PRACTICAL EXPERIENCE APPLIED TO THE DESIGN OF INJECTION AND SAMPLE MANIFOLDS TO PERFORM IN-PLACE SURVEILLANCE TESTS ACCORDING TO ANSI/ASME N-510

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Abstract

At the current level of maturity and experience in the nuclear industry, regarding testing of air treatment systems, it is now possible to design and qualify injection and sample manifolds for most applications. While the qualification of sample manifolds is still in its infancy, injection manifolds have reached a mature stage that helps to eliminate the "hit or miss" type of design.

During the design phase, manifolds can be adjusted to compensate for poor airflow distribution, laminar flow conditions, and to take advantage of any system attributes. Experience has shown that knowing the system attributes before the design phase begins is an essential element to a successful manifold design. The use of a spreadsheet type program commonly found on most personal computers can afford a greater flexibility and a reduction in time spent in the design phase.

The experience gained from several generations of manifold design has culminated in a set of general design guidelines. Use of these guidelines, along with a good understanding of the type of testing (theoretical and practical), can result in a good manifold design requiring little or no field modification. The requirements for manifolds came about because of the use of multiple banks of components and unconventional housing inlet configurations. Multiple banks of adsorbers and pre and post HEPA's required that each bank be tested to insure that each one does not exceed a specific allowable leakage criterion.

Introduction

The often critical application of nuclear air treatment systems (NATS) installed at various nuclear, chemical, and biological facilities has necessitated the testing of the individual components to ensure their leak tightness. As the various facilities have grown and matured over the years, so have the NATS. The design of NATS has gone from simple single bank, sheet metal, and silicone sealed units to multiple bank, stainless or coated steel, all welded construction. Since the industry needs to ensure with a high degree of confidence that the individual banks of components inside the NATS will perform as required, refined injection and sampling techniques had to be developed. The use of injection and sample manifolds has been introduced to meet this need.

While this paper will introduce some basic design guidelines for manifolds, it can in no way envelop all of the variables associated with system, component, and application design and installation. The major emphasis will be placed on injection manifolds required on post installation NATS. Although the major emphasis is on injection manifolds, most of these guidelines can be applied to the design of sample manifolds as well.

Discussion

One of the most important steps in the design of an injection manifold is deciding where to place the manifold in the NATS. The primary placement of the manifold is determined by the function of the manifold and the component layout of the filter bank. The best location takes advantage of system or component attributes that create increased velocity and flow turbulence in the housing (for example, at the outlet air slots of type II adsorber trays or at the inlet or outlet slots of a type III deep bed adsorber bank). Other locations could be at the air flow traverse station or just upstream of the system inlet plenum. All these options must be examined and the best location chosen before the design phase.

These steps are given in order of importance for determining the best location of the injection manifold:

- Function of the injection manifold.
    - Is it an injection or sample manifold only or is to be used as a combination injection / sample manifold?
- Airflow velocity.
    - What are the maximum and minimum velocities expected at the manifold location?
- Airflow distribution.
    - What is the velocity profile of the airstream at the manifold location?
- Ease of installation and use.
    - Is the manifold to be temporary or permanent?
    - Is the manifold to be installed in the ductwork or inside the NATS housing?
    - From what material should the manifold be constructed?

During the design process it is important to understand how the system and its components work. For example:

- The air velocity through a NATS housing is usually less than 200 feet per minute (fpm) which is considered to be in the laminar flow region. By being laminar, very little mixing will occur inside the housing.
- The air velocity at the face of a 24 x 24 x 11.5 inch standard size 1000 cfm HEPA filter is approximately 300 fpm.
- The air velocity at the face of the outlet air slot for a standard type II adsorber tray is approximately 1300 fpm.
- The airflow velocity at the inlet and outlet air slots of a type III adsorber bed is generally lower than that exiting a type II tray, and higher than at the face of a standard size HEPA.
- On most Type III adsorber beds the outermost air slots are, by design, operating at an assumed 50% of the airflow of the inner air slots due to the bed geometry.

