the required removal efficiency of the filter. Furthermore, it is not yet clear whether the iodine so deposited is in elemental form, which would be removed by a charcoal filter anyway, or is associated with the difficult-to-filter particles. It seems more prudent to assume the former until there is proof to the contrary.

It is emphasized that the specific mechanism by which the iodine is associated with the particles is of no great interest for the purpose of this paper. That is to say, it makes no difference whether the iodine is in compound form or attached as elemental iodine to some particle. It is only necessary for the purpose of this paper that the iodine somehow becomes attached to particles of this size or that the particles behave as though they were in this size range. Of course, in actual practice the form of the iodine would most likely be important if attempts were made to somehow increase its particle size or to convert it to elemental iodine. Also, certain forms may attach to particles more readily than others.

Last, it must be remembered that the major purpose of the vast amount of work currently in progress regarding air cleaning is for a specific end result; namely, use in plant-size facilities where extremely large amounts of biologically harmful materials exist. Even in case of a major accident, the design must be such that not more than a very small percentage of these materials can be released to the atmosphere. This means that information which can be used in the design of a practical, over-all filter complex must be available to the designers of these systems. Such information would include the distinctive efficiency of the various components of the air stream for the different types of filters and the amount and types of particles which could be expected from various types of reactor incidents or meltdowns, isotope-recovery plants, and fuel-reprocessing plants. From this information, a "tailor-made" filter system could be designed. This could be a formidable task for some reactors, such as research reactors, which usually have more than one type of fuel either in various test loops or as the reactor fuel. What may be practical in small-scale laboratory work may not be practical in a large plant.

DISCUSSION AND COMMENT

The complete penetration of the 0.3 micron particles, and below, and efficiencies were assumed in this paper.

Session Chairman: If there are no further questions, I will turn the podium over to Dr. First who will be the Chairman of Session IV.

SESSION IV - AIR AND GAS CLEANING METHODS

Afternoon - 22 October 1963

M. W. First, HACL, Chairman

Session Chairman: Since we are running considerably behind time, as I am sure you are aware, instead of taking a stretch as we might like, I am going to continue right on.

Session IV concerns Air and Gas Cleaning Methods. I am sure I do not have to introduce the first speaker, who will discuss "Performance of Diffusion Board for Radioactive Gases and Particulates." If I were to say the speaker is Mr. Air Cleaning I am sure you would understand I am talking about Les Silverman. He is Professor of Environmental Health, Engineering and Radiation Hygiene at Harvard University, and is the Head of the Department of Industrial Hygiene.

PERFORMANCE OF DIFFUSION BOARDS FOR RADIOACTIVE GASES AND PARTICULATES

by

L. Silverman

Harvard University School of Public Health

Those of you who were at the Seventh Air Cleaning Seminar heard me discuss the diffusion board concept.

One of the advantages of trying to solve the information explosion which we face are the benefits that accrue by having available here a summary of the last Air Cleaning Conference. If you will look at this summary you will see an abstract, in which the diffusion board concept is outlined.

Before going into our new studies I would like to acknowledge the contribution of my coworkers, Bob Gussman and Bill Kyritsis and Nertan Esman and Al Fisk. They were responsible for the experimental data I will discuss.

By way of orienting you, our concept of a diffusion board is a reverse procedure to the Chemical Corps development. Their concept is a medium equivalent to a porous wall; one that has both filtering and adsorbing properties. In their case it is a cellulose type building board containing activated charcoal. If you erected a building with these boards as panels, and entered the closed building, the walls would breathe outdoor atmosphere, and remove the chemical agents and particulates present as chemical or BW agents.

Our concept is the reverse of the Chemical Corps. We don't want to protect the people inside as much as to protect the public outside. We therefore proposed to develop a diffusion board which would act as a reactor containment, or confinement wall. All the material released to the atmosphere, in an accident, or perhaps routinely, would be cleaned. Nothing would escape to the atmosphere from the chamber except for the noble gases. We don't have as yet an inexpensive, simple mechanism for removing noble gases.

If you look at the diffusion board, criteria outlined in Summary of the Seventh Proceedings, which you have a copy of, you will note the objectives the board must meet. Performance specified includes efficiencies of 99.9% or better for fine particulates: iodine removal of a similar magnitude; resistance to steam; and structural resistance to shock waves.

FABRICATED HONEYCOMB DIFFUSION BOARD

The original Harvard diffusion board is a composite design to take advantage of everything we know in filter and adsorber theory and practice.

Figure 1 shows our original board concept. I also have a sample unit on the table which can be examined later. Figure 1 shows the honeycomb structure and the surface filters in which use 1106 B media or an equivalent filter medium. The honeycomb is a structural device which contains the adsorbent. We have since found it necessary to back the outer sheet with a support to prevent tearing. The honeycomb, which is a strong structural member used in airplane cabin structures, can be filled with silver-coated silica gel, one of the materials we have studied for elemental iodine, removal copper turnings, or activated charcoal. The Japanese have found that activated alumina performs well in iodine removal.

We are concerned with the potential fire problem, and for that reason the diffusion board resistance to ignition and fire must be considered. Activated carbon is combustible and any adsorbed activity would be released in such an instance.

Figure 2 shows the apparatus used for particulate removal measurements. Uranine disodium fluorescein can be generated in any size from about 0.05 microns up. In this case, an aerosol of 0.079 μ was used by using dilute uranine solution ($<0.5\%$). We sample up and down stream with millipore filters, and analyze them in a spectrophotofluorimeter. With this method we can detect 10^{-9} grams per ml in solution. The test setup for evaluating particulate efficiency can be used in combination with iodine and particulates being generated simultaneously.

Figure 3 shows the test equipment for evaluating the diffusion boards with elemental iodine. The iodine 127 can be tagged with iodine-131 if necessary. For our measurements inert iodine could be measured at 2 μg/ml using a spectrophotometer. A pair of absorbers were used for sampling the iodine in 5% potassium iodide (KI) solution and then analyzed for elemental iodine.

To get reliable tests the board must be sealed into a holder effectively. Efficiency and resistance tests were conducted at velocities ranging from 1 to 5 feet a minute.

The Harvard diffusion board results are shown in Tables 1 and 2. Several combinations were used in 1- and 1/2-inch thicknesses. They could be made thicker or thinner, depending on the behavior to be predicted. We used 1106 B media, which is an all-glass paper, at one foot per minute, velocity it would be in the diffusion range for particle separation. Penetration of the 0.079 μ uranine particles shown in Table 1 is about 10^{-4} per cent. These boards vary from one to the other almost because of construction, rather than because the media is not reproducible. Our construction of wood and cement cannot be made this closely reproducible since they are handmade boards. For iodine note that the board does remove iodine without any fill, simply because of adsorption of the iodine on the glass fiber surfaces.

The boards filled with 12 to 30 mesh columbia-activated charcoal, which is of the coconut-shell type, shows very little difference in particulate removal with 1106 B media. Iodine removal on a half inch of charcoal, or the silver plated silica gel, also give consistent data. The FG-50 media shows lower particle as well as iodine removal indicating the value of a high efficiency medium on iodine vapor removal. The FG-50 is a roughing filter material made of resin bonded 0.7 to 1$\frac{1}{2}$ micron fibers. It shows about 90% removal of atmospheric dust.

CERAMIC DIFFUSION BOARDS

For practical use, it is desirable to have a material that can be made cheaply in quantity. Such a material is needed in order to build a structure

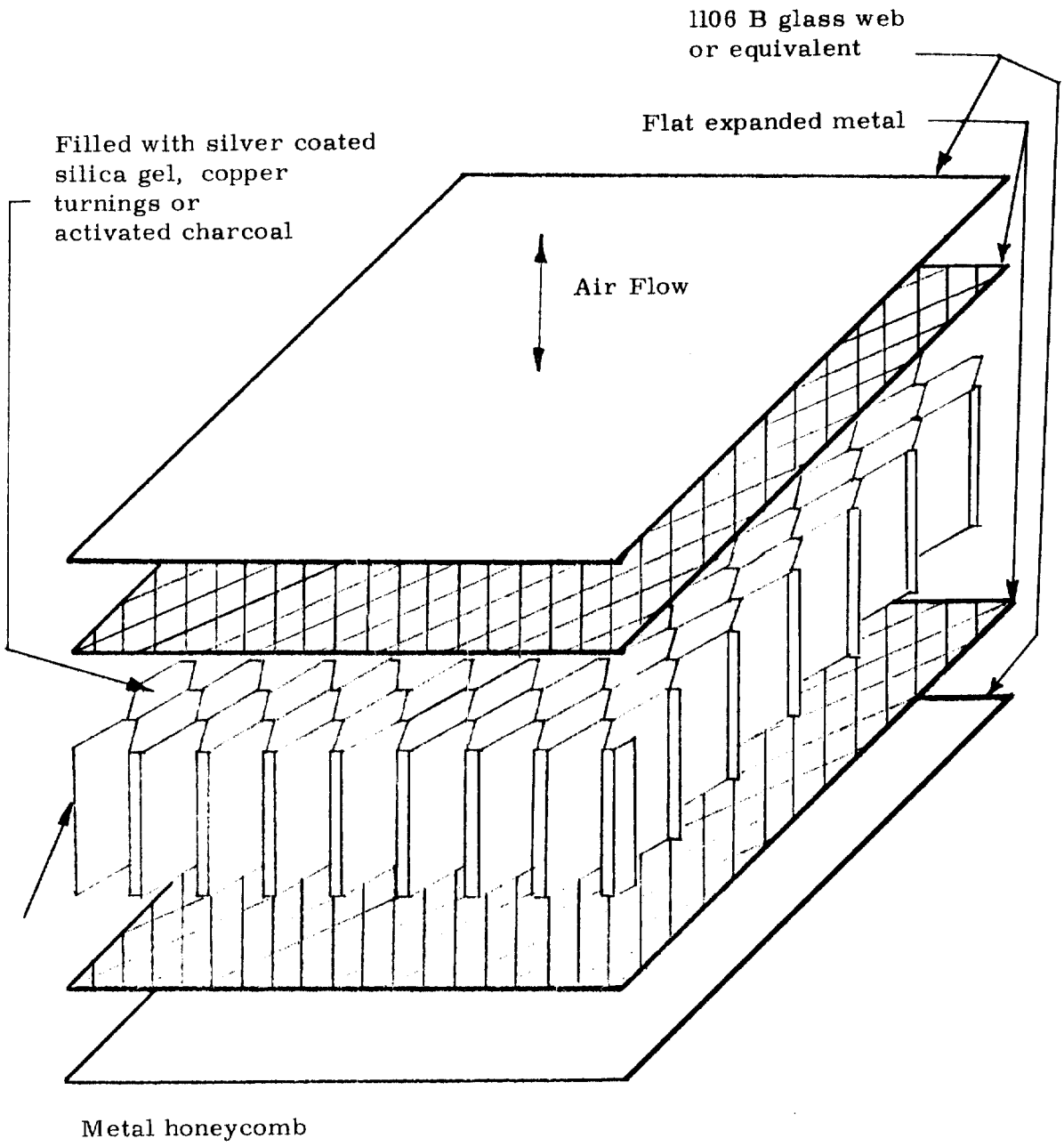

1106 B glass web
or equivalent
Flat expanded metal
Filled with silver coated
silica gel, copper
turnings or
activated charcoal
Air Flow
Metal honeycomb

FIGURE 1

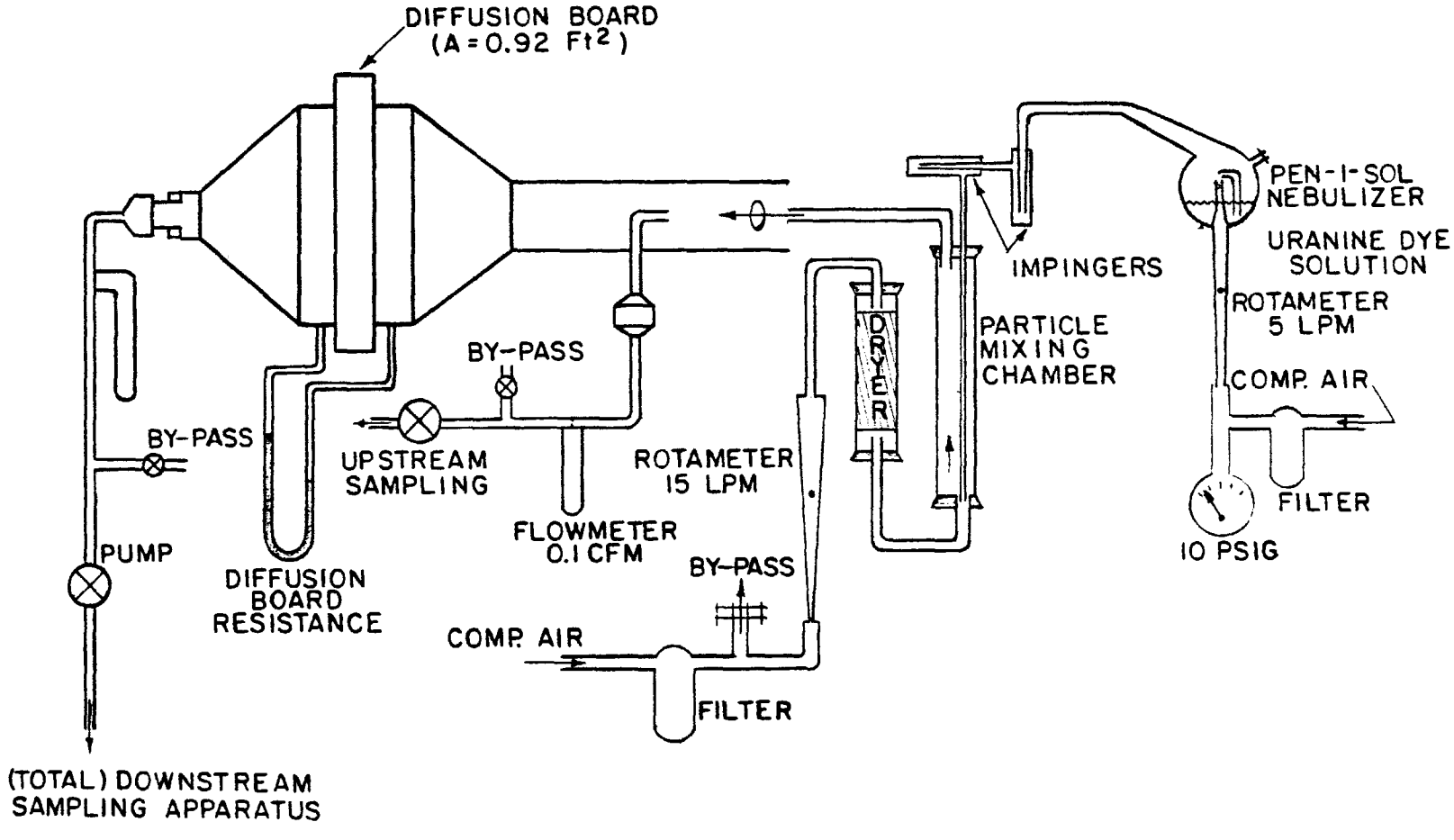


FIGURE 2. SCHEMATIC OF DIFFUSION BOARD TEST APPARATUS WITH URANINE GENERATOR.

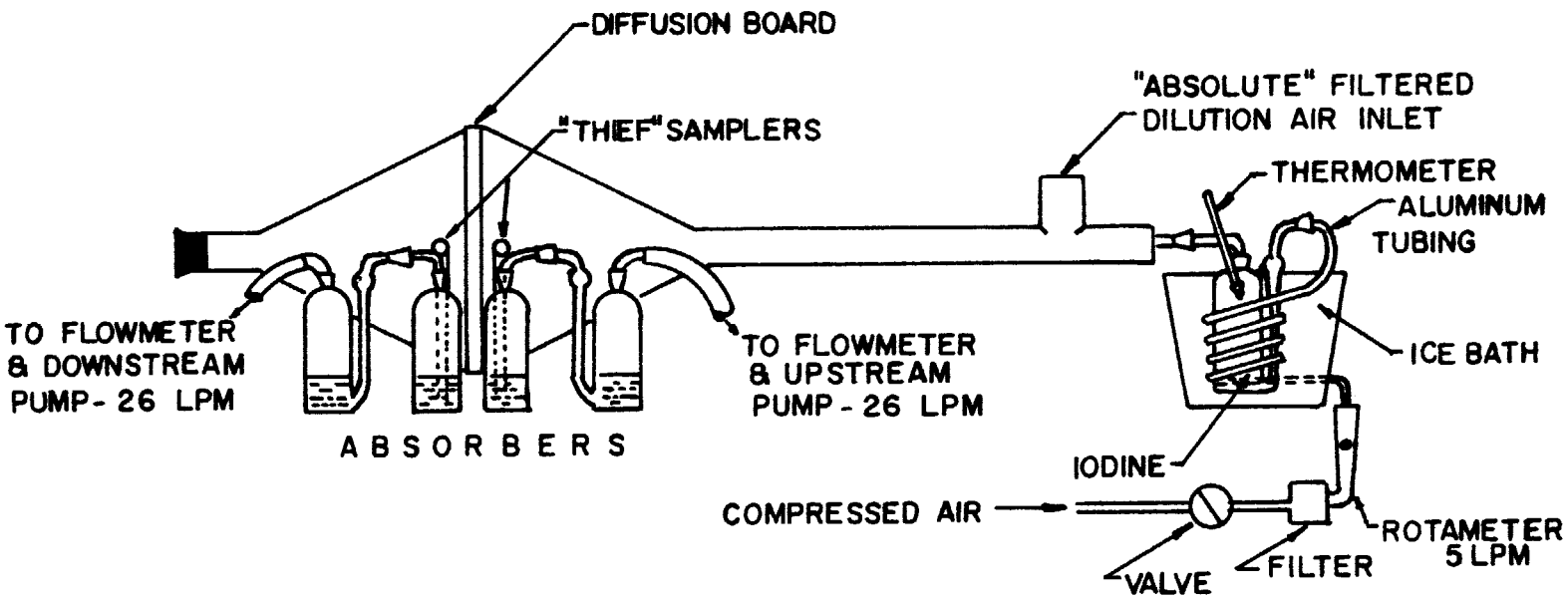


FIGURE 3. SCHEMATIC REPRESENTATION OF DIFFUSION BOARD TEST APPARATUS FOR IODINE COLLECTION EFFICIENCY STUDIES

TABLE 1

EFFICIENCY OF HARVARD DIFFUSION BOARD FOR PARTICULATE REMOVAL
(Uranine Aerosol - 0.07μ)*

Size and Adsorbent	1" Unfilled	½" Unfilled	1" Silvered Silica Gel 6-16 mesh	½" Silvered Silica Gel 6-16 mesh	1" Activated Carbon 12-30 mesh	½" Activated Carbon 12-30 mesh	1" Activated Carbon Fiberglas Layer Upstream	½" Activated Carbon with Fiberglas Layer** Upstream
Upstream loading mg/m^3	8.08	7.75	8.00	7.59	5.11	6.93	8.42	8.98
Downstream loading mg/m^3	0.064×10^{-4}	0.164×10^{-4}	0.128×10^{-4}	0.692×10^{-4}	0.320×10^{-4}	0.128×10^{-4}	0.471×10^{-4}	4.09×10^{-4}
Penetration %	0.79×10^{-4}	2.12×10^{-4}	1.60×10^{-4}	9.11×10^{-4}	6.27×10^{-4}	1.85×10^{-4}	5.59×10^{-4}	45.7×10^{-4}
Efficiency %	99.9999	99.9998	99.9999	99.9991	99.9994	99.9999	99.9994	99.996
Panel Resistance in. of H_2O at 1 fpm	0.266	0.260	0.266	0.272	0.250	0.252	0.130	0.129
Relative Humidity R.H. %	-	-	15	13	15	22	22	23

* MG = 0.079μ ; σ = 1.78

** Fiberglas mat consists of FG 50 3/8 inch thick Fiberglas medium purchased from the Owens-Corning Fiberglas Co., Newark, Ohio. Downstream face and all other panels use 1106-B all glass media purchased from the Mine Safety Appliances Co. (Mfg. by Hurlbut Paper Co., So. Lee, Mass.)

