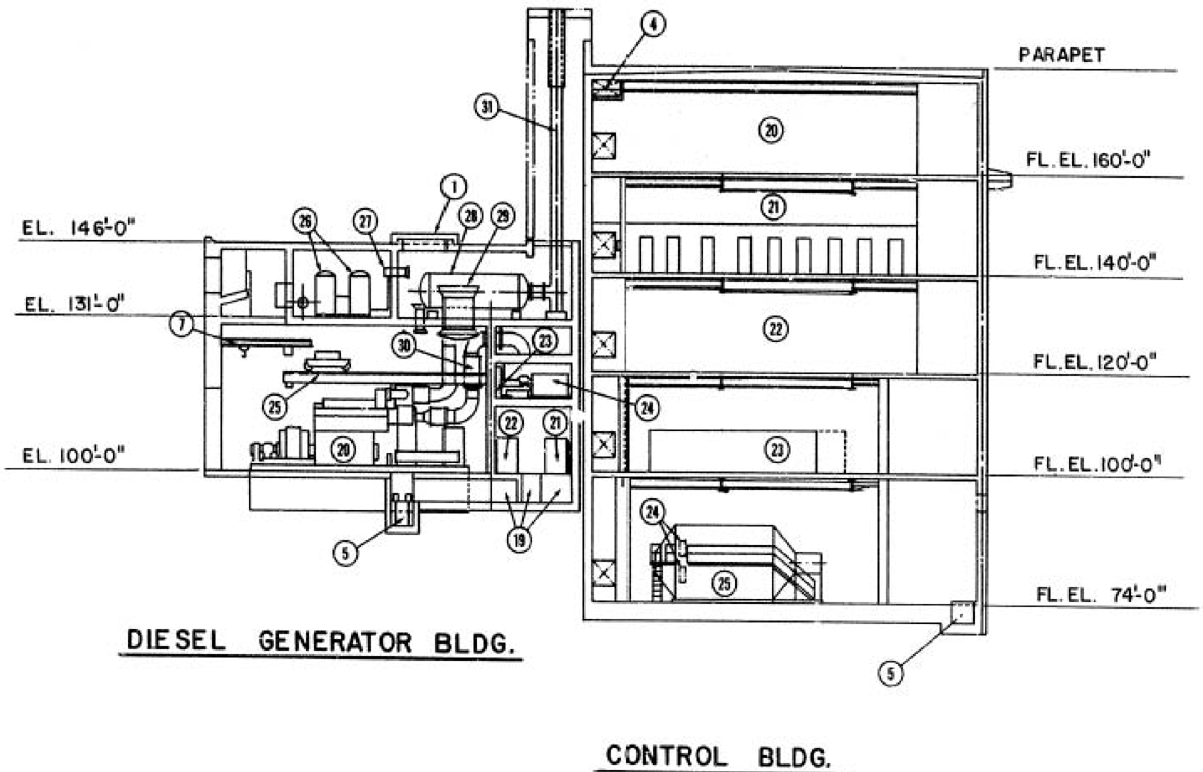

Figure 4. Section drawing of Palo Verde Diesel Generator Room.