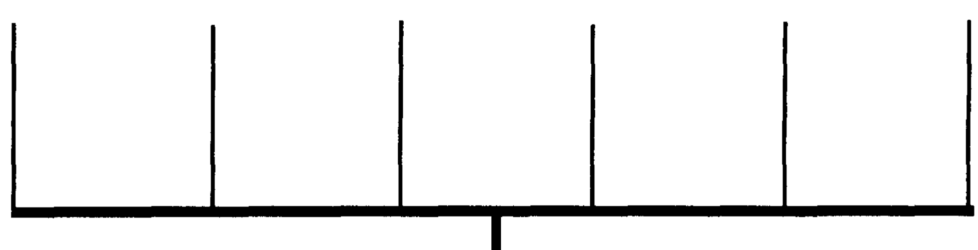
Another factor that will affect the manifold design is the airflow distribution (velocity profile) at the proposed manifold location. When designing an injection manifold for use downstream of the upstream HEPA bank, an airflow distribution test must be performed. If the airflow distribution meets the acceptance criteria of no one reading exceeding ± 20% of the average velocity, then no special design adjustments are required. However, if this ± 20% is exceeded then design adjustments of the manifold may be required.

Generally in most NATS there are other factors that enhance challenge agent mixing (e.g., distance) to eliminate a concern over a ≤ 20% difference in airflow distribution. If the manifold is to be located where the airflow distribution exceeds ± 20%, then the manifold should be designed proportionately. The need for proportionate design usually occurs when the manifold is to be installed in ductwork where short distance mixing is required.

A typical manifold consists of a header and risers (See Figure 1). Each riser has a series of holes through which the challenge agent is introduced to, or withdrawn from, the air stream. See Figure 2 for more details.

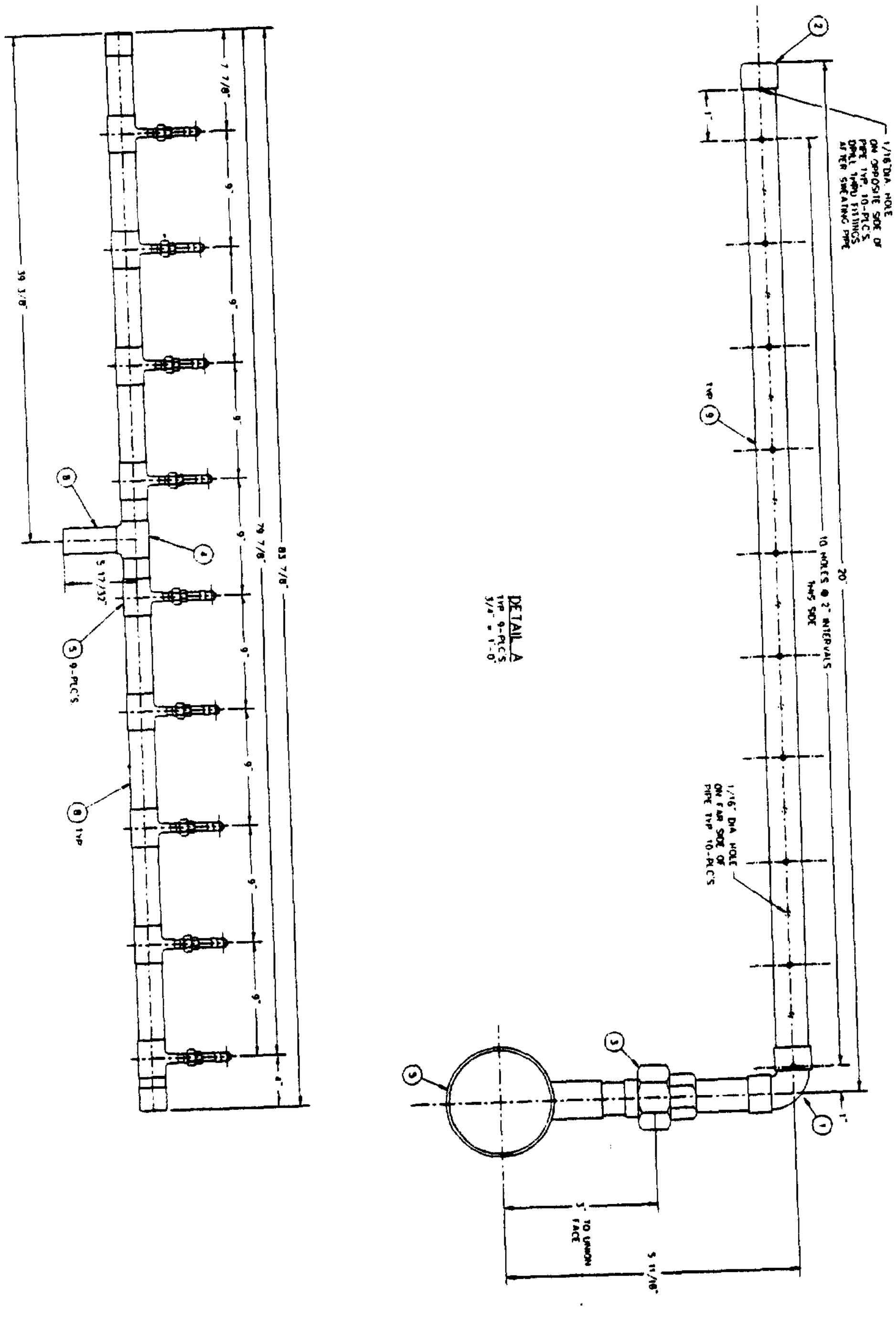
Figure 1 Simplified layout of an injection/sample manifold.