TABLE 2

EFFICIENCY OF HARVARD DIFFUSION BOARD FOR IODINE VAPOR REMOVAL*
(All one half-inch boards)

Size and** Adsorbent	½" Empty, 1106-B Both Sides (3 Tests)	½" Activated Charcoal 1106-B Both Sides (3 Tests)	½" Silvered Silica Gel 1106-B Both Sides (2 Tests)	½" Activated Charcoal, FG-50** Upstream, 1106-B Downstream (3 Tests)
Upstream Conc. ppm	5.69	5.49	5.40	6.14
Upstream conc. mg/l	0.0659	0.059	0.056	0.0636
Downstream conc. mg/l	0.0463	1.026×10^{-4}	1.023×10^{-4}	33.7×10^{-4}
Penetration %	78.3	0.18	0.18	5.35
Efficiency %	21.7	> 99.82	> 99.82	94.65
Panel Resistance in. of H_2O at 1 fpm	0.33	0.32	0.33	0.18

* All panels tested at 1 fpm (1 cfm per sq. ft.) for 15 minutes.

** Fiberglas mat consists of FG-50 3/8 inch thick Fiberglas medium purchased from the Owens-Corning Fiberglas Co., Newark, Ohio. Downstream face and all other panels use 1106-B all glass media purchased from the Mine Safety Appliances Co. (Mfg. by Hurlbut Paper Co., So. Lee, Mass.).

in which the walls, or interior walls inside a concrete block, are the diffusion media. We have been working with Dr. R. R. Sullivan of the Wood Conversion Company in St. Paul. He has developed a ceramic board for us. I have a sample here for inspection.

The board is composed of slag wool fibers, ceramic material, fluxes and cellulose. The latter burns out when the board is fired leaving a suitable void space. Because this media is porous in all directions, it has to be sealed into a steel ring holder for testing purposes. We are in the process of experimenting with various treatments for iodine removal. Iodine results presented were obtained on samples treated with ethyl silicate to give a high adsorptive surface. We believe that something additional as an adsorbent such as activated alumina should be incorporated into the material.

Figure 4 shows the test unit that was used for evaluating the ceramic boards. It is similar in principle to the previous unit, except the tests are made with a small disk. Pressure drop and efficiencies are measured in the same manner. At the present time we have a long tube unit arranged to measure steam and shock-wave resistance. This apparatus is comparable to that used to shock wave clean filters as discussed in the previous Air Cleaning Conference paper on shock wave cleaning.

Tables 3 and 4 present the data on particulate and iodine removal. The code numbers refer to the fiber-ceramic combinations that Wood Conversion has produced. Pressure drops at 1 fpm are somewhat higher about 35% than our fabricated boards. Their removal of 0.079μ particulates is very high and comparable to absolute filters. As a matter of fact, this value is close to our limit of sensitivity for measurement. Their efficiency might be better than stated. No effect of velocity could be observed in the range studied.

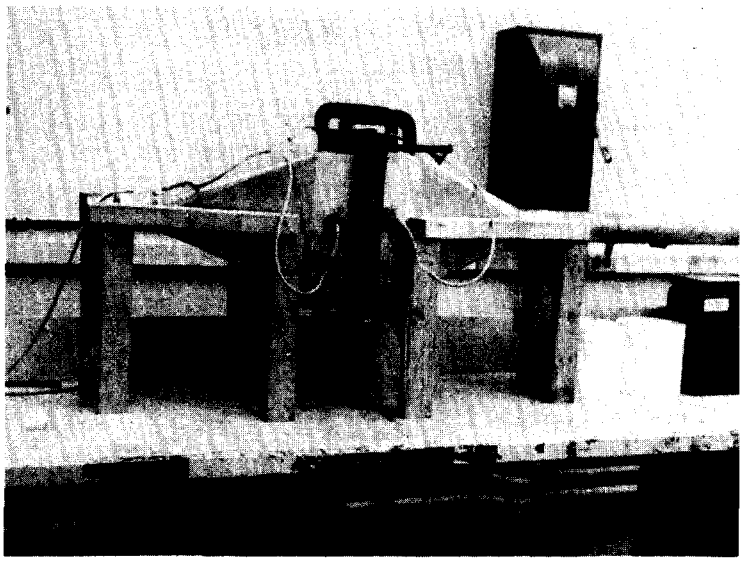
These boards were evaluated at velocities below 1 fpm up to the absolute filter range of 5 fpm.

We are quite pleased with these preliminary units for particulate removal. They appear to be a possible replacement for high temperature absolute filters. For such a use, because of the high pressure drop, of course, is such that you would need fairly large surfaces. Nevertheless if five feet a minute is used as the medium velocity for absolute filters, a diffusion board array with comparable area would yield a high removal efficiency.

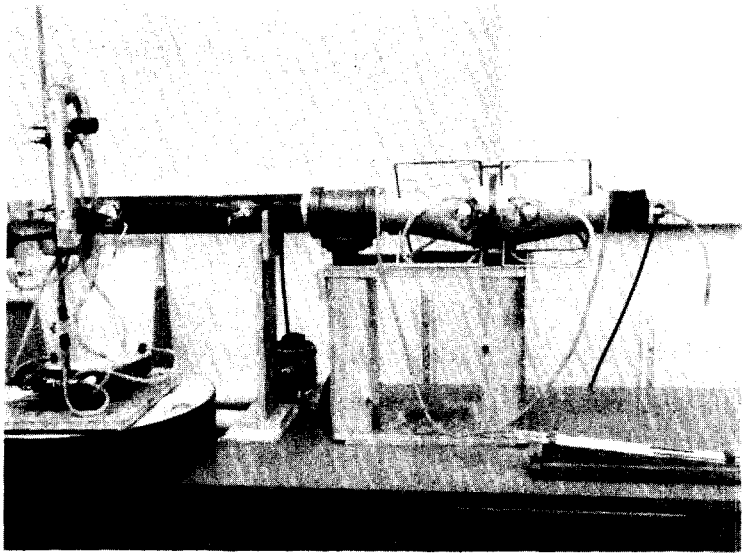
Table 4 shows the results of iodine removal for a board treated with ethyl silicate. Its elemental iodine removal was measured at one foot a minute. You will note the resistance has increased 2½ times, due to the treatment. A gel probably formed at the surface of the fibers which caused a deposit that would increase the flow resistance. With this treatment the ceramic board has given about 97% removal of elemental iodine for a 15 minute period. Another sample, as shown in Table 4 gave a higher result of 98.1%. A deterioration in efficiency is shown in Table 4 with continued testing. This is a stoichiometric problem - iodine if calculated in terms of curies might be tremendous. In terms of elemental iodine, however, they only had a 15-minute exposure to about 3 ppm of iodine-127. The results to date on iodine removal look very promising. Further studies on various treatments of these ceramic surfaces are planned as well as incorporation of various heat resistant adsorbents.

We believe that this board can be fabricated at a fairly low cost. We are thinking of something in the range of acoustic tile costs.

This concludes my discussion on the diffusion board performance at the present time. Our work is still in progress. We hope to develop a porous



4A - Large Diffusion Board Test Apparatus



4B - Small 6" Ceramic Diffusion Board Test Equipment

FIGURE 4

TABLE 3

WOOD CONVERSION DIFFUSION BOARD
URANINE PARTICULATE REMOVAL*

Type Diffusion Board	# Runs	Δp "H_2O	Face Velocity	% Efficiency
35-602 I	4	0.4	1 ft./min.	99.98+
35-602 II	4	0.4	"	"
35-606 I	1	2.2	"	"
35-602 II	1	0.1	0.25 ft./min.	"
35-602 II	1	1.8	5 ft./min.	"
35-606 I	1	6.1	5 ft./min.	"
35-606 I	1	0.3	0.25 ft./min.	"
35-605 I	2	0.5	1 ft./min.	"
35-605 I	2	0.1	0.25 ft./min.	"
35-605 I	2	2.7	5 ft./min.	"

* Uranine aerosol - 3.5 to 5.5 mg/m^3

Mg = 0.079

σ = 1.77

Elapsed time - 6 min.

Samples No. 35-602, density 18.5 pounds per cu. ft. and untreated other than having been fired at 2000 F.

Samples No. 35-606, were prepared by taking No. 35-602 material and impregnating with ethyl silicate gelled in place, and being approximately 65% add-on weight basis.

Samples 35-605, similar to No. 35-602, density 21.5 pounds per cu. ft. density.

Samples are 6" o.d. and 3/8 to 1/2" thick.

TABLE 4

WOOD CONVERSION DIFFUSION BOARD IODINE REMOVAL*

Type Diffusion Board	Time Elapsed	Δp "H_2O	Face Velocity	% Efficiency
35-606 II	15 min.	1.09	1 ft./min.	97.28
"	"	1.00	"	83.7
"	"	0.99	"	75.6
35-602 IV	"	0.35	"	98.11

* Approximate(parts per million)(vol.) I_2 = 2

Samples No. 35-602, density 18.5 pounds per cu. ft. and untreated other than having been fired at 2000 F.

Samples No. 35-606, were prepared by taking No. 35-602 material and impregnating with ethyl silicate gelled in place, and being approximately 65% add-on weight basis.

Samples 35-605, similar to No. 35-602, density 21.5 pounds per cu. ft. density.

Samples are 6" o.d. and 3/8 to 1/2" thick.

medium which will allow containment, or confinement, at much lower cost. If you can rapidly relieve the pressure in a containment vessel, that is, let the steam and gases pass out, all the stored energy problem which is now of major concern in designing a containment vessel, will be eliminated. The cost of construction that people feel is excessive can be reduced.

Session Chairman: Thank you, Dr. Silverman.

In the interest of time, I will ask the audience to kindly hold the questions until all of the papers have been delivered.

The next paper, a HASL contribution, will be delivered by J. W. Thomas. The paper is entitled "Aerosol Penetration Through 9 mil HV-7 Filters With and Without Pinholes." The authors are J. W. Thomas and G. D. Crane.

AEROSOL PENETRATION THROUGH 9 mil HV-70 FILTER PAPER WITH AND WITHOUT PINHOLES

J.W. Thomas
G.D. Crane

U. S. ATOMIC ENERGY COMMISSION
HEALTH AND SAFETY LABORATORY
NEW YORK, NEW YORK

ABSTRACT

Studies were made of the penetration of two polydispersed dioctylphthalate aerosols of different particle size distribution through 9 mil HV-70 type filter paper with and without pinholes at several different air velocities.

It was found, as was expected from elementary considerations, that the penetrations of the two aerosols of different particle size differed greatly for an intact filter, but approached the same value for the filters oontaining pinholes. This result implies that in testing filters or filter installations for leaks, aerosol particle size is much less important than in evaluating filter materials per se.

To account for the pinhole effect, a generalized equation was developed which relates change of aerosol penetration through a filter to air linear velocity. This equation was confirmed within limits.

INTRODUCTION

Basic theory predicts, and numerous experiments have shown, that the penetration of an aerosol through a filter is a strong function of aerosol particle size. This statement, of course, implicitly assumes an intact paper without pinholes. For filters with relatively large pinholes, a different situation exists; the aerosol penetration is due mainly to flow through the pinhole rather than flow through the filter per se. Hence, one would assume much less change in penetration with particle size.

The reason for this assumption can easily be visualized. Let us suppose for example that there was a hole 0.25 millimeters in diameter in a filter. Penetration of an 0.3 micron aerosol through such a hole would be about 100%, as would penetration of a 1 micron aerosol; in either case the hole is hundreds of times as large as the particle and there is no reason to believe that there would be any significant removal of either size aerosol in passing through the hole. Thus if the filter material itself is high grade but with a leak, one would expect, for example, about the same penetration for an 0.3 micron aerosol as for a 1.0 micron aerosol.

Experimental confirmation of this assumption would have great practical significance since (1) there is reason to believe that leaks or holes in filters or filter installations are the principal cause of poor filtration systems, and (2) questions have been raised as to whether it is valid to test filter installations with Naval Research Laboratory (NRL) air operated generators, which produce a polydisperse aerosol containing particles larger than the standard 0.3 micron aerosol used in the acceptance test of filters and filter units. If it could be shown that particle size is not critical in evaluating filters with holes, it would be a strong indication that polydispersed aerosols are acceptable for testing filtration systems.

This paper describes an investigation made of the assumed lack of sensitivity of aerosol penetration through pinholed filters to particle size differences. A generalized equation for the pinhole effect is also developed and experimentally confirmed.

THEORETICAL ANALYSIS OF PINHOLE EFFECT

A. Effect of Particle Size on Aerosol Penetration Through Leaky Filters

Let us assume that there exists a leaky filter so that due to holes or poor seals 1% of the incoming aerosol leaks

through it. We can see no reason to believe that there would be any appreciable aerosol removal from the stream passing through the leak.

Suppose the fractional penetration of the intact filter is P'_s for a given small aerosol (s) and P'_ℓ for a given large aerosol (ℓ). Suppose P_s and P_ℓ be the fractional penetrations of the small and large aerosol through a filter with leaks. Then if the fraction of air through the leak is small, as it normally would be, to a good approximation

$$P_s = P'_s + 0.01$$

$$P_\ell = P'_\ell + 0.01$$

If both P'_s and P'_ℓ are very small, which would certainly be the case with an absolute type filter, then, very nearly

$$P_s = P_\ell = 0.01$$

Hence aerosol particle size would make very little difference in the penetration of a filter with holes.

For the case of intact filters having appreciable penetrations, the equations may be written in a more general form

$$P_s = P'_s + (Q_h/Q_t)$$

$$P_\ell = P'_\ell + (Q_h/Q_t)$$

where Q_h and Q_t are the flows through the hole and entire filter respectively. Solving the two equations gives

$$P_s = P_\ell + (P'_s - P'_\ell) \qquad (1)$$

Equation (1) may be used to calculate the penetration of a leaky filter for one aerosol from data on the penetration of another aerosol, and penetrations of both aerosols on intact filters.

B. Effect of Flow Rate on Penetration of Leaky Filters

Derivations of the equation for change of penetration with flow rate for a filter with pinholes or leaks have been given by Knudson and White[1] and recently by Parrish and Schneider.[2] The derivation of Knudson and White uses the assumption that the penetration of an intact filter is directly proportional to the flow rate. This assumption is generally not true, which makes the Knudson and White derivation of little use.

The Parrish and Schneider derivation is correct, granting their assumption that the flow through the hole is negligible

compared to the flow through the main body of the filter. Their final equation however, is not given in an explicit form which may be readily used. The authors have developed a generalized derivation which is more direct and readily useful. The following assumptions are made in this derivation:

1. The hole is sufficiently small so that the air linear velocity through the main body of the filter is the same as if the hole were not present,

2. The aerosol that passes through the hole does not undergo any absorption by the hole edges,

3. Flow rate through the hole is proportional to the square root of the pressure drop through the hole,

4. Flow through the main body of the filter is proportional to the flow rate.

The following nomenclature is used:

P = penetration of a filter, with holes, at flow rate Q,

P' = penetration of the filter, without holes, at the same flow rate Q,

P_1 = penetration of the filter, with holes, at flow rate Q_1,

P_1' = penetration of the filter, without holes, at flow rate Q_1,

Δp = pressure drop of filter at flow rate Q,

Δp_1^1 = pressure drop of filter at flow rate Q_1,

Q = any flow rate,

Q_1 = some flow rate at which P and P' values are known,

Q_h = flow through the hole at total flow rate Q, and

Q_{h1} = flow through the hole at total flow rate Q_1.

It is desired to write a general equation for P, as a function of Q, using the known quantities P', P_1', and Q_1, without using the unknown quantities Δp, Δp_1, Q_h, and Q_{h1}. From assumptions 1 and 2, two equations may be written express-

ing that the total penetration is the sum of the penetrations through the main body of the filter and the hole:

$$P = P' \left(1 - \frac{Q_h}{Q}\right) + \frac{Q_h}{Q} \tag{2}$$

$$P_1 = P_1' \left(1 - \frac{Q_{h1}}{Q_1}\right) + \frac{Q_{h1}}{Q_1} \tag{3}$$

From assumptions 1, 3, and 4, the following equations may be written:

$$\frac{Q}{Q_1} = \frac{\Delta_p}{\Delta p_1} \tag{4}$$

$$\frac{Q_h}{Q_{h1}} = \sqrt{\frac{\Delta_p}{\Delta p_1}} \tag{5}$$

The principal problem of the derivation is to eliminate the unknown quantity Q_h from equation (2).

From Eqs. (4) and (5),

$$Q_h = Q_{h1} \sqrt{\frac{\Delta_p}{\Delta p_1}} = Q_{h1} \sqrt{\frac{Q}{Q_1}} \tag{6}$$

From Eq. (3)

$$Q_{h1} = Q_1 \left(\frac{P_1 - P_1'}{1 - P_1'}\right) \tag{7}$$

Substituting Eq. (7) into Eq. (6),

$$Q_h = Q_1 \left(\frac{P_1 - P_1'}{1 - P_1'}\right) \sqrt{\frac{Q}{Q_1}} \tag{8}$$

Substituting Eq. (8) into Eq. (2),

$$P = P' + (P_1 - P_1') \left(\frac{1 - P'}{1 - P_1'}\right) \sqrt{\frac{Q_1}{Q}} \tag{9}$$

which is the desired relationship. The penetrations P' and P_1' are usually very small compared to unity, so a very good approximation of Eq. (9) is:

$$P = P' + (P_1 - P_1') \sqrt{\frac{Q_1}{Q}} \tag{10}$$

It is of interest to compare Eq. (10) with an equation that may be obtained from the work of Parrish and Schneider[3] (P&S). Their equation for the penetration P as a function of Q may be written:

$$1 - P = (1 - P') - \sqrt{\frac{A/B}{Q_1}} \qquad (9, \text{P\&S})$$

where A/B is a proportionality constant and is obtained from

$$1 - P_1 = (1 - P_1') - \sqrt{\frac{A/B}{Q_1}} \qquad (7, P\&S)$$

Solving (Eq. 7, P&S) for the quantity (A/B) and inserting in (Eq. 9, P&S), the authors obtained:

$$P = P' + (P_1 - P_1') \sqrt{\frac{Q_1}{Q}}$$

which is Eq. (10) of this report.