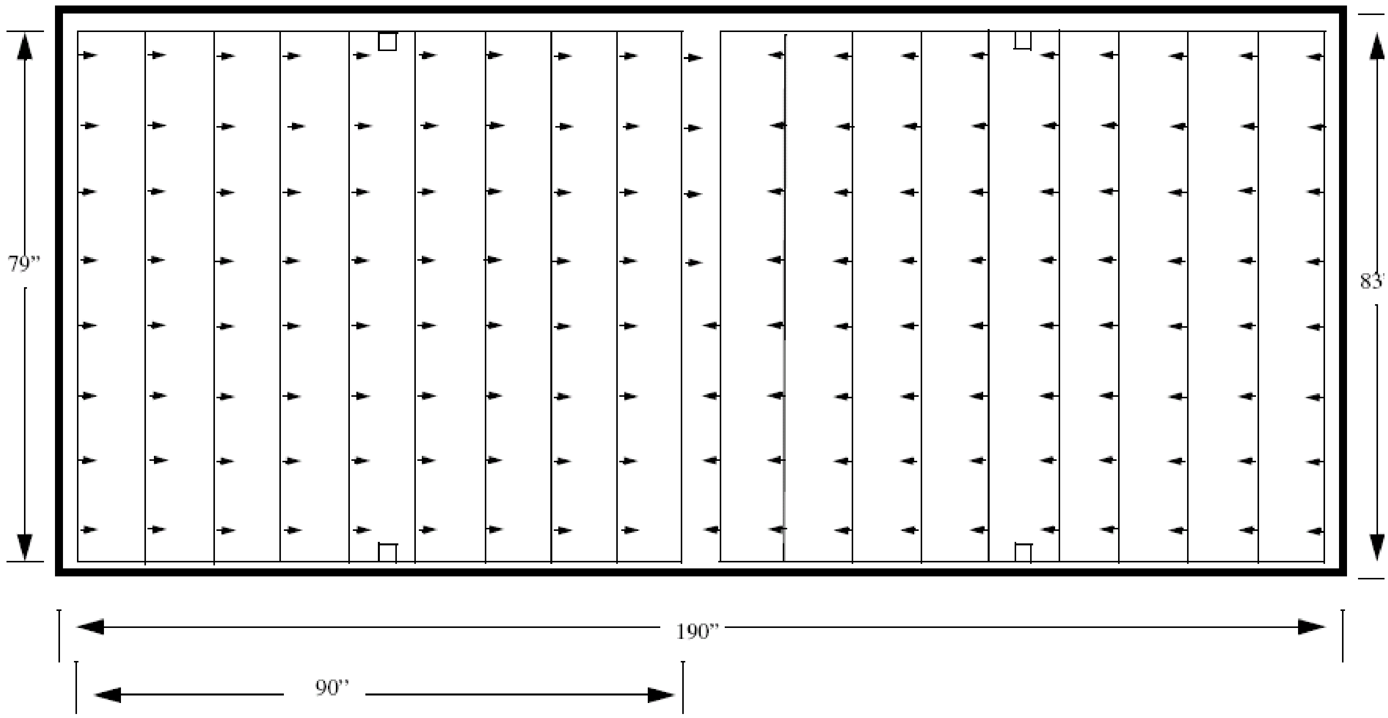

Figure 5. Outside Air Intake Tracer Gas Injection Manifold

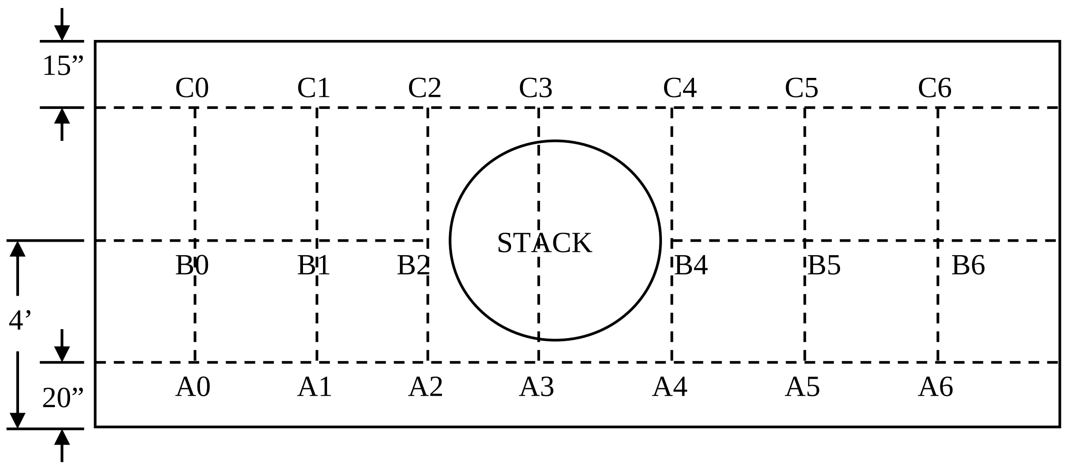

Figure 6. Stack sample locations