Risers (6)



Header

Figure 2
Typical combination manifold (injection & sample) designed to be installed in the air channels of a type II adsorber bank.



Once the location of the manifold is identified, the next step is determining the location of each riser. The risers should be placed to take advantage of system or component designs that increase velocity. For example, risers placed directly in the air channel of a type II or type III adsorber bed will take advantage of the increased velocity associated with those air channels.

If the manifold is to be placed in rectangular ductwork suppling the NATS, then divide one axis of the ductwork into equal areas using the same methodology for determining the traverse points for a rectangular duct airflow traverse. Each manifold riser should be positioned in the center of these equal areas. The distance between these equal areas should generally not exceed six inches. Depending on the velocity of the airflow, duct layout and the distance to the bank being tested, the distance between these equal areas could exceed or be less than six inches. This methodology can also be applied to a round duct.

Another possible location is at the downstream face of the prefilter bank or upstream HEPA bank. The latter would be necessary if the NATS contained a downstream HEPA bank that was required to be tested. While this location is usually less desirable due to the low exit airflow velocity of these components, designing a suitable manifold is possible. Two items to keep in mind are; first, if the filters do not load evenly (dirt loading) this will affect the performance of the manifold and second, when the filter bank is replaced it should be a full replacement rather than a partial replacement. The location of the risers is determined using the same method as for ductwork. The risers need to be positioned to cover only the face of each filter. No holes should be drilled in an area of no airflow (i.e., between filters).

An ideal location for a manifold in a NATS housing will take advantage of the high airflow velocities associated with type II or Type III adsorber banks. The risers for these manifolds need to be located at each air channel. The best position for each riser is just inside each air channel (approximately 50% should be inside the air channel) to take full advantage of the higher velocities.

Design Method

After the location of the manifold and positioning of the risers has been established, the next step is designing the manifold. The basic steps in designing a manifold require determining:

1) Riser hole layouts (spacing and angular position with respect to airflow).

2) Quantity of holes per riser.

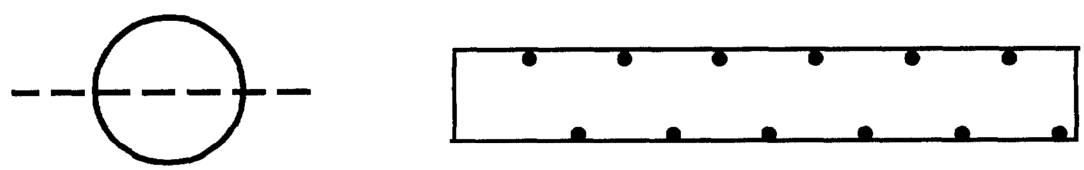
3) Diameter and area of the riser holes.

4) Riser pipe diameter and area.

5) Header pipe diameter and area.

The hole layout on each riser should cover the effective airflow area. From applied experience a hole spacing of approximately two inches apart per side and staggered on each side is desirable. Hole location should be 180° degrees apart and perpendicular to the direction of airflow.

Figure 3 Typical hole layout of a riser.



The riser pipe diameter depends on the quantity of holes per riser and the sum of their areas. Depending on the positioning of the individual risers and the adjacent components (if any), the riser diameter can also be used to increase the velocity and turbulent flow of the air stream. Experience has shown that the decrease in air channel area will add approximately 0.5 to 1.0 inches of pressure drop across the bank. This does not apply when the risers are to be positioned in the ductwork or on the downstream side of a prefilter or HEPA bank.

Two rules apply to the sizing of riser holes:

- The cross-sectional area of the riser should be greater than or equal to (±10%) the sum of the areas of the holes per riser.
- The cross-sectional area of the header should be greater than or equal to (±10%) the sum of the areas of the holes in all the risers.

When designing a manifold to be placed where the airflow distribution (velocity profile) exceeds ± 20% of the average and short distance mixing is required, the hole sizing on the risers must be proportional to the airflow. The use of any spreadsheet program with plotting capabilities is very useful when performing the following steps:

1) Perform an airflow distribution test by measuring the airflow velocities at equal areas for each riser region position.