EXPERIMENTAL PROCEDURE

Figure 1 is a schematic of the filter test apparatus. Aerosol from an air operated generator is diluted to a useable range with room air and pulled by the blower through the large 2' x 2' x 1' clean up filter. A sample of aerosol is removed and filter penetration determined by alternately pulling the aerosol at a known linear velocity through the filter contained in the filter holder and through the by-pass line to the photometer. Details of the apparatus follow.

Aerosol Generators - The two NRL type, air-operated DOP generators include the small generator specified in NRL drawing D3356 and the large generator specified as NRL drawing F3609. The small generator consists of two one quart cans, the first containing an atomizer head having four #60 drill (0.040") atomizing jets, and the second containing an impactor. The impactor slit is 0.36 inches by 0.031 inches. Aerosol flowing through the slit impacts on a plate 0.072 inches distant. The large generator consists of a five gallon can containing six atomizing heads, each head having four #60 drill (0.040) atomizing jets. No impactor is used with this generator. The size of the two different polydispersed aerosols produced was not determined. It was known from other work that the aerosols from both generators were in the 0.1 to 1.0 micron range, and that the large generator produced larger particles than the small generator.

Filter Holder - Figure 2 shows an exploded view of the filter holder. Several sets of area-defining metal plates are provided so that different filter areas can be used.

Flowmeters - The accurate capillary type flowmeters used consist of a fine capillary and a water manometer. The flow through the capillaries is measured as a function of pressure drop by use of an accurate wet type gas meter. An accuracy of $\pm$ 1% in flow may be obtained.

Photometer - The photometer, NYAEC 7219, was manufactured by National Instrument Laboratories, Washington, D.C. It is equipped with a light leak and light shield.

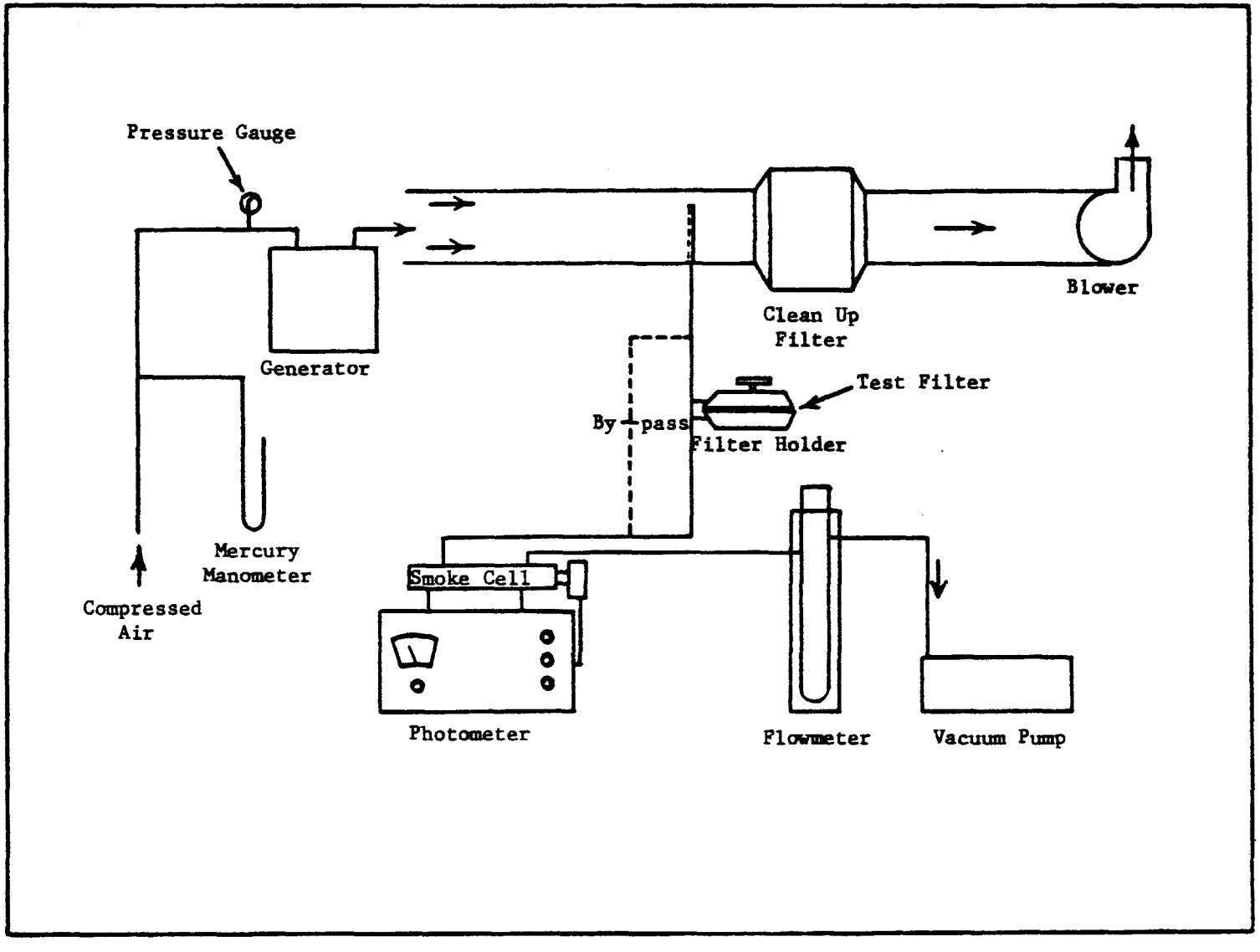


Figure 1. Filter Test Arrangement

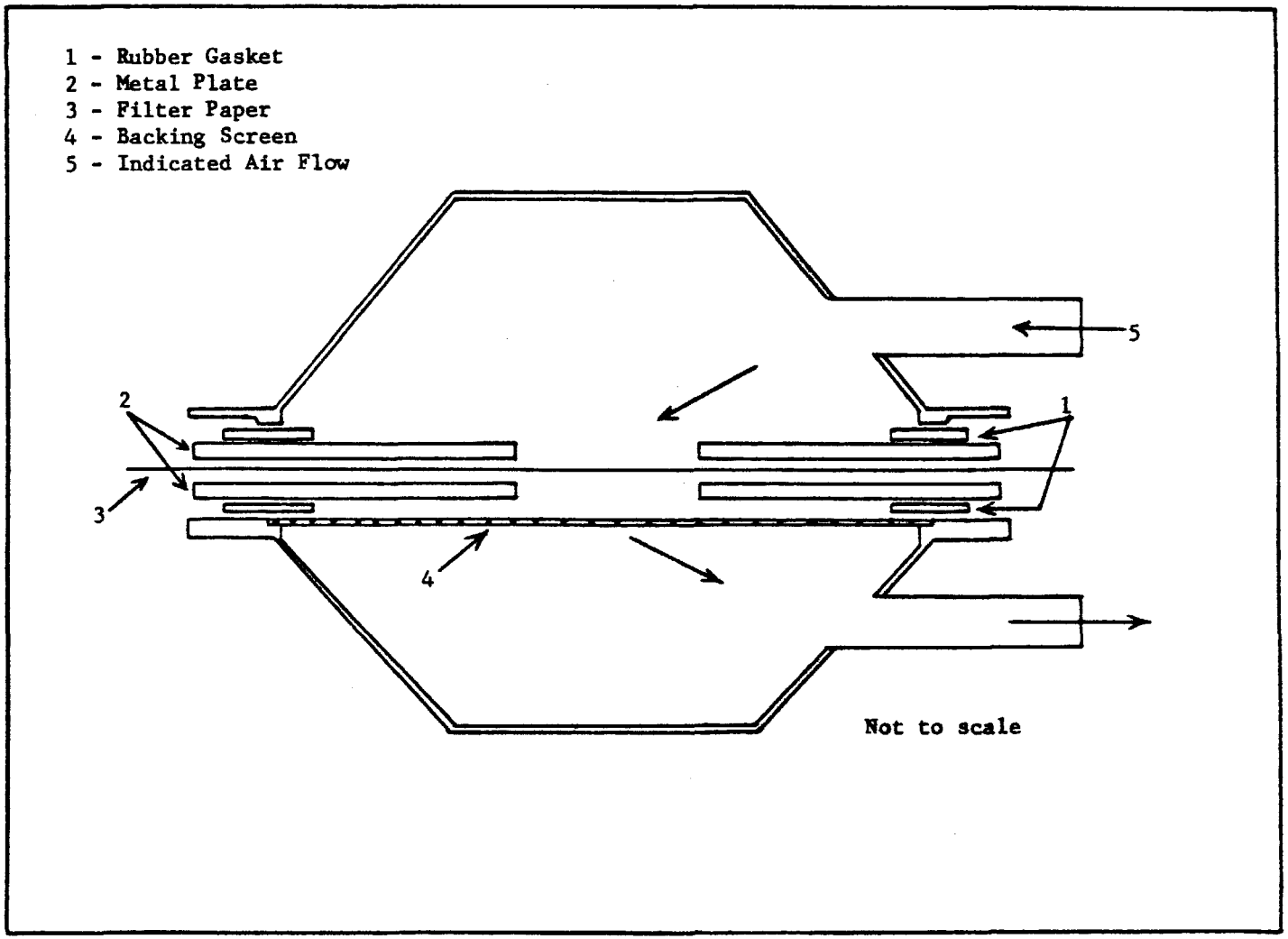


Figure 2. Filter Holder

Essentially, the procedure was to (1) test an intact filter paper sample with two different aerosols having different size distributions, and (2) retest the same filter paper, but with a hole, with the two different aerosols. If the test with the intact paper showed great differences in penetration, it was evidence that the particle sizes of the two aerosols were substantially different.

It was necessary to have readily available sources of two different aerosols so that the input to the filter paper under test could be rapidly switched from one aerosol to another without changing other test conditions, which might introduce errors. The small generator and large generator, previously described, were used for this purpose.

The comparison of filter penetration with the two different generators was done as follows. First, the photometer was warmed up and zeroed with respect to "meter zero" and stray light with clean air in the smoke cell. The flowmeter was adjusted to the proper flow rate. The blower was turned on, one of the generators placed at the duct inlet, and the generator air pressure adjusted to a standard value (5.0 + 0.2" of mercury for the large generator, 8 1/2 $\pm$ 1 lb/in^2 for the small generator). The resulting aerosol was then pulled through the by-pass line for a sufficient time to sweep out the volume of the system, and the photometer reading noted. Then the connections were switched to the filter holder, and the filter penetration noted. This procedure was repeated several times to complete one test at one flow rate on one of the aerosols. The generator was then removed, and the other generator placed at the duct inlet, and the test repeated. In most cases, after completing the filter paper test on both of the aerosols, the first aerosol tested was again used to insure that no change had occurred in the apparatus or filter paper with time. The following other routine checks were made during the test.

Aerosol Stability - A sample of input aerosol was isolated in the smoke cell and the rate of change of the photometer reading with time noted (no flow in the cell). This change was always found to be slow, less than 5% per minute.

Leaks - The filter holder, photometer smoke cell, etc. were closed off and a vacuum applied. The rate of decrease of the vacuum, after removal of the vacuum source, gave an indication of magnitude of leakage, which was always found to be negligible.

RESULTS AND DISCUSSION

In the first set of experiments for determining penetration with and without pinholes, Table I, seven different samples of HV-70 paper were evaluated at linear air velocities from 0.17 to 15.0 cm/sec.

The results of Table I are compared in Table III to equation (1) which states that

$$P_s = P_\ell + (P_s' - P_\ell') \qquad (1)$$

or that the penetration of a pinholed filter is the same for two different aerosols, except for the differences in penetration of the intact filters. Agreement is considered to be fair. The three figures (Figs. 3, 4 and 5) graphically present the data from Table I. Figure 3 confirms that the pressure drop of 9 mil HV-70 paper is proportional to the flow rate over the range of flows studied. This verifies assumption 4 used in deriving the equation for change in penetration with flow rate of pinholed filters (Eq. 10). Figure 4 shows penetration of the two aerosols through intact 9 mil HV-70 paper versus air velocity, and shows that the two aerosols were of different particle size.

Figure 5 shows a plot of the ratio of penetration of the small aerosol to the large aerosol as a function of air linear velocity, for both intact and pinholed filters. This figure shows explicitly that while penetrations of intact filters might differ by a factor of about three with two different aerosols when pinholes (or leaks) are present the differences in penetration can fall to 50% or less. Had an absolute type paper been used instead of HV-70, theory indicates that the differences in penetration of pinholed absolute filters would have been much less. Figure 5 implies therefore that in testing filters or filter installations for leaks, particle size is much less important than in testing intact papers.

In the second set of experiments for confirming the pinhole equation, Table II, the same piece of filter paper, containing a 0.25 mm diameter hole, was evaluated at air linear velocities from 2.5 to 15.0 cm/sec using the two different

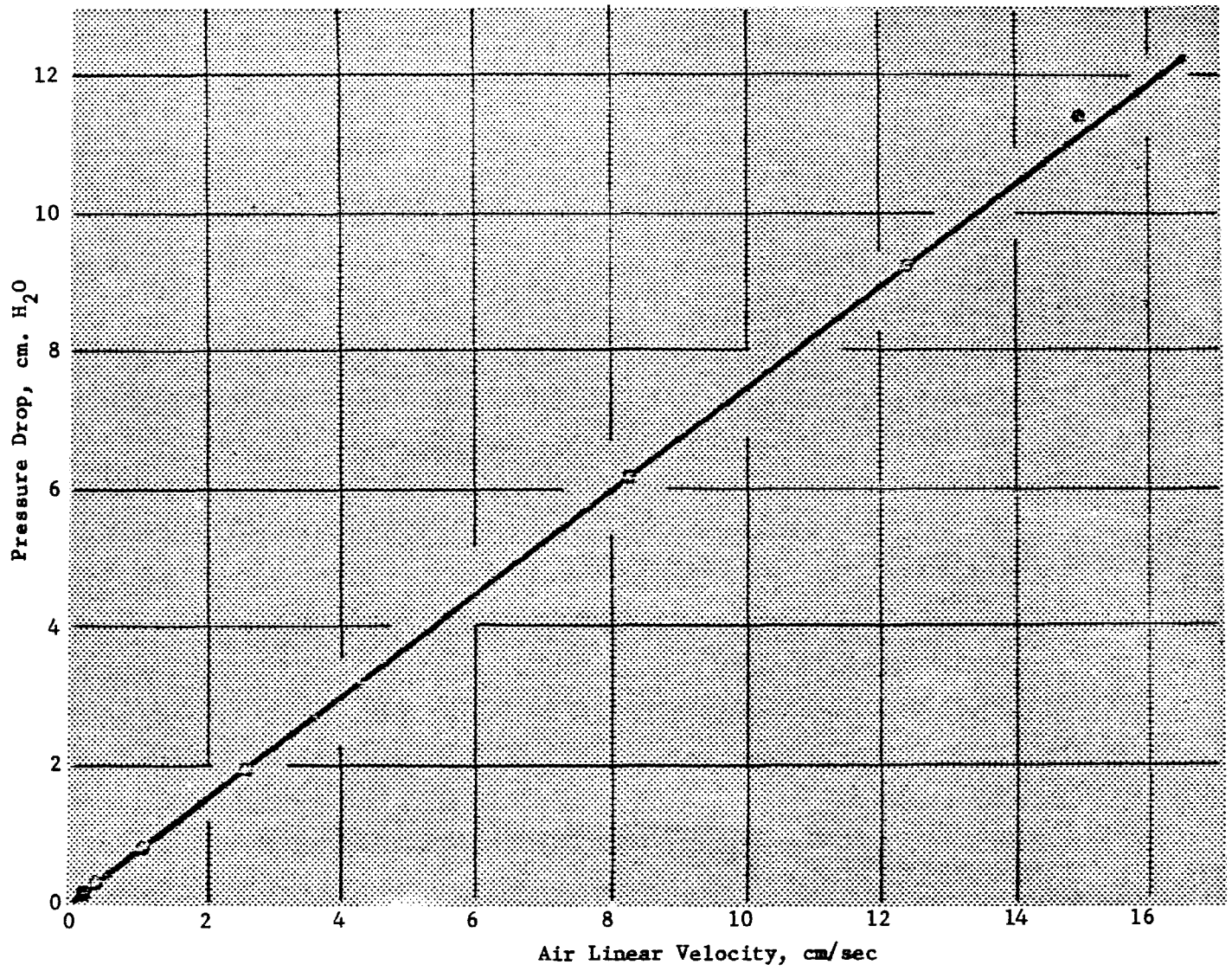


Figure 3. Pressure Drop of 9 mil HV-70 Paper

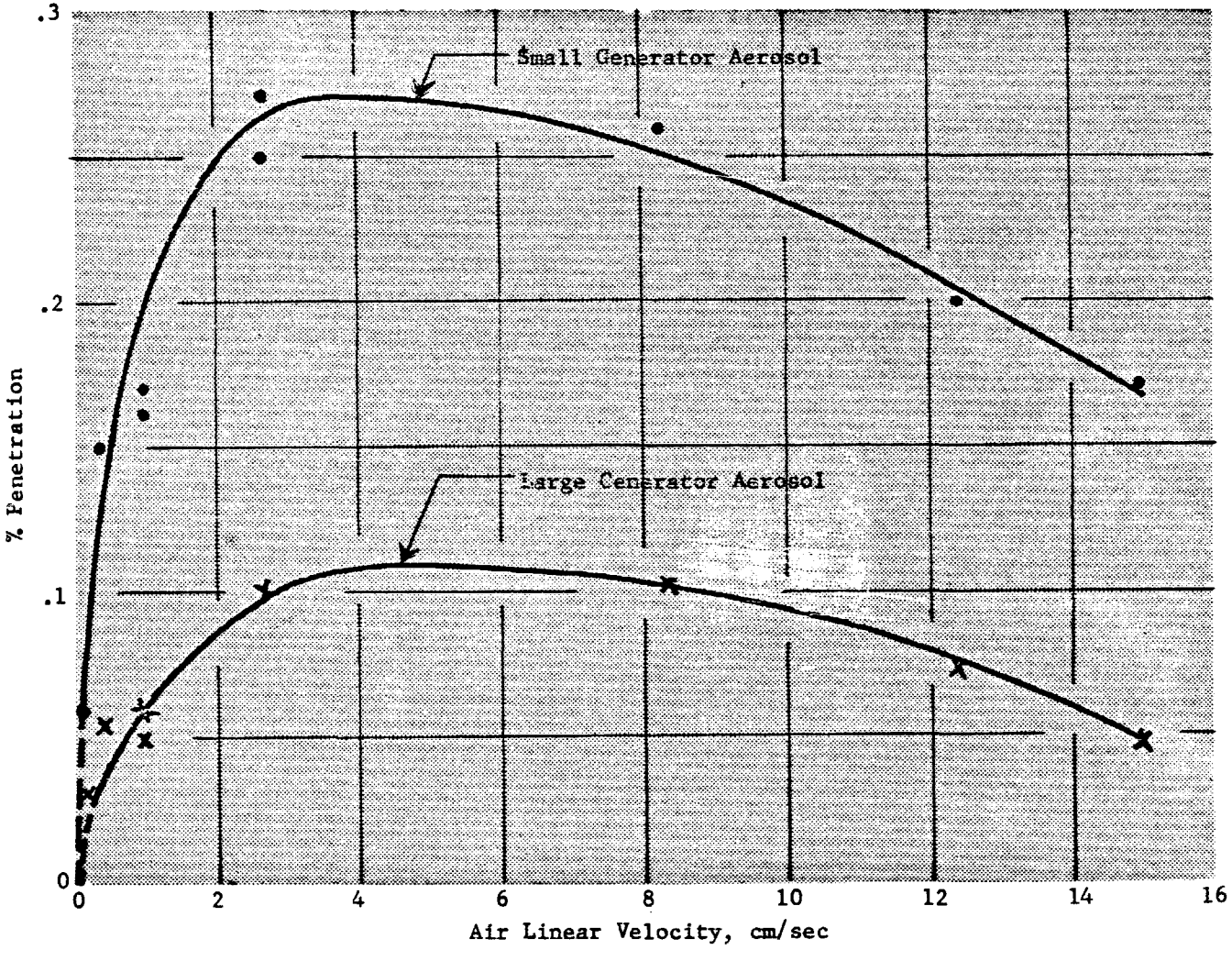


Figure 4. Aerosol Penetration Through Intact 9 mil HV-70 Paper

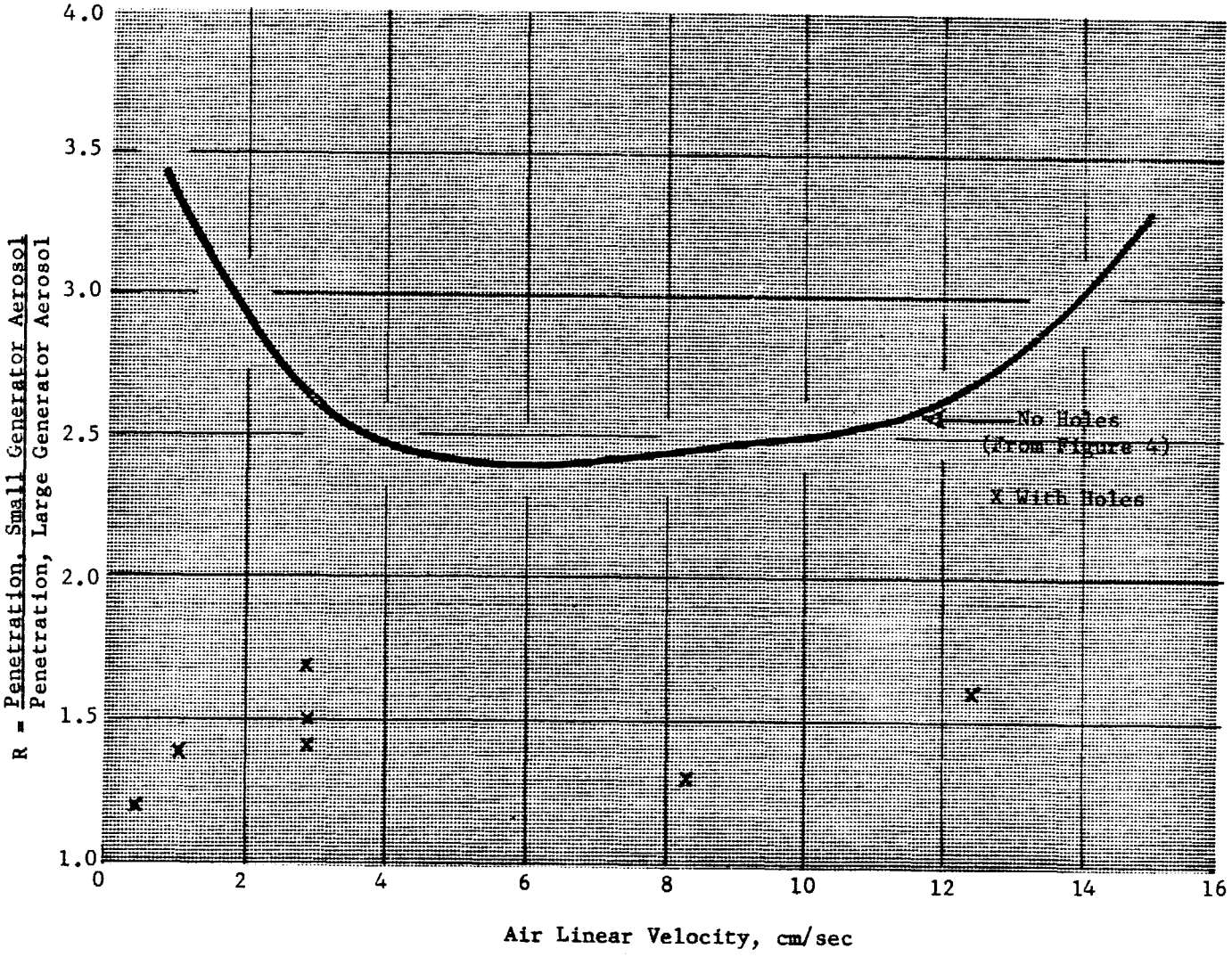


Figure 5. Aerosol Penetration Ratios

TABLE I

TESTS OF FILTER PAPER WITH AND WITHOUT HOLES

Filter Paper Number	Linear Velocity (cm/sec)	Filter Paper Condition	% Penetration, 9 mil HV-70 Paper		R*	Filter Area Used (cm^2)	Flow Rate (liters/min)	Pressure Drop (cm H_2O)
			Small Generator	Large Generator				
1	0.17	No holes	0.059	0.028	2.1	100	1.0	0.1
2	0.4	No holes	0.15	0.054	2.8	100	2.4	0.3
"	0.4	4 holes, #80 drill	0.95	0.76	1.2	100	2.4	0.3
3	1.0	No holes	0.16	0.050	3.2	100	6.0	0.8
"	1.0	1 hole, #73 drill	0.64	0.46	1.4	100	6.0	0.8
"	1.0	Holes sealed	0.17	0.057	3.0	100	6.0	0.8
4	2.65	No holes	0.27	0.10	2.7	100	15.9	1.9
"	2.65	2 holes, #80 drill	0.43	0.25	1.7	100	15.9	1.9
"	2.65	6 holes, #80 drill	0.78	0.54	1.4	100	15.9	1.9
"	2.65	10 holes, #80 drill	1.18	0.76	1.5	100	15.9	1.9
"	2.65	Holes sealed	0.25	0.10	2.5	100	15.9	1.9
5	2.65	1 hole, #68 drill	0.90	0.58	1.5	100	15.9	1.8
"	2.65	Hole sealed	0.25	0.10	2.5	100	15.9	1.8
6	8.3	No holes	0.26	0.10	2.6	31.7	15.9	6.1
"	8.3	2 holes, #80 drill	1.03	0.76	1.3	31.7	15.9	6.1
"	8.3	Holes sealed	0.26	0.10	2.6	31.7	15.9	6.1
"	12.4	No holes	0.20	0.074	2.7	31.7	23.6	9.1
"	12.4	4 holes, #80 drill	0.78	0.48	1.6	31.7	23.6	9.2
7	15.0	No holes	0.17	0.048	3.5	10.2	9.18	11.3

*R = $\frac{\text{Penetration, Small Generator}}{\text{Penetration, Large Generator}}$

TABLE II

PENETRATION OF A FILTER WITH 0.25 MM. DIAMETER HOLE

Linear Velocity (cm/sec)	% Penetration, 9 mil HV-70 Paper	
	Small Generator	Large Generator
2.5	1.71	1.22
5.0	1.29	0.96
10.0	0.84	0.55
15.0	0.65	0.42
2.5	1.71	1.33

TABLE III

CALCULATED AND OBSERVED VALUES OF PENETRATION OF SMALL AEROSOL, P_s

Filter Paper Number	Air Velocity (cm/sec)	Calculated $P_\ell + (P_s' - P_\ell') = P_s$	Observed P_s
2	0.4	0.76 + (0.15 - 0.05) = 0.86	0.95
3	1.0	0.46 + (0.16 - 0.05) = 0.57	0.64
4	2.65	0.25 + (0126 - 0.10) = 0.41	0.43
4	2.65	0.54 + (0.26 - 0.10) = 0.70	0.78
4	2.65	0.76 + (0.26 - 0.10) = 0.92	1.18
5	2.65	0.58 + (0.25 - 0.10) = 0.73	0.90
6	8.3	0.76 + (0.26 - 0.10) = 0.92	1.03
6	12.4	0.48 + (0.20 - 0.07) = 0.61	0.78

aerosols. Figure 6 is a plot of the data of this test, which also shows, for purposes of comparison, the penetration versus air velocity of the intact paper taken from Figure 4. Figure 6 shows in a striking manner the different behavior of an intact and a pinholed filter containing one 0.25 mm pinhole.

Results of Tables I and II show that aging effects were non-existent or negligible during the two sets of experiments. For example, in the test of the filter paper sample #4, Table I, the paper was tested (1) without holes, then (2) with holes, and (3) with holes sealed. The area of the holes, including the adjacent area covered by the rubber cement sealer was less than 0.1% of the area of the filter under test, therefore, the sealed filter was equivalent to an intact filter. If no aging effects existed, the penetration after sealing should be the same, within experimental error, as the penetration of the original intact filter. This was found to be the case. The lack of aging effects is confirmed by results of Table II, where the first and last tests on the paper at 2.5 cm/sec air velocity show essentially the same results.

Figure 7 is a comparison of values computed from the pinhole effect equation (Eq. 10) with the experimental results of Table II. The equation is written for linear velocity V instead of volumetric flow rate Q,

$$P = P' + (P_1 - P_1') \sqrt{\frac{Q_1}{Q}} = P' + (P_1 - P_1') \sqrt{\frac{V_1}{V}} \qquad (11)$$

In equation (11), a value of 5 cm/sec was selected for V_1. Corresponding values of P_1 and P_1' were 1.29 and 0.27 for the small generator aerosol, 0.96 and 0.11 for the large generator aerosol, from Table III and Figure 4. Hence equation (11) became, for the small generator aerosol,

$$P = P' + 1.02 \sqrt{\frac{5}{V}} \qquad (12)$$

and for the large generator aerosol,

$$P = P' + 0.85 \sqrt{\frac{5}{V}} \qquad (13)$$

Values of P' for the two aerosols were taken from Figure 4 which gave the theoretical curves in Figure 7. The figure shows fair agreement of theory and experiment. Parrish and

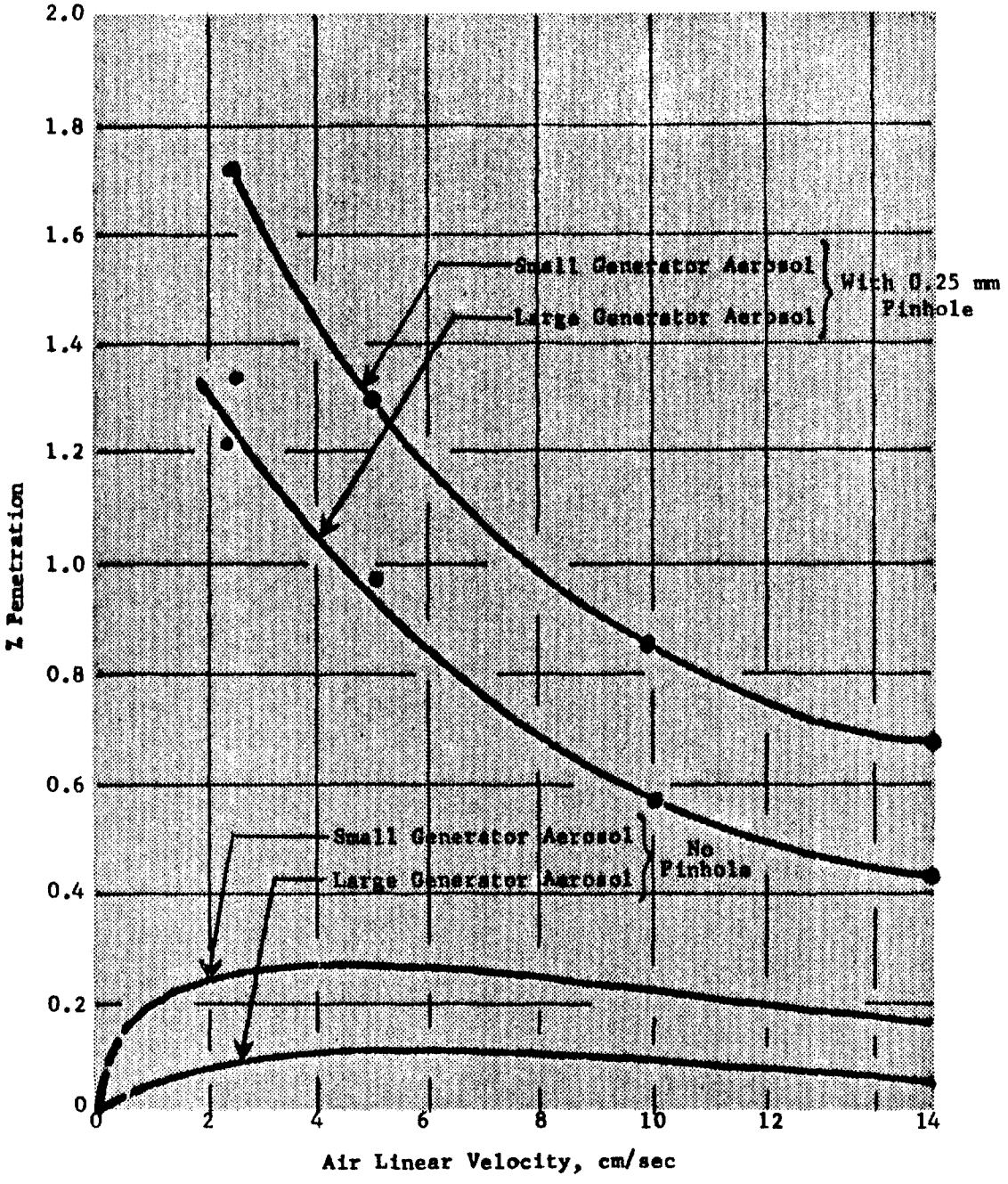


Figure 6. Aerosol Penetration of 9 mil HV-70 Paper, With and Without a Pinhole, as a Function of Air Linear Velocity

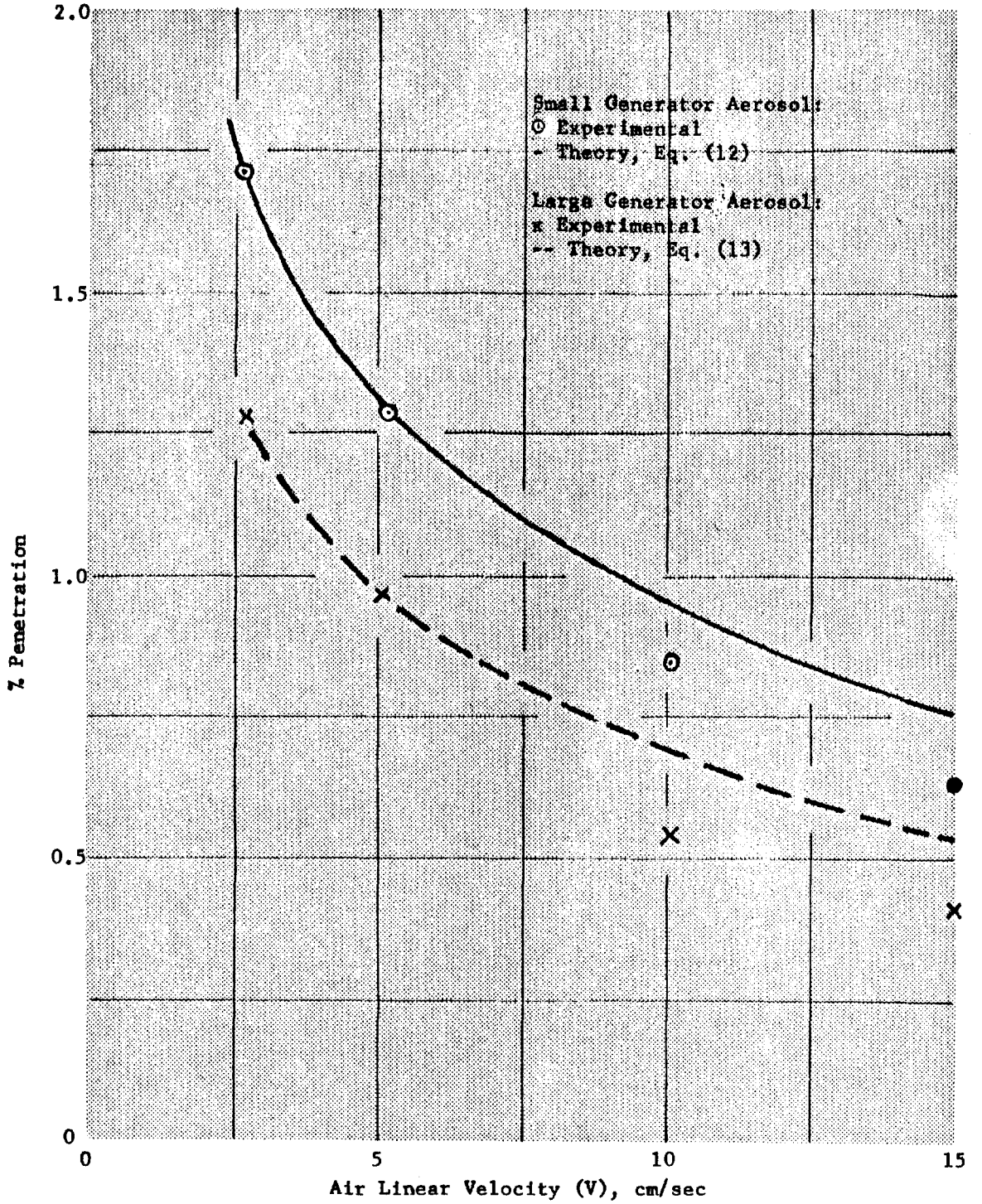


Figure 7. Test of Pinhole Effect Equation

Schneider[2] also made a test of equation (11), using a filter and an external synthetic leak combination having much lower penetrations, in the range 0.08 to 0.17%. Their results, also, confirm fairly well equation (11).