2) Calculate the velocity total for all readings.

3) Calculate the % of average for each velocity reading.

4) Determine the % of total velocity for each riser region.

5) Determine the total riser area.

6) Calculate the required total hole area for each riser region.

7) Determine the quantity of holes corresponding to each riser region from the location of the velocity readings and the desired hole layout.

8) Determine the hole diameter for each riser region.

The sizing of the holes, riser, and header may allow several variations from which to decide. From these options, several items should be evaluated:

- Difficulty in drilling the holes.
    - Very small holes are difficult and time consuming to drill.
- Ease of use if it is only installed temporarily for testing.
- Complexity of assembling temporary manifolds.

Once the design is finished, the material from which to construct the manifold needs to be chosen. Things to consider when deciding on construction materials are:

- Composition of the airstream (e.g., acid or alkaline gases, particulate types and concentration, moisture, etc.).
- Temperature of the air stream.
- Velocity of the air stream at the manifold location.
- Decontamination requirements, especially if it is a temporary manifold.

While PVC, stainless steel, and mild steel have all been used in the past, copper tends to be the best overall choice. It is easy to work with, relatively light, and cost effective. After the manifold has been constructed it is important that all burrs be ground smooth and provisions made to clean the internals of the manifold. This is especially important when the manifold is to be used as a combination injection and sample manifold.

Once the manifold has been constructed, it still must be qualified by performing an air-aerosol mixing test. If the design guidelines have been properly followed then this test should be uneventful. However, if the design guidelines were not followed or some unforeseen problems occur, then field modifications of the manifold may be required. This field modification may range from minor changes, such as hole plugging or enlarging holes, to major redesign work.

The following is an illustration of a 30,000 CFM NATS. Although it contained only a single HEPA and adsorber, bank an injection manifold was required. The only available injection point was located at the pitot traverse location. This location was approximately four feet from the inlet to the housing (See Figure 4). First, a velocity traverse was performed and this profile was graphically plotted out (See Charts 1 & 2). After analyzing the velocity profile and determining the riser hole layout a spreadsheet was designed to simplify the process of calculating the required velocity percentages and hole areas (See Table 1). The manifold was designed using this information and a successful air-aerosol mixing test was performed with no field modifications required of the manifold (See Figure 5).

Figure 4 Physical layout of the 30,000 CFM NATS.