CONCLUSIONS

1. Particle size has much less effect on aerosol penetration through pinholed filters than it does on penetration through intact filters. This result implies that in testing filters or filter installations for leaks, aerosol particle size is less important than in evaluating filter materials per se.

2. A generalized pinhole effect equation

$$P = P' + (P_1 - P_1') \sqrt{\frac{Q_1}{Q}}$$

where P and P' are the penetrations of pinholed and intact filters, respectively, at flow rate Q, and P_1 and P_1' are the penetrations of pinholed and intact filters at some fixed flow-rate Q_1, has been developed.

3. The generalized pinhole effect equation has been confirmed within limits.

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2. Parrish, E.C., and Schneider, R.W., "Tests of High-Efficiency Filters and Filter Installations at ORNL". Oak Ridge National Laboratory, Report ORNL-3442, June 3, 1963.

3. Lindekin, C.L., et al., "Portable DOP Tester for Inspection of High Efficiency Filters". University of California, Lawrence Radiation Laboratory, Report UCRL-6597, February 1, 1962.

Session Chairman: Thank you, Mr. Thomas.

The next paper is "Gaseous Radioactivity Associated With the Operation of the RPI Linear Accelerator," and will be presented by the author, Mr. R. M. Ryan, Assistant Radiological Safety Officer, Rensselaer Polytechnic Institute.

Gaseous Radioactivity Associated with the Operation of the Rensselaer Polytechnic Institute Linear Accelerator

by Robert M. Ryan
Assistant Radiological Safety Officer
Rensselaer Polytechnic Institute

Abstract

Recent measurements made at the R.P.I. Linear Accelerator indicate that radioactive nitrogen 13 and oxygen 15 are the most prominant gases which are being produced. The measurements were made with commercially available equipment. Surveys were also performed in the environment surrounding the Linear Accelerator when diffusion calculations indicated the environmental activity could be marginal on instrument sensitivity.

Concentration Guides for nitrogen 13 and oxygen 15 were established.

During December 1962 the first substantial indication of gaseous radioactivity was observed on the Rensselaer Polytechnic Institute Linear Accelerator stack monitoring equipment. The original trace of the activity is shown in figure A and the calibration curve for this trace is presented in figure II-3. Since this time some gaseous activity has been routinely observed. As a result of the indication of gaseous radioactivity an investigation was initiated to identify the activity. This investigation resulted in the following:

1. The gaseous activity was short lived and consisted of two components-one with a half life of about 2 minutes and the other with a half life of about 10 minutes. These half lives were obtained from actual decay measurements of the gas within the monitored volume.

2. The major portion of the activity detected by the gaseous monitor was proved to be either beta particles or positrons by absorption measurements.

3. A gamma spectrum was obtained at steady state conditions using an automatic scan, single channel gamma spectrometer and a 2 X 2 NaI(Tl) crystal submerged in the sensitive volume of the fluid monitor. The spectrum provided only one identifiable peak at about 0.51 mev. This 0.51 mev. photon is most probably associated with annihalation radiation of positrons.

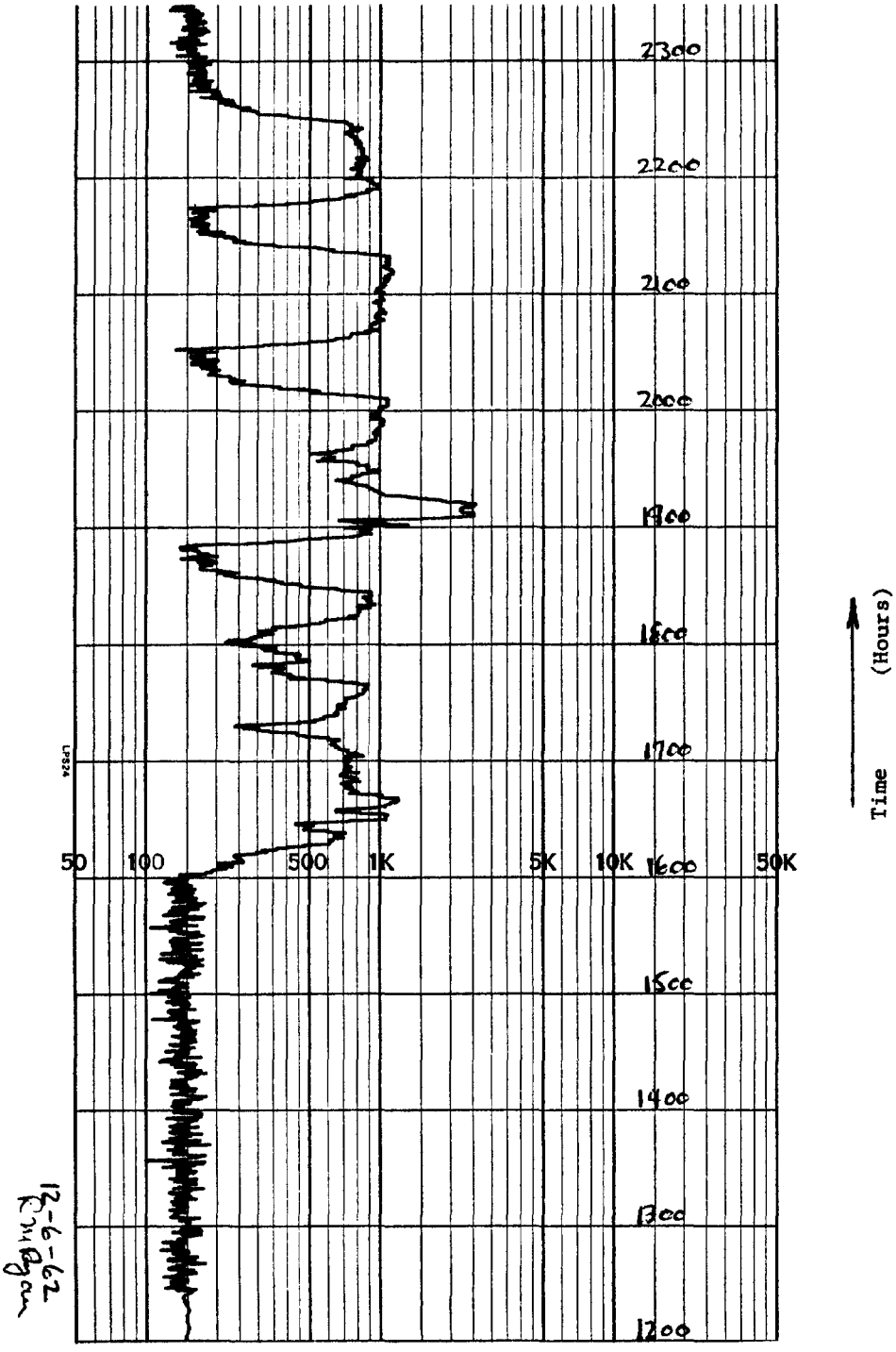
An investigation as to the various possible sources within the target room, and the half life and spectrum measurements indicated that the gaseous radioactivity was identifiable as nitrogen 13 and oxygen 15. Table 1 lists some of the physical characteristics of these two isotopes. Both isotopes decay by positron emission. The interaction for production of the isotopes is (γ,n), the reaction having the thresholds listed in Table 1. The origin of the photons is the bremstrahlung from the interaction of the high energy electrons with both the target and sections of the accelerator drift tube.

During the initial indication the R.P.I. Linac was operating at approximately 4 kilowatts of beam power at the target, the electron beam was being produced at approximately 50 mev. peak energy and 400 milliamps, peak current; other machine parameters such as pulse width, repetition rate, and target location and shielding were varied. Observations during recent experiments indicate that beam bending or rake off, target shielding (which determines bremstrahlung air path) and Linac beam power are factors which affect the magnitude of the gaseous activity.

Measurements and calculations of the quantity of nitrogen 13 and oxygen 15 being discharged from the Linac were made. During the half life measurements it was evident that about 75% of the activity being discharged was oxygen 15. The remaining 25% was nitrogen 13.

The gaseous activity being released has averaged between one and ten millicuries per minute. Figure A, the trace of the initial indication of this gaseous activity is also an example of the routine indication. The base line of 150 cpm was set by taping a beta source on the end of one of the detectors so as to keep the trace on scale (above 50 cpm). The increase and decreases shown on the trace are due to the production,

Trace of Initial Indication of Linac Production of
Nitrogen 13 and Oxygen 15



Fluid Monitor
Count rate meter indication
(cpm)

Figure A

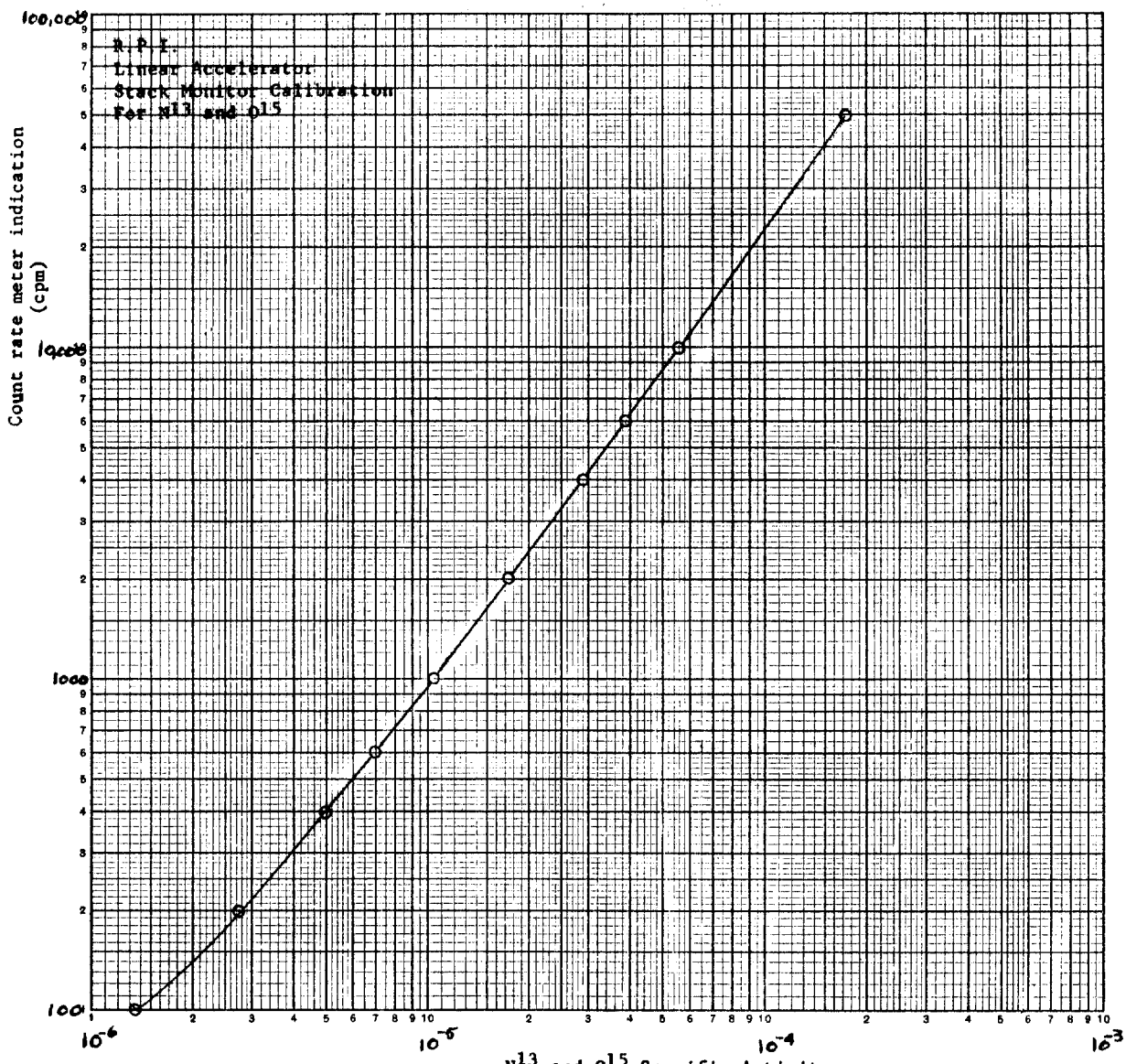

R.P.I.
Linear Accelerator
Stack Monitor Calibration
For N13 and O15
Count rate meter indication
(cpm)
100,000
10,000
1000
100
10^{-6}
10^{-5}
10^{-4}
10^{-3}
N^{13} and O^{15} Specific Activity
(uc/cc)

Figure II - 3

TABLE I

Physical Characteristics of Nitrogen 13 and Oxygen 15

Isotope Produced	N^{13}	O^{15}
Target Nuclide	N^{14} (99.64%(	O^{16} (99.75%)
Threshold	10.5 MEV	15.6MEV
Interaction	(ɣ,n)	(ɣ,n)
Decay Product	Positron (1.19 MEV)	Positron (1.68 MEV)
*Gamma Radiation	0.511	0.511
Half Life (7)	9.90 min.	2.05 min.
Daughter Isotope	C^{13} (stable)	N^{15} (stable)

* The positron particle, after completing its ionizing path in matter interacts with an electron, the results being two 0.511 MEV photons given off in opposite directions and commonly called annihalation radiation.

and decay and exhaust of the radioactive gases. The increases are associated with startup of the accelerator and the decreases due to shutting off the electron beam for experimental changes or access to the target room, etc. Petree in his papers (reference 2,3, and 4) made conservative calculations for the production of nitrogen 13 by a linear accelerator but with assumptions varying from our conditions - especially air path. Our measurements indicate that he could be conservative by as much as a factor of 100.

When the positive identification of the isotopes was completed an effort was made to approximate the concentration of these isotopes in the air in the surrounding environment. The Health Protection Engineering Division of the AEC Health and Safety Laboratories (HASL) provided technical assistance to R.P.I. in the meteorological determinations deemed necessary. The calculations based on "Suttons Equation" (reference 8) indicated that the concentrations in the environment would not exceed the calculated concentration guides, set forth in Appendix IV, for population exposures. Surveillance of the environment using portable survey meters during routine operations has indicated no perceptable increase above background not only in vicinity of the Linac but also in the most probable directions up to about 2 miles from the Linac.

The attached appendices provide detailed information on some of the pertinent aspects of the investigations. These appendices are:

Appendix I	Exhaust System Description of the R.P.I. Linac
Appendix II	Stack Monitoring Equipment
Appendix III	Instrument Calibration
Appendix IV	Concentration Guides for Nitrogen 13 and Oxygen 15

REFERENCES

(1) Health Physics Vol. 3, June 1960, Report of ICRP Committee on Permissable Dose for Internal Radiation (1959)

(2) Toxic Gases Produced by Irradiation of Air, B. Petree 11/11/58 NBS Internal Report

(3) Disposal of Ozone and Radioactive Air Produced by Linac, B. Petree 5/20/59, NBS Internal Report

(4) Expected Concentrations of and Dose Rates from N^{13} Generated by the NBS Linac, B. Petree 5/3/61 NBS Internal Report

(5) Nuclear Physics by I. Kaplan, Chapter 14

(6) Shielding for High-Energy Electron Accelerator Installation draft copy of report by subcommittee on Protection for High Energy Electrons to the National Committee on Radiation Protection dated September 1962.

(7) Trilinear Chart of Nuclides, William H. Sullivan

(8) Meteorology and Atomic Energy prepared by the United States Department of Commerce Weather Bureau (July 1955)

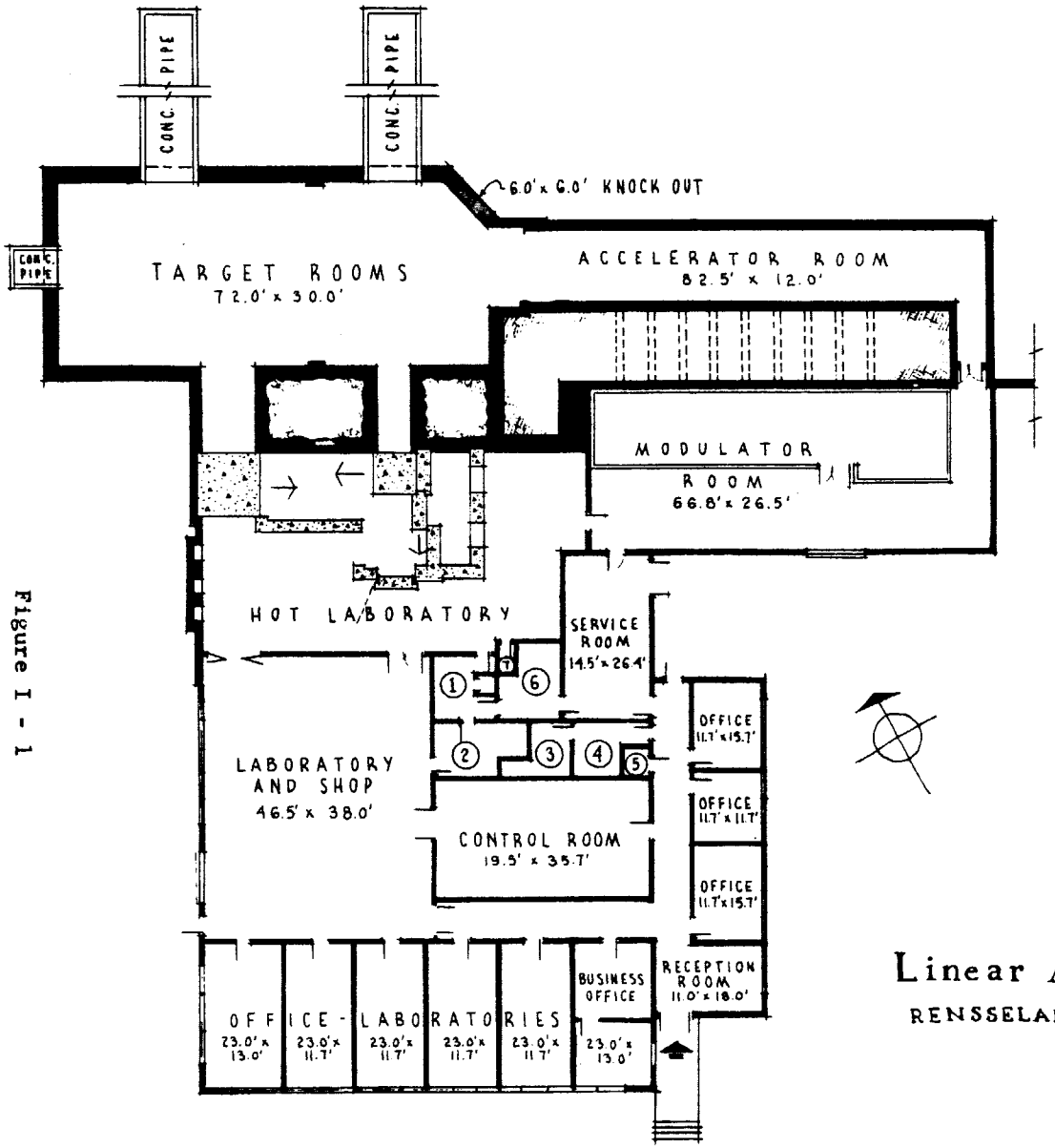
Session Chairman: We appreciate hearing your paper, Mr. Ryan.

Appendix I
R.P.I. Linac Exhaust System Description

The R.P.I. Linac, the floor plan of which is shown in figure I-1, utilizes the exhaust system of the target and accelerator rooms as a barrier to possible airborne contamination by maintaining a negative pressure between the target and accelerator rooms and the occupied spaces of the laboratory. The target room is exhausted at a rate of about 14,000 cfm by two 7000 cfm fans operated in parallel. This flow rate provides an air change of about once every three minutes. Circulating fans have been installed within the target and accelerator rooms when dead spaces were observed during dop tests of the filter banks. Since installation of the fans, the mixing of the air within the target room is excellent.

The exhaust from the target and accelerator room is through three banks of pre-filters and absolute filters and a 20 meter, 3 foot diameter stack. The filter banks are located about 12 feet off the ground floor and at the east and west ends of the target room and at the east end of the accelerator room. Air is swept the length of the accelerator room to provide cooling for the accelerator component. All the exhaust ducts merge to a single duct before reaching the fans which are located at the base of the stack.

The necessity for the exhaust system not only lies in the production of the radioactive gases nitrogen 13 and oxygen 15 but also in the production of other toxic gases such as ozone and NO_2.



1. CHANGE AREA . . . . . (10.6' x 10.3')
2. MEN'S LAVATORY . . . . (15.0' x 8.8')
3. WOMEN'S LAVATORY . . (9.3' x 8.8')
4. WOMEN'S REST ROOM (8.0' x 8.8')
5. SERVICE CLOSET . . . . . (4.4' x 4.4')
6. DARK ROOM . . . . . (10.6' x 10.3')
7. LAVATORY . . . . . (3.0' x 5.0')

FLOOR PLAN OF

Linear Accelerator Laboratory

RENSSELAER POLYTECHNIC INSTITUTE
TROY, N.Y.

SCALE : 1/32" = 1'-0"

JIM HARPER '60

Figure I - 1

Appendix II
Linear Accelerator Stack
Monitoring Equipment

The stack monitoring equipment consists of a particulate monitor NMC *Model Am-3A which exhausts directly to a fluid monitor. The particulate monitor is of the moving filter paper design. The fluid monitor is an NMC Model FMS-1 which is simply a 30 liter right circular cylinder with dished ends surrounded by two inches of lead shot. The sample is drawn through an isokinetic sampling head located in the stack then exhausted to the environment.

The detector for the particulate monitor is a thin window, gas flow, Geiger tube sensitive to both alpha and beta particles. There is no time delay in the monitoring of the particulate activity from its time of collection on the moving filter paper. The two detectors for the fluid monitor are thin walled Amperex 90 NB Geiger Mueller tubes. These tubes are emersed in the gas volume for monitoring. The minimum detectable activity of the fluid monitor is about 3.0×10^{-6} uc/cc for krypton 85. This produces a signal approximately twice background or about 100 cpm as indicated on the recorder. The krypton 85 calibration curve is shown in figure II-1

For the period of identifying the gases and instrument calibration a second fluid monitoring system was also used in series with the stack monitoring equipment. This consisted of a Tracerlab Model D-11 large area Geiger Mueller probe and a Model MW-4 liquid sampler with associated logrithmic readout. This system also had approximately the same sensitivities and the calibration curve to krypton 85 is shown in figure II-2. This instrument has a background of about 250 cpm.

Extrapolation to the energies of the positron emitters of nitrogen 13 and oxygen 15 from the beta energies of krypton was made by taking the ratio of the GM tube responses to sources of similar energies. These responses were obtained from absorption curves of various beta emitters. The calculated ratio was about 1.8. The resulting calibration curves for the Linac operation is shown in figure II-3.

* Nuclear Measurements Corporation

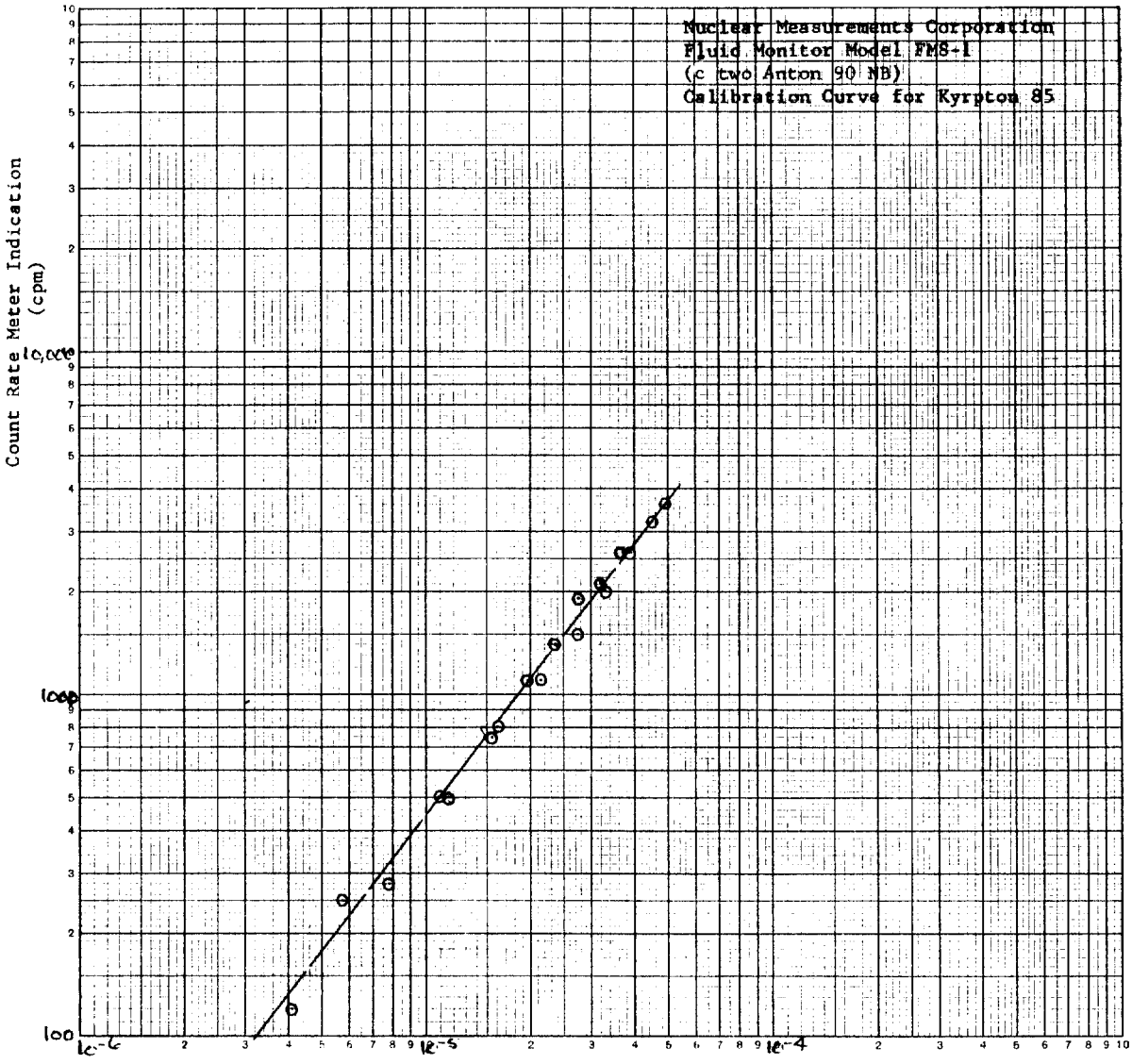

Nuclear Measurements Corporation
Fluid Monitor Model FMS-1
(c two Anton 90 NB)
Calibration Curve for Kyrpton 85
Count Rate Meter Indication
(cpm)
10,000
1000
100
1e-6
1e-5
1e-4
uc per cc as Krypton 85

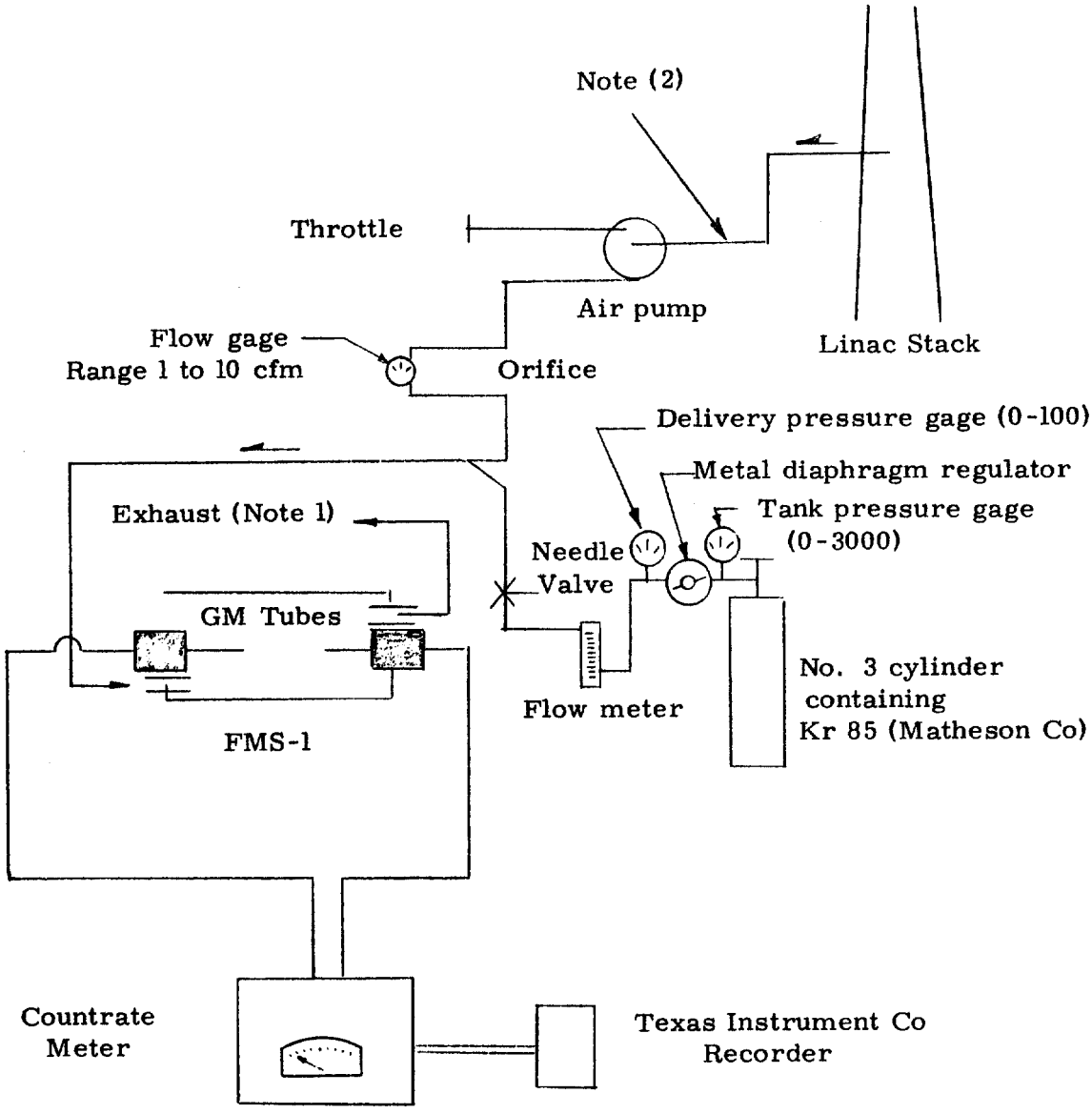
Figure II - 1

Appendix III
Instrument Calibration

The calibration of the gaseous monitor was completed in two steps. First the linearity of the countrate meter and recorder was measured. This was accomplished by using a pulse generator, timer and decade scaler. The pulses for the pulse generator were varied over the full scale of the countrate meter and integrated for 1 minute periods. Readings from the countrate meter were obtained for each interval. The plot of integrated counts and countrate meter indication was obtained and indicated good linearity.

Next we obtained a radioactive gas - krypton 85 mixed in an air atmosphere and containing approximately 0.85 uc/liter. The actual response of the fluid monitor detectors to this gas were measured and an extrapolation made to the positron energies of nitrogen 13 and oxygen 15. The calibrating gas krypton 85 was obtained from the Matheson Company and calibrated to their standard. The gas was fed into the system as shown in figure III-1. Calculations were made to obtain the approximate uc/cc in the volume when equilibrium was reached. Flushing of the chamber with air left no residual activity. Two runs were made using different rates of flows obtaining a total of 19 points. The results were excellent and shown in figure II-1. The calibration will be repeated periodically and when the detectors are replaced to assure accuracy.

FLOW DIAGRAM FOR LINAC STACK MONITORING



Note (1) Exhaust from FMS-1 to Tracerlab monitor for calibration only

(2) NMC AM-3A Particulate Monitor

Figure III-1

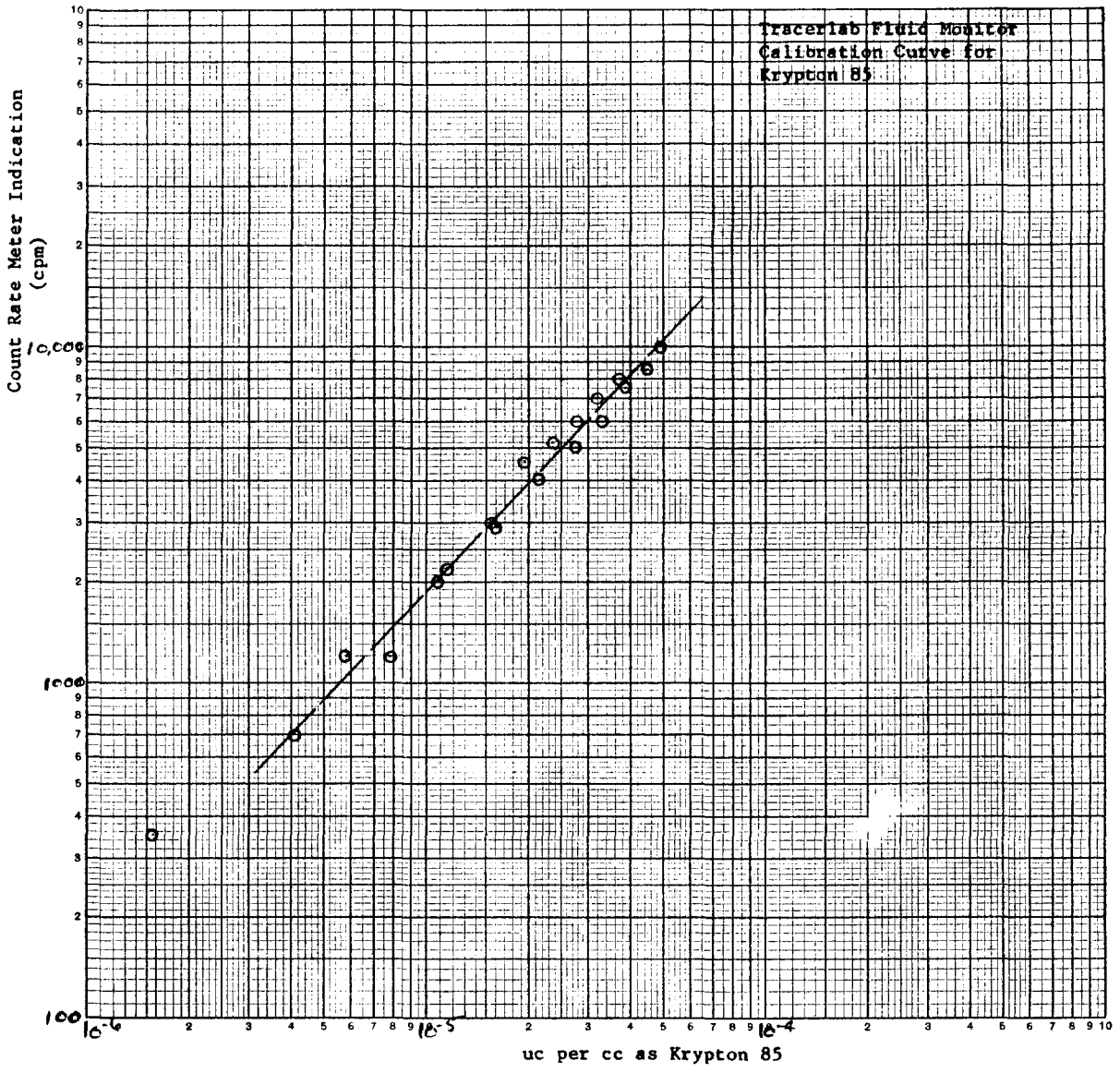

Tracerlab Fluid Monitor
Calibration Curve for
Krypton 85
Count Rate Meter Indication
(cpm)
10,000
1000
100
10^-6
10^-5
10^-4
uc per cc as Krypton 85

Figure II - 2

Appendix IV
Concentration Guides For
Nitrogen 13 and Oxygen 15

Calculations for Concentration Guides were made utilizing the information set forth in reference 1. These guides were calculated for two conditions. The first being occupational 40 hour exposure and the second a population exposure. Table IV-1 list the guides for both nitrogen 13 and oxygen 15 calculated from the equations furnished in the ICRP report (reference 1). As expected the condition of importance is submersion in a cloud of the gas containing the two constitutients, nitrogen 13 and oxygen 15. The population guide was established from the following equation.

$$\text{Concentration Guide (40 hour)} \times \frac{40}{168} \times \frac{1}{10} = \text{Concentration Guide (population)}$$

Table IV-1
Concentration Guides for
Nitrogen 13 and Oxygen 15

Isotope	Occupational (40 hour) (1)	Population
Nitrogen 13	2×10^{-6} uc/cc	5×10^{-8} uc/cc
Oxygen 15	2×10^{-6} uc/cc	6×10^{-8} uc/cc

(1) Based on continuous exposure at a rate of 100 mrem per week.