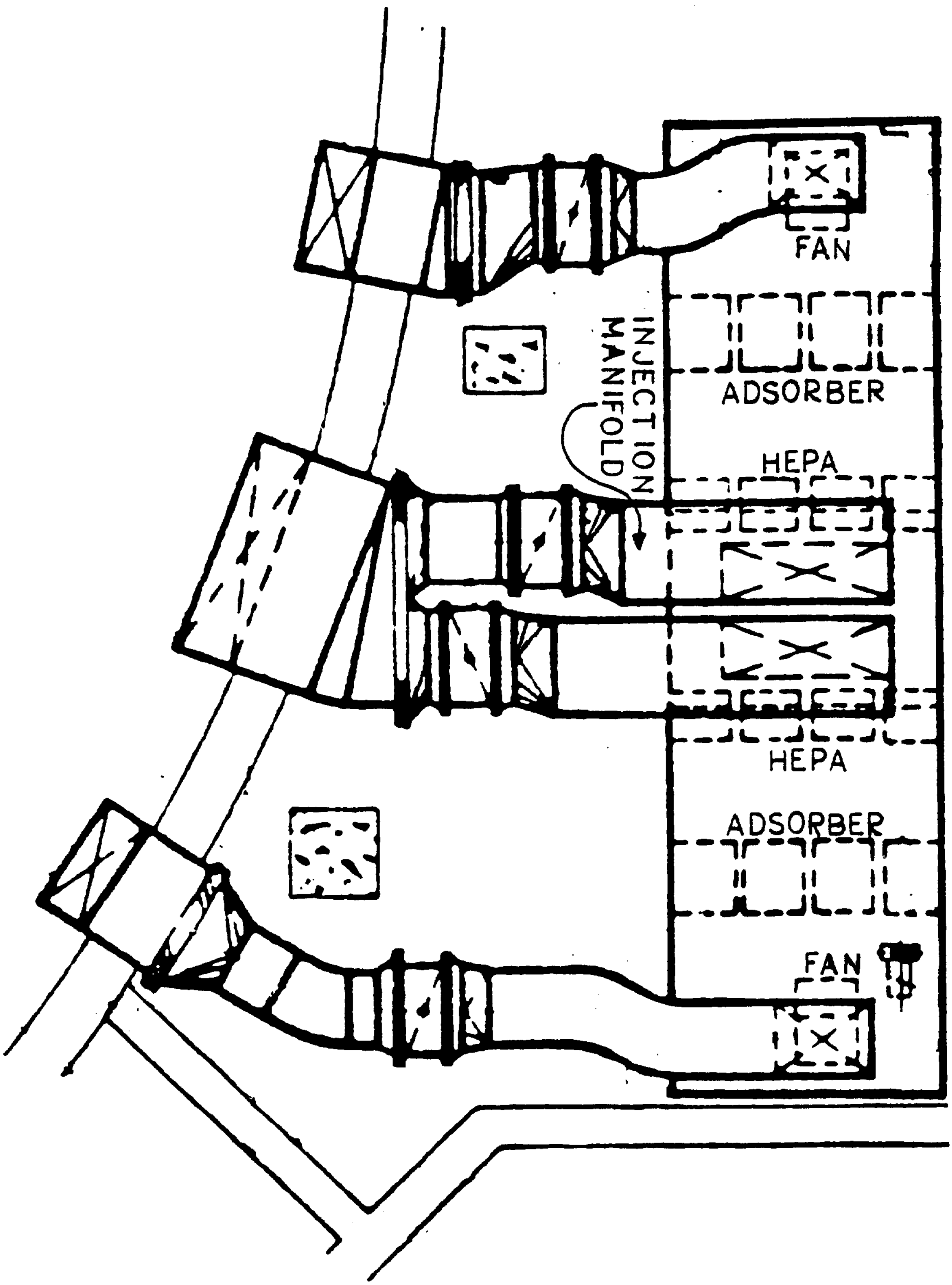


Chart 1 Bar graph plot of the individual velocity points inside the duct.

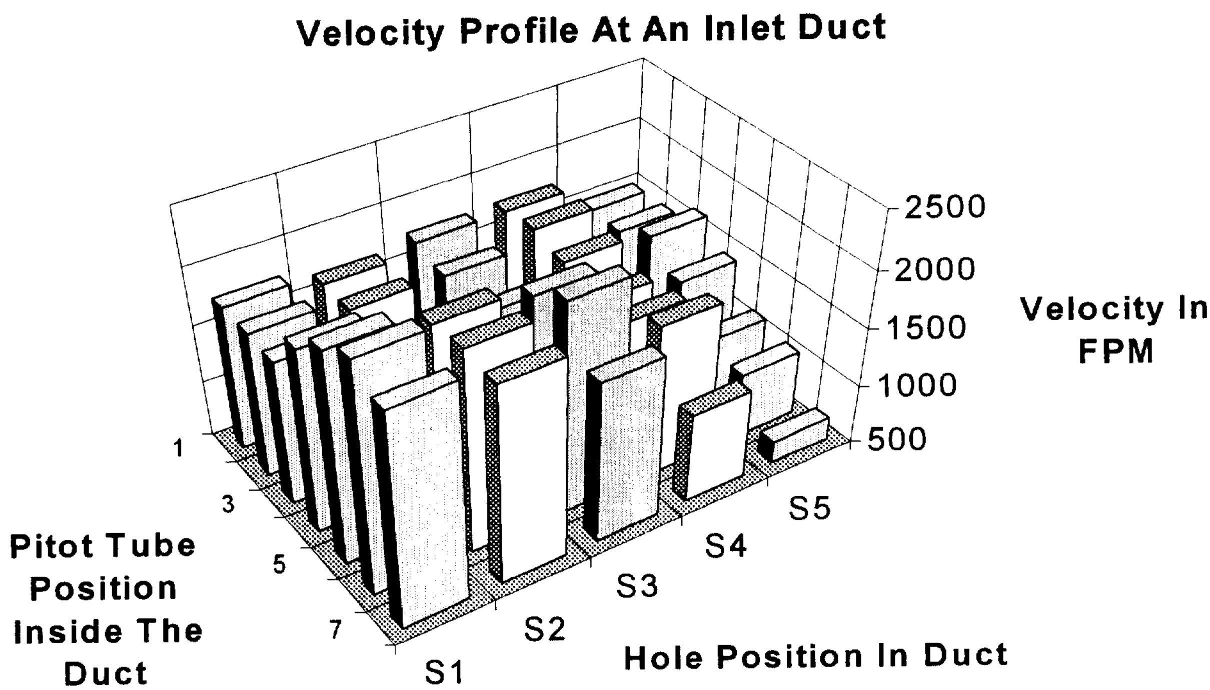


Chart 2 Surface plot of the velocity profile inside the duct.