NEW AIR CLEANING ACTIVITIES AT ARGONNE NATIONAL LABORATORY

C. L. CHEEVER

Abstract

The emergency exhaust filter system for ANL's new zero power reactor cells and uranine efficiency tests on this system are described. The system has been designed to handle high temperature and high pressure discharge from the cells. Exhaust air cleaning changes being made in the Chemical Engineering Division's principal cave facility are also discussed. These changes will improve removal of radioiodine from the cave exhaust.

The emergency air cleaning system for two new ANL zero power fast reactor cells and uranine efficiency tests on this system will be reviewed. I will also discuss exhaust air cleaning system changes being made at our Chemical Engineering Division's main cave facility.

Zero power fast reactor tests are carried out in Argonne's new Experimental Reactor Building within cells 30 by 40 feet by 30 feet high. These cells were designed to withstand overpressures up to at least 40 psig. One cell houses the ZPR 6 Argonne fast critical facility, and the other cell contains ZPR 9, a fast reactor for study of nuclear rocket propulsion systems. Reactor operation is under sealed cell conditions from a control console outside the cell. As much as 1500 kg of enriched uranium reactor fuel may be used in a cell at one time.

The emergency exhaust filter system for these cells is designed for possible venting to the atmosphere of high temperature and high pressure cell gases. These conditions might evolve from a spontaneous fire in the pyrophoric reactor fuel or from a reactor excursion and fire incident. Figure 1 is a schematic diagram of this system indicating the flow conditions during our uranine efficiency tests. The room housing the primary filter chamber was formed by walling off the end of the fan loft room with concrete blocks. The primary filter chamber was designed for filtration of gases at temperatures of up to 800° F. It has ten gauge sheet steel, continuous welded to the sides, top and bottom of a one-quarter by two inch flat iron frame. The two foot diameter heavy steel exhaust pipe from the cell leads to a secondary standard ANL filter plenum. This path is used to exhaust air from the cell when personnel work inside for extended periods. An eight inch steel branch pipe ties into the high temperature AEC filter housing. A butterfly valve in this pipe is designed to act as a flow-limiting valve when in the open position. It passes 3000 scfm when the cell is at a pressure of 10 psig. The steel-seated butterfly valve in the eight inch pipe and both steel and rubber-seated butterfly valves in the two foot pipe are operated from the reactor control console. The position of the valves, fan operation, cell pressure, filter room temperature, and the radioactivity level at exhaust discharge points are all shown on the console. On automatic control the steel butterfly valves open and the roof fans start through relay action when the cell pressure exceeds 10 psig. The rubber-seated valves are protected from excessive heat by fire dampers designed to close at about 135° F.

Sampling points for our efficiency tests are marked "X". A dilution factor of two had to be applied to the downstream samples due to air infiltration into the room housing the high temperature filters. Efficiency tests were run with uranine aerosol generated from Pen-i-sol nebulizers operated at 12 psig. We used a .5%, by weight, aqueous uranine solution. Figure 2 is an electron microscope photograph of a grid sample taken by electrostatic precipitation within

ANL D-315 CELL EXHAUST FILTER SYSTEM

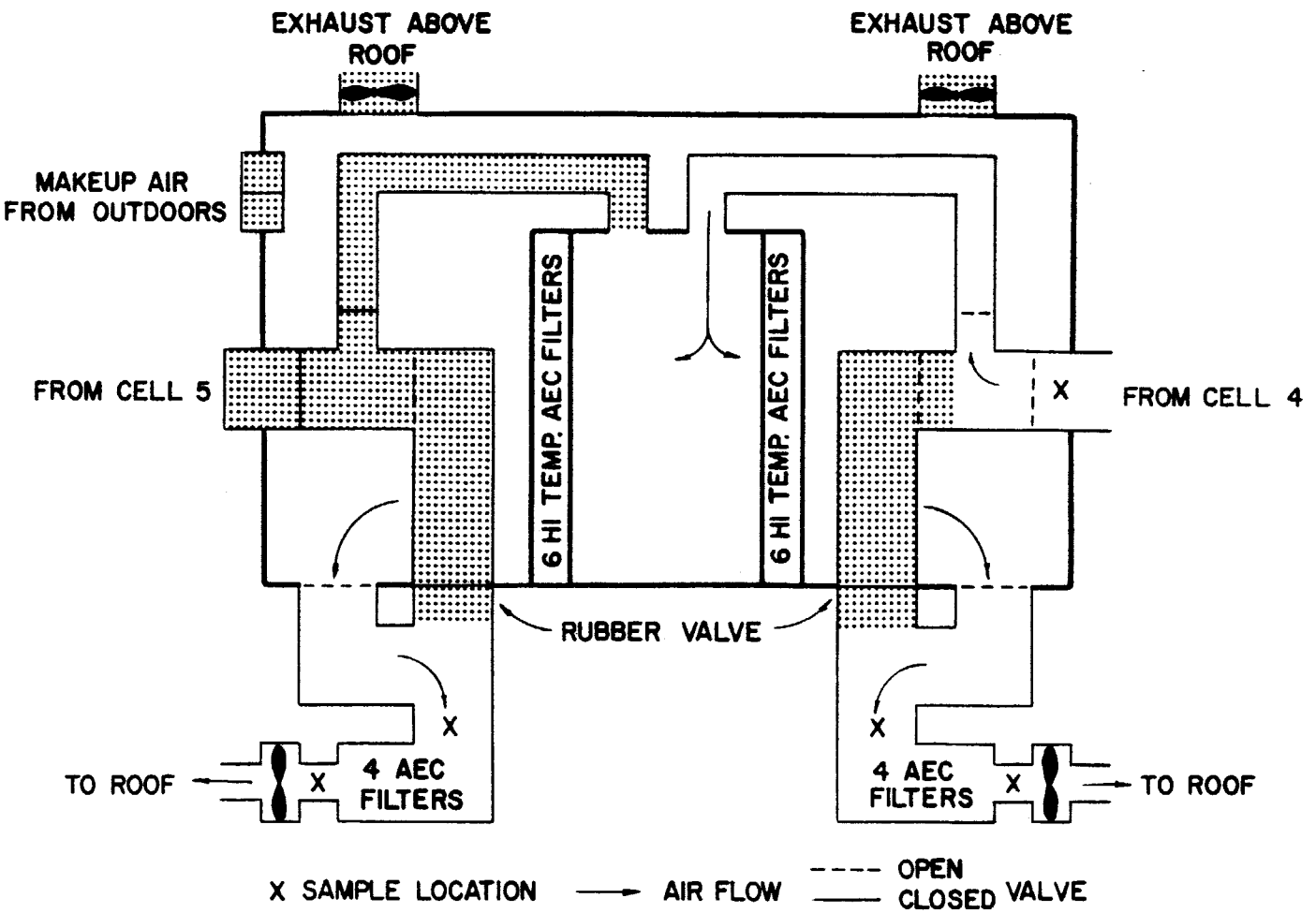


Figure 1

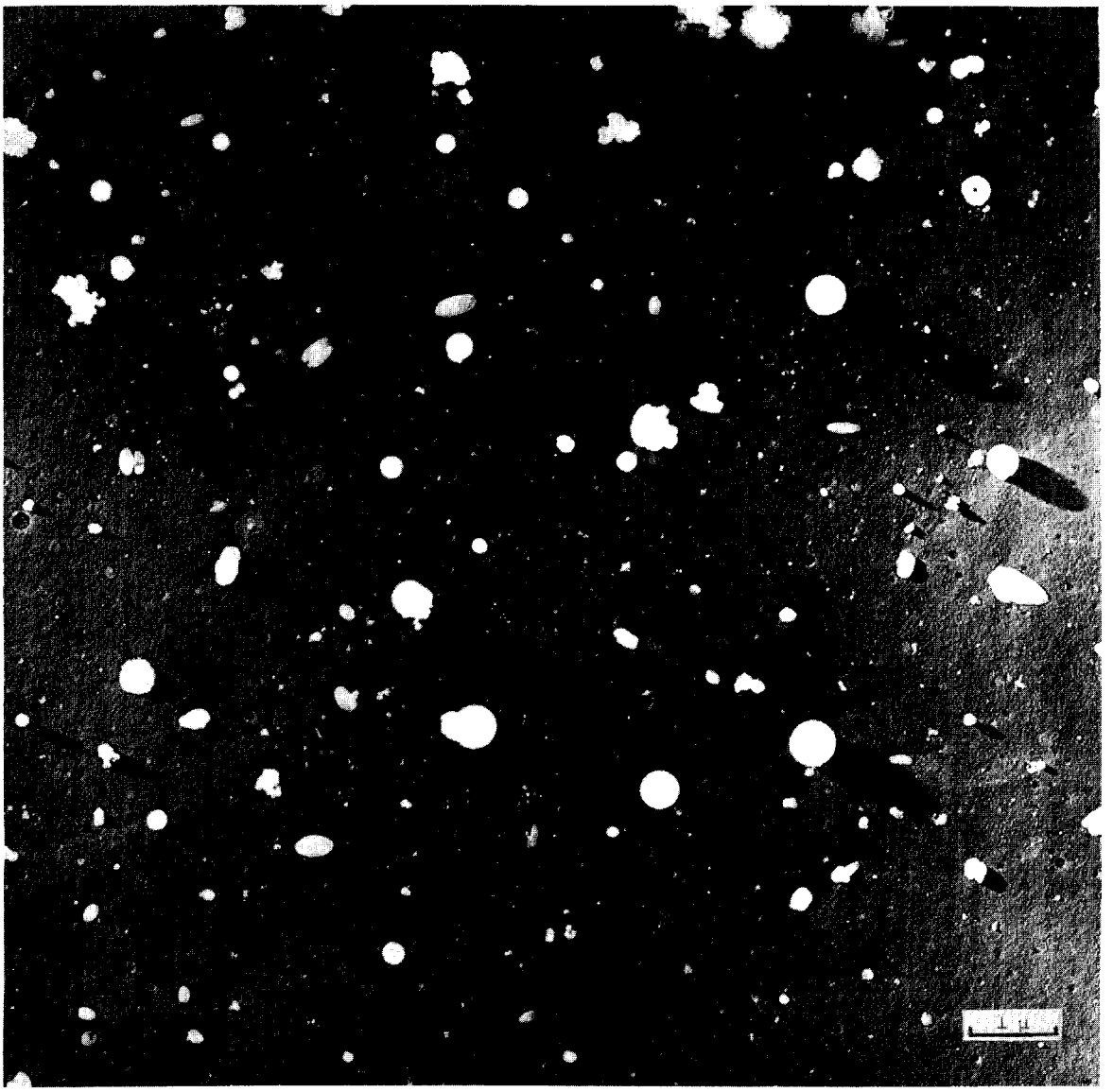


Figure 2

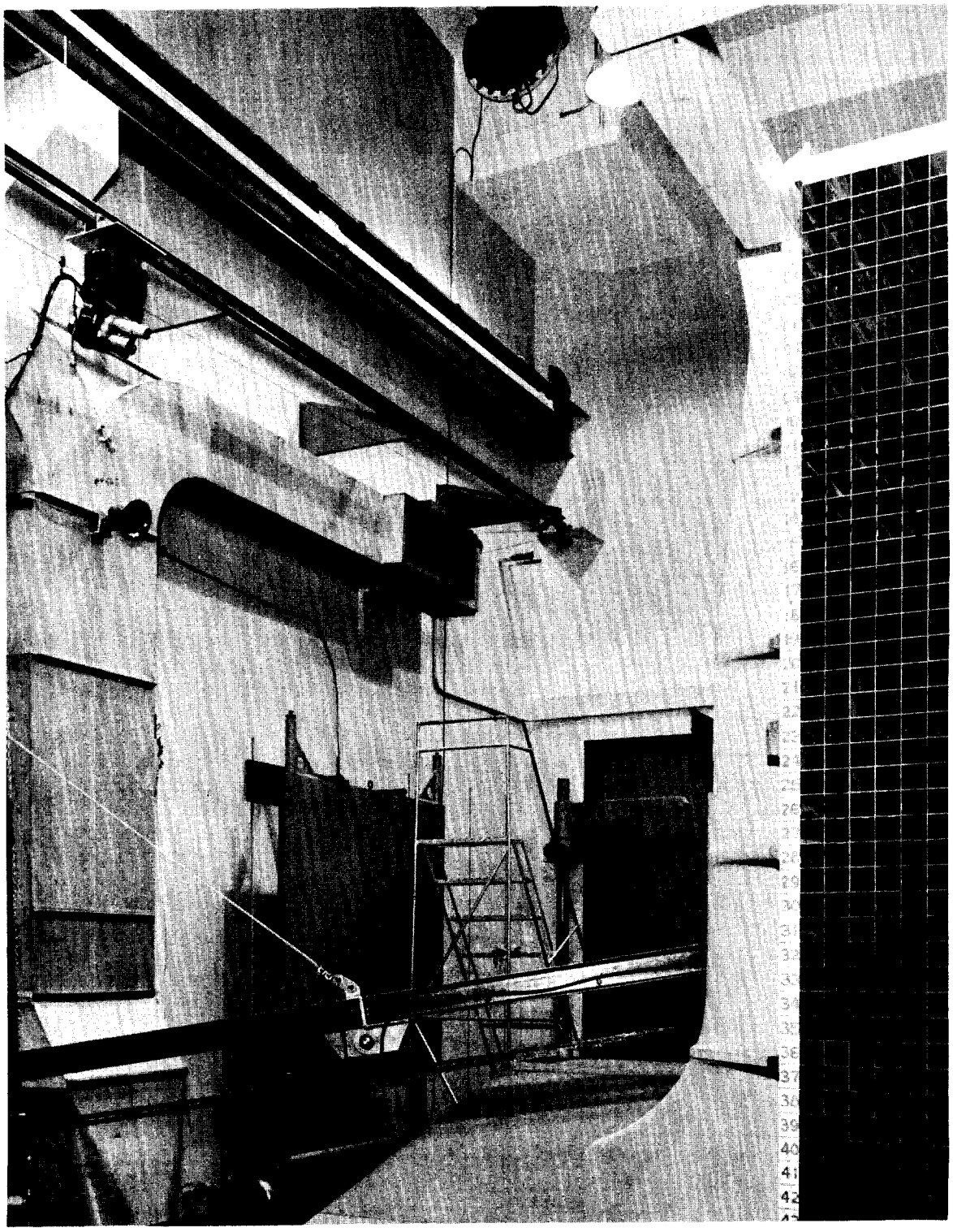


Figure 3

the duct at the upstream sampling point. Our particle size determinations have generally shown a mass mean diameter of about .4 microns with a geometric standard deviation of about 2.4; however, the particles in this photograph are smaller. This sample has been shadowed with palladium vapor to produce the three-dimensional effect. The spherical uranine particles are distinguishable from atmospheric dust particles. Incomplete drying of uranine mist particles has been a problem, and we, therefore, plan to change our generating technique to produce a dependably dry aerosol.

Figure 3 is a photograph taken within the reactor cell showing the location of the aerosol-generating equipment in the exhaust pipe opening near the ceiling. The overhead crane used for access to the pipe has been moved back out of view. The edge of the movable half of the reactor assembly is at the right.

The upstream sampling position and the remotely-operated steel butterfly valves are shown in Figure 4. The amount of uranine collected on type AA millipore filters was determined by standard fluorescence measurement technique.

A portion of the outside, or downstream, side of the primary AEC high temperature filter plenum is shown in Figure 5. Each of these filters had been checked here in the Oak Ridge DOP filter test facility. They have cadmium-plated steel frames and silicone adhesive for increased heat resistance. Gaskets of the same fiberglass material as the filter media were glued to the underside of the filter flanges. When the filters are mounted in the housing, the gaskets are pressed against the chamber frame. Figure 6 shows the sampling station downstream from the primary filters. This ANL standard type of AEC filter mounting precludes filter bypass leakage.

Initial efficiency tests indicated penetration to the secondary filters was 1%. After plastic tape was placed over the filter flanges, tests indicated .15% penetration. Uranine penetration through both the primary and secondary filters was about .02%.

The cells are equipped with a 60,000 scf argon gas purge system to allow fighting fires remotely. This cylinder manifold system dumps its argon into the cell in about 20 minutes. Test dumping of 20,000 scf of argon showed that reduction in oxygen concentration in the cell during venting was considerably more than calculations based on ideal mixing indicated. The denser argon has a higher concentration in the lower portion of the cell, while the exhaust pipe opening is near the ceiling. After dumping, argon gas remains in the cell, as there is no supply air to displace it.

At this point I will switch to a discussion of changes being made in the exhaust air cleaning system at our Chemical Engineering Division's main cave facility. The changes stem from limitations on cave work due to the potential hazardous release of fission gases to the environment. The principal concern is containment or trapping of radioiodine released from high burnup, short cooled reactor fuel elements during reprocessing experiments. The changes will provide an improved backup for measures taken within the cave to contain the radioactive gases.