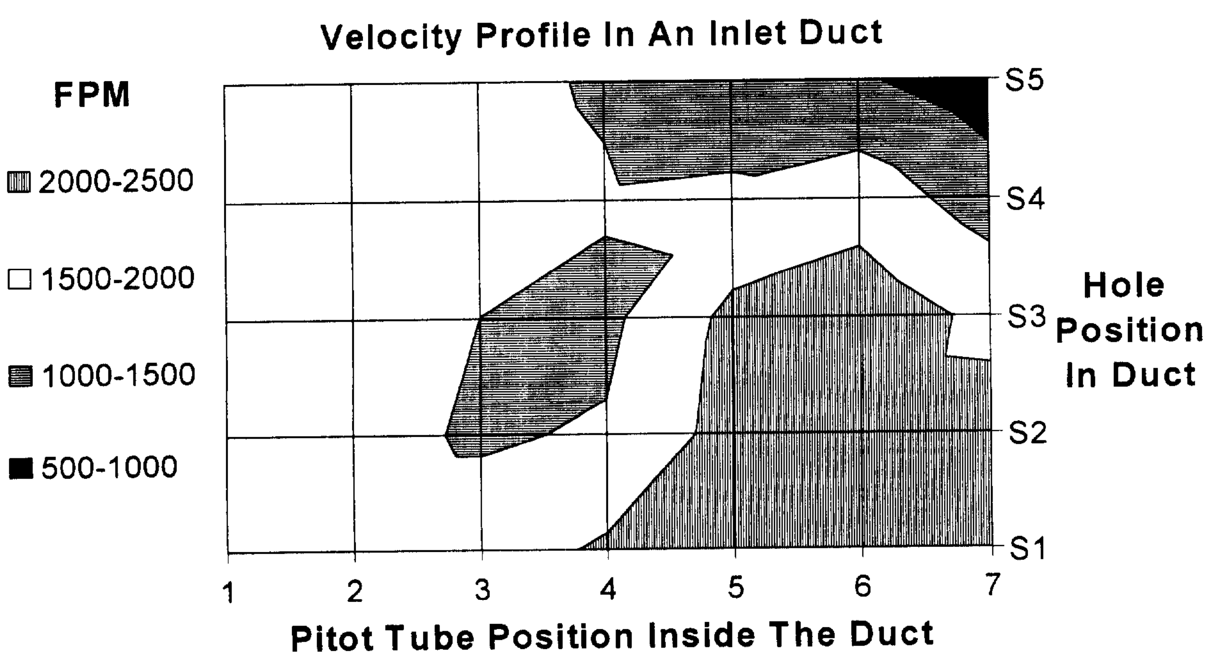


Table 1 Worksheet used to plot velocity graphs and calculate hole size.

DATA VELOCITY

								TOTAL BY TUBE	% BY TUBE
	1499	1499	1651	1444	1133	1060	694	8980	15%
	1746	1791	1699	1551	1602	1791	1266	11446	19%
	1746	1651	1499	1387	2119	2301	1879	12582	21%
	1651	1651	1444	1551	2194	2230	2194	12915	21%
	1746	1746	1746	2081	2301	2469	2335	14424	24%
TOTAL	8388	8338	8039	8014	9349	9851	8368	60347	100%

PERCENT OF AVERAGE FLOW

87%	87%	96%	84%	66%	61%	40%
101%	104%	99%	90%	93%	104%	73%
101%	96%	87%	80%	123%	133%	109%
96%	96%	84%	90%	127%	129%	127%
101%	101%	101%	121%	133%	143%	135%

PERCENT OF FLOW BY RISER

16.7%	16.7%	18.4%	16.1%	12.6%	11.8%	7.7%	100%
15.3%	15.6%	14.8%	13.6%	14.0%	15.6%	11.1%	100%
13.9%	13.1%	11.9%	11.0%	16.8%	18.3%	14.9%	100%
12.8%	12.8%	11.2%	12.0%	17.0%	17.3%	17.0%	100%
12.1%	12.1%	12.1%	14.4%	16.0%	17.1%	16.2%	100%

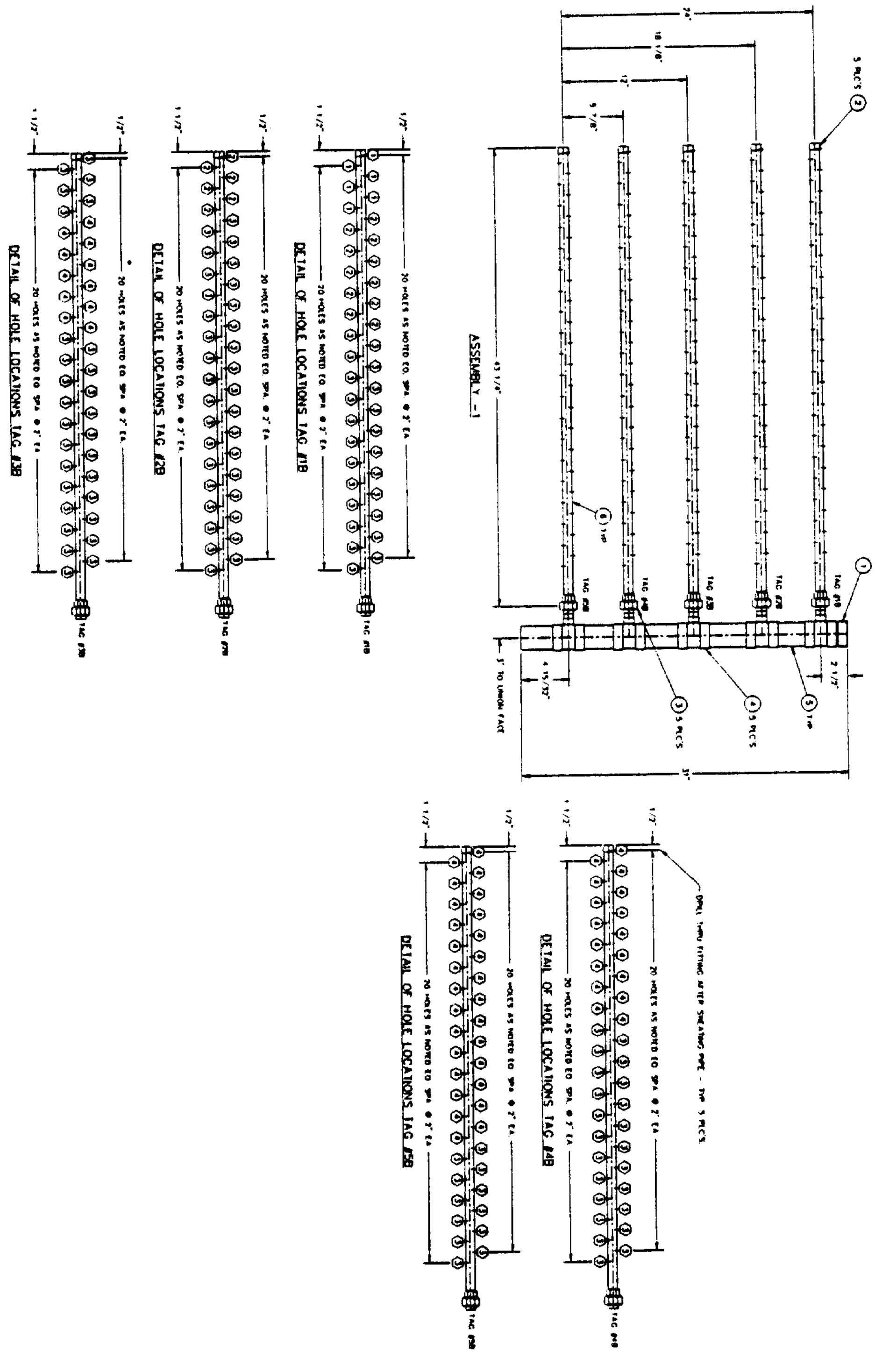
AREAS OF OPENINGS BY REGION

							TOTAL	AREA OF HOLES 2
0.050	0.050	0.055	0.048	0.038	0.035	0.023	0.298	0.30
0.058	0.059	0.056	0.051	0.053	0.059	0.042	0.379	0.38
0.058	0.055	0.050	0.046	0.070	0.076	0.062	0.417	0.42
0.055	0.055	0.048	0.051	0.073	0.074	0.073	0.428	0.43
0.058	0.058	0.058	0.069	0.076	0.082	0.077	0.478	0.48

HOLE SIZE BY REGION

QTY	6	6	5	6	5	6	6
	0.103	0.103	0.118	0.101	0.098	0.086	0.070
	0.111	0.112	0.120	0.104	0.116	0.112	0.094
	0.111	0.108	0.112	0.099	0.134	0.127	0.115
	0.108	0.108	0.110	0.104	0.136	0.125	0.124
	0.111	0.111	0.121	0.121	0.139	0.132	0.128

Figure 5 Injection manifold designed for the inlet duct of a 30,000 CFM NATS.