The once-through, 2000 cfm, cave exhaust system will be supplemented by an optional use, nominally rated 10 cfm exhaust system. The cave will be sealed to the point where the maximum leakage is 10 cfm at -.35 inches of water cave pressure. This low leakage rate into the cave is effected by neoprene gasketed cave entry doors, improved wall plug seals, and neoprene gasketed metal covers clamped over the cave supply air filter intakes. Figure 7 shows a flow diagram of the alternate cave exhaust paths. During normal cave operations, 2000 cfm is exhausted from the cave through shielded AEC filters followed by activated

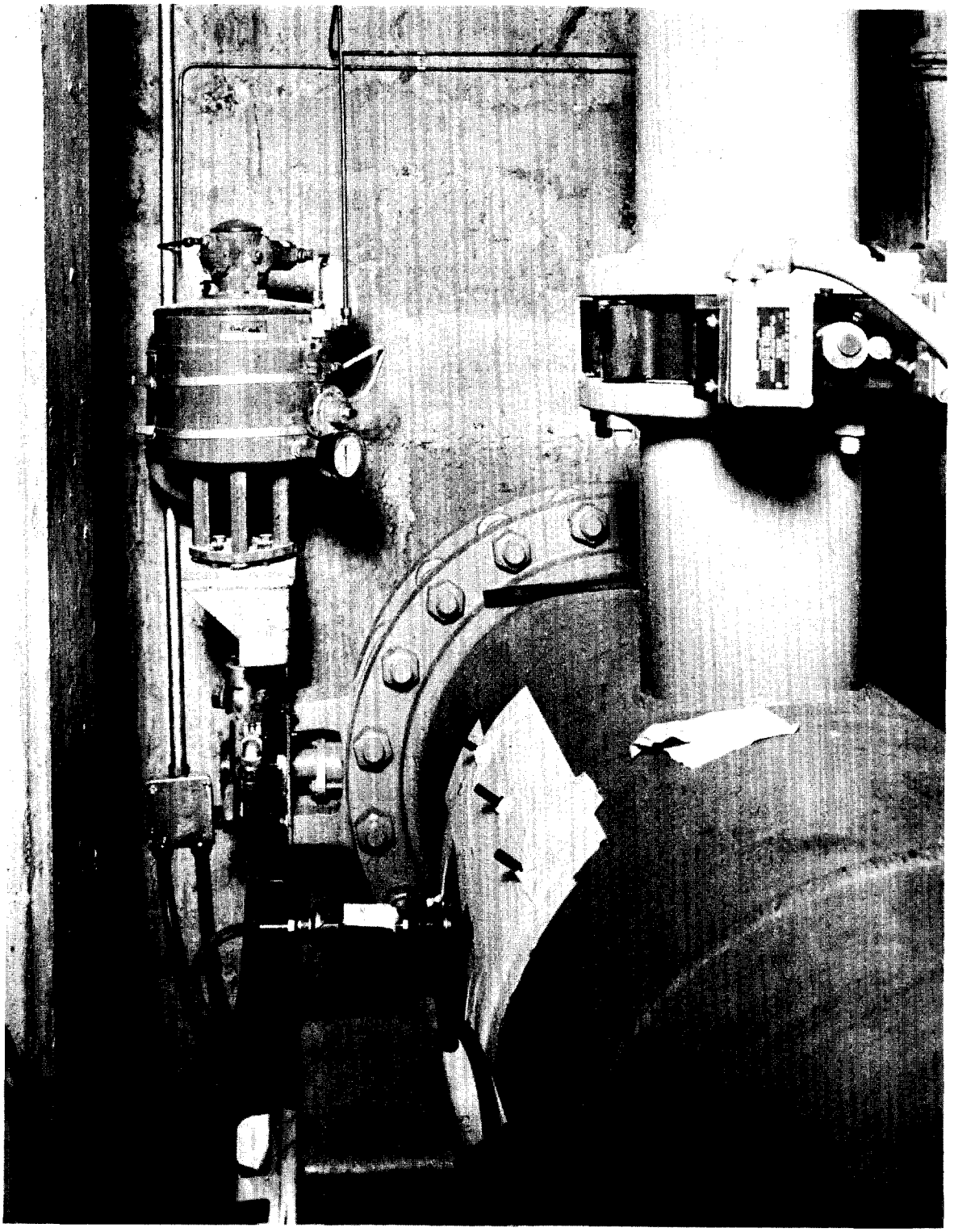


FIGURE 4

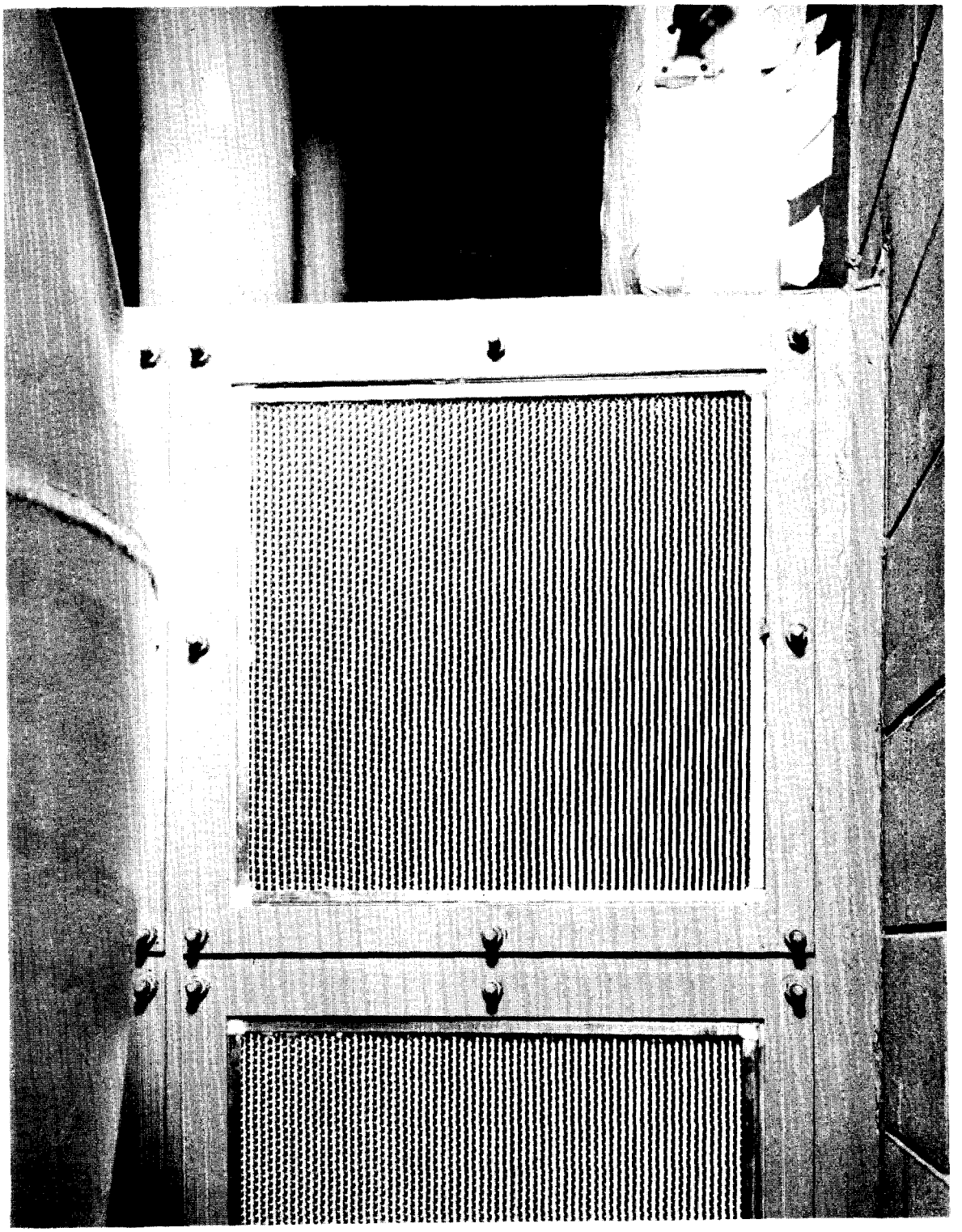


FIGURE 5

FIGURE 6

ANL D-205 CAVE EXHAUST FILTER SYSTEM

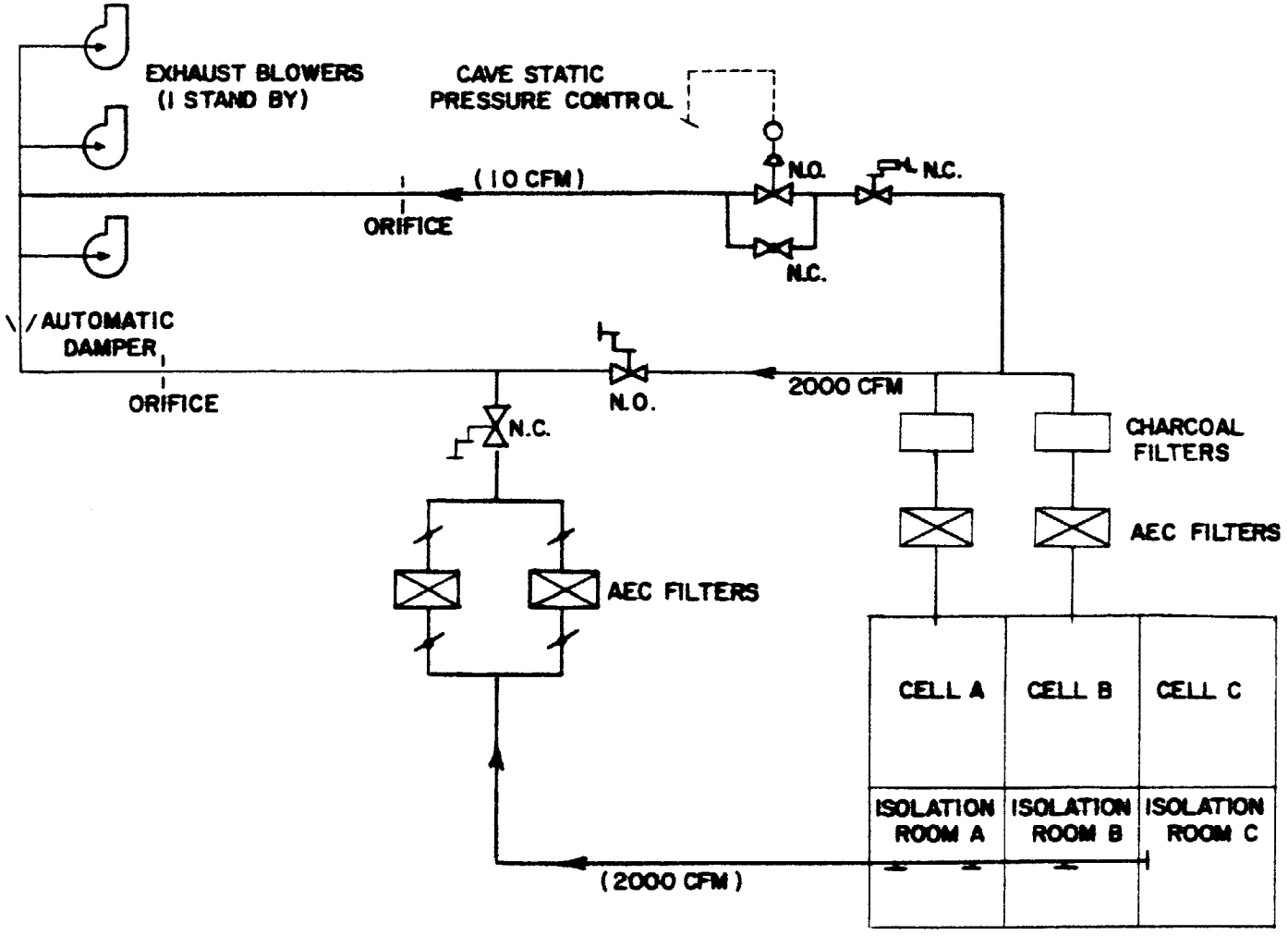


Figure 7

charcoal filters. The 24 x 24 x 11½ inch charcoal filters are the same as the Savannah River units. Their rating is 1000 cfm at .7 inch water drop through a one inch layer of charcoal. They contain 56 pounds of 10 to 14 mesh highly activated coconut shell charcoal.

When work is to be conducted on reactor fuel having a high fission gas content, the cave exhaust will be manually changed over to the ten cfm system. Handwheel operated, rubber-seated butterfly valves will be used to change the flow paths, and the cave will be sealed up as previously indicated. The automatic flow controller valve in the ten cfm exhaust line maintains the cave static pressure at -.35 inches of water by modulating the exhaust air flow to match the up-to-ten cfm cave leakage rate. Air exhausted through this two inch stainless steel pipe dumps into the main exhaust blower plenum and is discharged along with 2000 cfm of air from the cave isolation rooms. The dilution factor of 200 or more will reduce the discharge concentration of any radioactivity which penetrates the air cleaning system. The valve in the bypass line around the automatic flow control valve can be manually opened to increase the exhaust rate up to about 50 cfm. A spool piece in the two inch exhaust line will allow easy installation of a secondary charcoal filter system, if desired.

The normal air flow pattern during exhaust of 2000 cfm from the cave is from the cave operating area to the cave service area, to the isolation rooms, through AEC filters into the cave, and then through the cave exhaust system to the atmosphere. A separate 2000 cfm filtered exhaust from the isolation rooms will be used when the cave is on the ten cfm exhaust system. This will prevent disruption of air balances and air flow patterns.

One of the problems encountered was that of cooling the cave when operating at the low air flow rate. Cave lights, manipulator motors, and experimental equipment all produce heat within the cave. This heat is normally dissipated by temperature rise of the 2000 cfm of conditioned cave supply air. The problem was compounded by the non-availability of space within the cave for recirculation cooling units. Our Plant Engineers came up with small, ANL-assembled, fan-coil units for installation within the ten inch diameter cave wall plug holes. Five of these 7800 BTU, vane axial fan, direct expansion, freon 12 coil units will be used to maintain the cave temperature below 90° F. The coil temperature is thermostat regulated to provide only sensible cooling with no condensation.

In summary, I have briefly described the emergency exhaust filter system for the ANL zero power fast reactor cells and uranine aerosol efficiency tests on this system. I have also reviewed the air cleaning system changes being made at our Chemical Engineering Cave Facility, that are designed to improve control of fission gases.

CAPTIONS FOR FIGURES 1 THROUGH 7

1. ANL D-315 Cell Exhaust Filter System

2. Sample from Exhaust Duct Showing Uranine and Atmospheric Dust Particles

3. ZPR 6 Cell Showing Uranine Generation Point in Exhaust Duct Near Ceiling

4. Exhaust Pipes from ZPR 6 Cell Showing Upstream Sampling Point

5. Primary AEC Filters and Portion of Plenum

6. Sampling Point Downstream from Primary AEC Filters

7. ANL D-205 Cave Exhaust Filter System

DISCUSSION AND COMMENT

Question: I would like to get a little more information on this diffusion board. The point that interests me is actual application wherein there is normal building construction using a roof to keep out the rain, and a floor, and walls. Your flow approximately 1 cfm per square foot, or something in this range, depends on gasometer design and pressure drop. What are the practical applications to which this board might be applied, considering present-day reactors, and potential for release rates that we are faced with?

HACI Comment: I think there are several applications. The first thing I would like to call your attention to is the work that A-I (Atomics International) has done in making ordinary buildings fairly leak-tight. They released a rather lengthy publication about three months ago. I am sorry I don't have the number in mind. It is the result of an extensive AEC project. They evaluated what ordinary buildings can do and how they may be improved to reduce leakage.

Applications of the diffusion board involve two principal approaches. One method of use is to make a container that fits over the reactor. In other words, you could build a structure over the reactor inside a building, for example, if it were a water power reactor. You could build a small removable structure around it.

Secondly, if you had a reactor within a building, for example, a reactor like the Humboldt Bay reactor, which has a refueling building above the reactor, the walls and ceiling of this building could be lined with this material. The same general philosophy of sealing a filter in place must be used since diffusion boards are a filter membrane unit. It is a filter made in large panels that can fit inside a structure.

The other approach is for instances with less needed area. Building windows in a building could be removed and replaced with sealed diffusion boards. These would act as relief valves but require protection from weathering.

The ceramic-type diffusion board may have adequate weather characteristics. It will take up moisture like sponge. It will, however, dry out again without damage. If a building was made of porous concrete blocks - and most of them are quite porous - diffusion board could be the inner liner. If it were sealed in place - much as the acoustic tile boards overhead in this room are sealed - you would have a suitable type of structure. In other words, this is a structure with an impermeable floor and in which the five walls are made of diffusion board material.

We think this diffusion board could be made in a price range of 15 to 25 cents per square foot. This would be an acceptable low cost for providing halogen and particulate removal.

The Chemical Corps wood composition board is in this price range.

If you follow my general discussion it is apparent that the ingenuity of the designer can incorporate this material in containment or confinement in several ways. It may be used for relief valving, a filter, or an inner structure inside another one. Does that answer your question?

Comment: The limitation of the capacity of the board as applied to some of the incidents is the question that most concerns me when you talk about release rates, and laminar flow equivalent, say, to low pressure. You could be talking about high release rates in some incidents.

HACL Comment: Well, assume the calculations that go with the MCA, or the worst conceivable accident. There will be a rapid pressure rise within the containment. These values may be as low as 25 psi for Dresden, up to 150 psi for the SAVANNAH. You should never reach such pressures with a containment system if a diffusion board such as I describe here were installed, because it would be venting the steam all the time. You would be decontaminating the steam at the same time. We must assume that the probable loss of coolant accident proceeds something like this: You vent the steam first, then lose cooling. Melt-down then occurs. Hence the stored energy high-pressure conditions are not present when you actually release the fission products. If the steam is already contaminated, then the diffusion board would also take care of it.

As we see the diffusion board use is a fairly simple concept in terms of application. There may be more involved in the sealing problem, because the heart of our filter problem has always been how good they mounted, how well they are placed and sealed, and how well they are inspected. But assuming that you get thorough inspection, the important question is how well you will install them?

Comment: I am interested in the acoustic properties of this type of board. I wonder if it might serve a dual purpose in the lining of the reactor, or in this type of an area.

HACL Comment: If I can be a little facetious - I am not a reactor engineer - so I don't know too much about noise within reactors. If you are trying to cut down the noise from nucleate boiling, why, I don't think this board is going to help.

On the other hand, if you are looking for a noise-absorbent material for walls its composition is not too different from acoustic tile, in which fiberglass and a supporting matrix is used. In fact the only reason Wood Conversion Co. is interested in helping us, is they are a leading manufacturer of acoustic tile. The present tiles made from wood-board fiber and given treatment for fire-retardent purposes are not good enough to meet some of the new specifications. In other words, there is a level at which you want to reduce noise. A less expensive ceiling tile has a lower fire rating. I would rather have others talk about the fire-rating aspect.

Certainly in terms of its acoustic properties, which we have never really thought much about, it might be what is called serendipity. Maybe this is an added benefit that could serve this added function in a reactor room. I don't know enough about its potential here to comment further.

COMMENT: I would like to point out that this is very important in the design of a reactor room. Reverberation time is quite long, and quite objectionable, in large concrete buildings. And so we are interested in that it might serve a dual purpose.

Question: In the event this type of diffusion board were used as part of a containment structure, following a nuclear incident, would you not have to wash down the entire interior of the containment volume, including the diffusion board, with decontaminating solutions? If so, would this diffusion board be resistant to these decontaminating solutions, or would they tend to release the material that they have filtered out?

HACL Comment: I think you have a good point. We believe that this material would, of course, take out elemental and particulate iodine which will decay. If you had a significant amount of fission products, like strontium and cesium, from the so-called MCA, I don't think anybody is going to recover

much anyway. You would just as soon leave the contaminated surface and add a new one over it. On the other hand, we have not considered the possibilities of trying to decontaminate the surface. It is rather an involved problem. It is like trying to decontaminate a filter. Usually we bury them, or burn them, and try to reduce their volume that way.

If the board has a significant deposition of fission product particulates, I would be afraid of the problem of decontamination. It would be pretty serious.

Panel Chairman: If there are no others, I would first remind you that tomorrow Session V starts at 8:30 A.M., and, secondly, I would like to thank our four speakers for an excellent group of papers.

SESSION V - CONTAINMENT AND CONFINEMENT APPROACHES

Morning - 23 October 1963

M. D. Thaxter, LRL, Chairman

Session Chairman: Good morning, gentlemen. This is Session V, Containment and Confinement Approaches. We have been scheduled to start at 8:30 A.M.

The first paper this morning is by Mr. T. D. Anderson of ORNL with the title, "The Holdup Effect of Double Reactor-Containment and Its Influence on Dose from Airborne Radioactive Materials."