While this paper does not address manifolds dedicated to sampling only, the general design guidelines for an injection manifold may be applied to the design of sample manifolds. When a manifold is to be used as both an injection and sample manifold, the design guidelines that apply to the injection manifold take precedence.

Summary

The need to test multiple banks of components in a single NATS required that a method be developed to introduce a test agent uniformly for each bank in the NATS. For a single bank of components, this requirement for uniform distribution of the test agent is still required. To meet the acceptance requirements of the various testing documents and Regulatory Guides, a qualified method of test agent distribution had to be developed. Injection and sample manifolds have made it possible to test entire NATS without having to disturb a single bank of components or by placing test personnel inside the NATS to perform a multi-point sample or shroud test method.

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References

1. ANSI/ASME N-509, "Nuclear Power Plant Air-Cleaning Unit and Components."

2. ANSI/ASME N-510, "Testing of Nuclear Air Treatment Systems."

3. ASME, CONAGT, AG-1, "Code On Nuclear Air and Gas Treatment."

4. USNRC, Regulatory Guide 1.52, "Design, Testing and Maintenance Criteria for Atmosphere Cleanup System Air Filtration and Adsorption Unit of Light-Water-Cooled Nuclear Power Plants."

5. USNRC, Regulatory Guide 1.140, "Design, Testing and Maintenance Criteria for Normal Ventilation Exhaust System air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants."

DISCUSSION

SCRIPSICK: Has size dependent particle loss been considered when testing HEPA filter systems? Photometry can introduce you to uncertainties. Are you evaluating injection sample manifolds for size-dependent effects? I do not think that has been addressed in this work. For the kinds of testing being conducted the type generator being used, and the amount of aerosol generated, there should be no such effects. I do not think there is a problem in that regard because they are using 0.3 μm particles according to the procedure in N510. When using a light scattering photometer the response is strongly dependent on particle size. Therefore, if you introduce a size bias either to your sampling technique or your injection device, the size distribution upstream will be different from the size distribution downstream. Alternatively, if you have losses in the sampling system that are not balanced, you will not have the same losses as a function of size upstream as you do downstream. The error propagates into your photometer measurement, and ultimately will affect the error in your test results.

GRAVES: I am not sure I follow you, but we can always make the case that our sampling lines will affect the results. I do not believe the aerosol was degenerated. We were using NUCON equipment, we were not using laser light for particle light scattering. I don't think that is a problem with this technique.

KOVACH, B: I know you are talking about large particles becoming lost in different places. This means that you are going to smaller and smaller particles when you use a manifold. Let me tell you that the aerosol generator being used has no particles above 2μm. There is a baffle plate that collects the larger particles. Therefore the manifold is contributing little to change the particle size. Using the particle size spectrometer we have at NUCON, we could not see much difference. Therefore size change if any, has been neglected. If we used a laser spectrometer we might find size differences, but they would not make much change in the results.

ENGELMANN: As a quality control-quality assurance matter, did you, by any chance, sample without any intervening filtration? Did you look at the release characteristics to see if your sampler showed the same thing as is present in the air stream?

GRAVES: After installation you have to qualify manifolds. You do this with an aerosol mixing test; in this particular case, at 30,000 CFM maximum flow rate as shown on the view graphs. You must make the usual scan to see if you have good aerosol mixing. Between the injection point and the measurement point all you have is duct length so there is no filtration involved.

ENGELMANN: The reason for looking at particle size might be to see to what extent the particle size distribution may become biased between the release point and the sampling point in the interpretation of the results. They should show the same sizes.

GRAVES: I would expect them to be the same sizes.

ENGELMANN: What about concentration?

GRAVES: You inject aerosol upstream through a manifold to solve a maldistribution problem. You are using a device that generates an aerosol of the appropriate particle size distribution. You use one that is know to do that. You are simply directing it in such a way as to cover the cross section of the airstream and to get the required distribution. You are solving a problem with a single point injection into the manifold.

and to get the required distribution. You are solving a problem with a single point injection into the manifold.

ENGELMANN: I wonder if you determined the need for an injection manifold based on a mixing test, or just on the geometry of the housing?

GRAVES: In this particular case a single injection point without aa manifold was deemed to be unsuitable because mixing was not very good. A manifold was needed to solve that problem.

HOLTORP: Did you perform some air-aerosol mixing uniformity tests before installing the manifold? What was the improvement you saw on the mixing test results?

GRAVES: This was used as an example because of the quality of the solution. In this particular case, there was no good place designated for this particular system, it just didn't work. After installation it went from failure to easy pass. We are very happy with this particular installation.